Sructural Control and Prospects of Searches of Gold Mineralization in the Nuralino-Voznesensko-Buibinsky Fault Zone (the Southern Urals)

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Abstract. Zone of Nuralino-Voznesensko-Buidinsky fault is the main gold-controlling fault structure in the northern part of the Magnitigorsk megazone of the Southern Urals. Results of structural and tectonophysical analysis of gold-sulfide and gold-sulfide-quartz deposits located in fault zone were considered in this article. Fault evolution consists of two stages: early left-sided and right-sided dislocations. It is shown, that formation of gold-sulfide deposits is connected with early left-sided dislocations. Late right-sided deformations controlled a distribution of gold-sulfide-quartz mineralization. The junctions of faults, transtensional duplexes, formed at offsets of wrench faults, and combine structures, consisting of junctions of faults and extensional strike-slip duplexes, determine position of gold deposits of both types. Prospective areas for search of gold-sulfide mineralization have been distinguished.

Keywords: structural control, gold mineralization, fault zone, strike-slip fault, transtensional duplex
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Introduction

Nuralino-Voznesensko-Buidinsky fault (NVBF) of ex-meridian stretch is located on the northern circuit of Magnitogorsk megazone (synform) of the Southern Urals. It is a zone of low-amplitude strike-slips and angled fractures that can be traced along the strike over a distance of 90 km and a width of 4-9.5 km. According to the gravity survey, depth of the fault zone is not less than 5-6 km. NVBF is included into the system of secondary faults of large left-hand transtensional duplex, which occupies the northern end of synform (Fig. 1) (Znamensky, Znamenskaya, 2009). Duplex refers to the extension structures of the regional Eastern strike-slip zone of ex-meridian stretch along the synform contact with the East Urals uplift. The shear zone was formed in the Late Paleozoic stage of the overall collision after the main phase of overthrust deformations (Znamensky, 2008).

Transtensional duplex has played a leading role in placing on the synform northern circuit of deposits and occurrences of gold, the vast majority of which has a Late Paleozoic age (Znamensky, Znamenskaya, 2009). Within the duplex the main gold-controlling structure is NVBF area. It concentrates more than 70 gold objects. According to the modern conditions gold-sulfide and gold-sulfide-quartz deposits are of the industrial importance. On the northern flank of the fault zone small intrusions and dykes are localized of Balbukskian syenite-granite-porphyry complex (Pz_3).

We performed a detailed structural, tectonic and physical study of 14 deposits and occurrences of gold, located in NVBF area. The data obtained, as well as materials of previous works allowed specifying the structure and kinematics of NVBF, to find out the basic laws of the structural control of the gold-sulfide and gold-sulphide-quartz mineralization and provide recommendations for the direction of search operations.

Research Methods

The main method of research was structural-paragenetic analysis of ore-bearing tectonic disturbances. It included the study of morphogenetic features of fold and fault structures, the study of fault kinematics based on the analysis of small structural shapes (drag folds, kink-bands, cleavage cracks, etc.) (Cowan, Brandon, 1994; McClay, 1995; Turner, Weiss, 1963), tectonophysical reconstruction of paleo-stress fields using statistical method of P.N. Nikolaev (1977) and the actual paragenetic analysis of structures (Starostin, 1988; Sylvester, 1988). Data of detailed mapping of their surface, the documentation of underground mine workings and drill-hole cores were the basis of structural imaging.

Research Results

Two stages are sent in the history of the NVBF formation: early left strike-slip and late right dislocations. In the first stage gold-sulphide deposits were formed with Rb-Sr isochron age of 295 (Murtykty) and 286 (Karagaily) million years (Fig. 2) (Gorozhanin, 1998). The formation of gold-sulfide-quartz deposits and occurrences with Rb-Sr age of 266 (Maliy Karan) and 255 (Rytovsky veins) million years occurred in the conditions of the late righ dislocations (Znamensky et al., 2014; Gorozhanin, 1998). It was found that the position of deposits and occurrences of gold is determined by both types of fault intersection nodes, transtensional duplexes and combined structures, combining fault intersection nodes and strike-slip duplexes.

Gold-sulfide deposits are localized mainly at the nodes of intersection of secondary fractures of the NVBF, previously formed upthrow-overthrust of the northeast strike. Deposits Veseloye, Sredneye Ubaly (Znamensky et al., 2012) and Murtykty have such a structural position.

Murtykty deposit with proven reserves of 30 tons lies among the volcano-sedimentary strata of Karamalytashskian suite (D_2), overlain by ulutauskian terrigenous-siliceous sediments (D_{2-3}). It is confined to intersection of the regional Tungatarovsky fault of the northeast strike with later Saytakovsky strike-slip zone, part of the NVBF (Fig. 3 A).

Tungatarovsky fault in the deposit area is a scaly upthrow-overthrust of the southeastern fall, followed in the rear part by east-vergent upthrows (Znamensky, 1992). The system of Tungatarovsky faults involves transfer disturbances of the northwestern strike. Saytakovsky area at the intersection node is characterized by curvature counterclockwise. Bending is associated with inheritance of disturbances that limit strike-slip zone, northwest transfer faults. During the formation of deposits there was a movement to the left sign.

This is evidenced by paleo-stresses, which were reconstructed by us on ore veins, occurring in the eastern boundary fault of the strike-slip zone (diagram in Fig. 3 A). As shown by the simulation results (Geological and structural methods..., 1982), there are local areas of absolute or relative strain on curves of strike-slip zone that contribute to the displacements (Fig. 3 B). It should be noted that during the experiments the strain areas were extended beyond the fault zones.

Four ore zones have been explored on the field: Intermediate, Eastern, Western and Ik-Davlyat. Vein-nodule gold-sulfide mineralization is localized in the secondary disturbances of scaly upthrow-overthrust (Fig. 4). On ore-bearing faults we reconstructed intra-mineral strike-slip displacements, mainly with the left sign. Ore bodies and ore columns within them are confined to fault curves mainly along the strike.

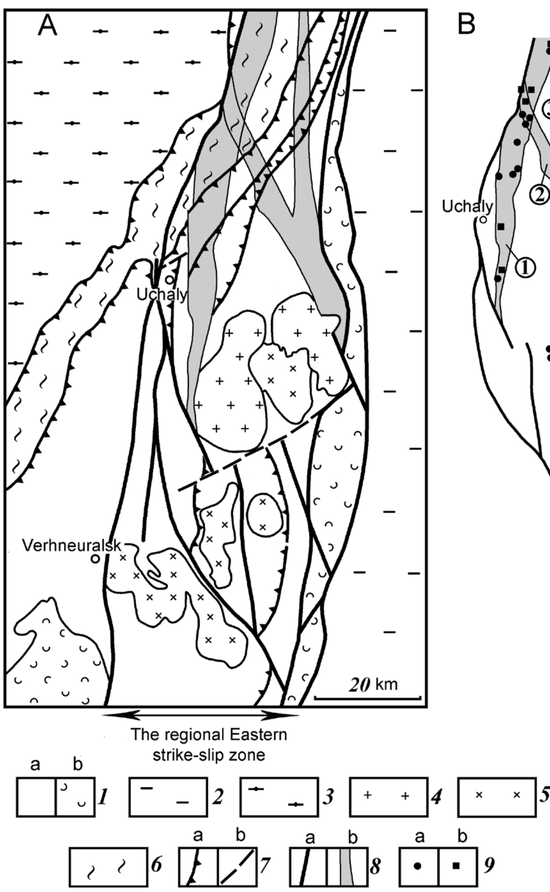

Fig. 1. Structural diagram of the northern flank of the Magnitogorsk synform (A) and the main elements of the transtensional duplex (B). 1 – sedimentary and volcanic complexes of Magnitogorsk synform of Devonian (a) and Carboniferous (b); 2 – Paleozoic sediments of the East-Ural uplift; 3 – Precambrian metamorphic strata of Bashkir anticlinorium and Uraltau zone; 4 – granites of Akhunovsky and Karagaisky arrays (C_2); 5 – Granitoid complexes (D_3-C_1); 6 – melange zone of the Main Uralian Fault; 7-8 – collision faults: 7– Early overthrusts (a) and adjacent transfer faluts (b), 8– Late strike-slips (a), including secondary strike-slip zones of transtensional duplex (b): 1 – Nuralino-Voznesensko-Buydinsky, 2 – Malokaransko-Siratursky, 3 – Orlovsko-Vydrinsky; 9 – deposits (a) and ores (b) of gold.

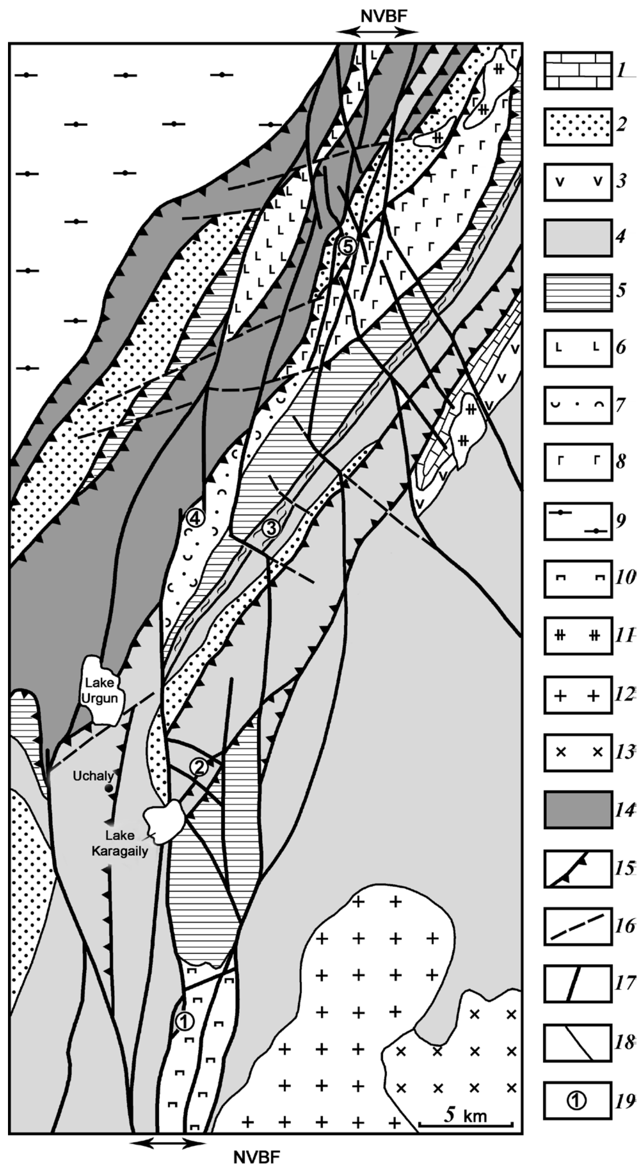

Fig. 2. Geological and structural diagram of the southern flank of the Nuralino-Voznesensko-Buydinsky fault (compiled using data from geological survey in scale 1: 50,000) (Anisimov, 1978, 1982). 1 – limestone (C_{1-2}); 2 – graywacke deposits of Zilair suite (D_3-C_1); 3 – basalts, andesite-bazalts and tuffs of Buraminskian strata (D_3), 4 – volcanic and volcanic-sedimentary strata of Karamalytashskian (D_2) and Ulutauskian (D_{2-3}) suites; 5 – volcanic rocks of irendykskian suite (D_2); 6 – basalts (D_1); 7 – terrigenous-siliceous rocks of Mansurovskian strata (D_1); 8- diabase of Polyakovskian suite (O_2); 9 – Precambrian metamorphic rocks; 10 – ophiolite gabbro-ultrabasic complex; 11 – intrusions of Balbukskian complex (C_2-P); 12 – granite of Akhunovsky array (C_2); 13 – granitoids (D_3); 14 – serpentinite; 15 – overthrusts and upthrows; 16 – transfer faults; 17 – strike-slips; 18 – geological borders; 19 – deposits and ores of gold: 1 – Ganeevsky, 2 – Karagaily, 3 – Murtykty, 4 – Rytovskie Veins, 5 – Maliy Karan.

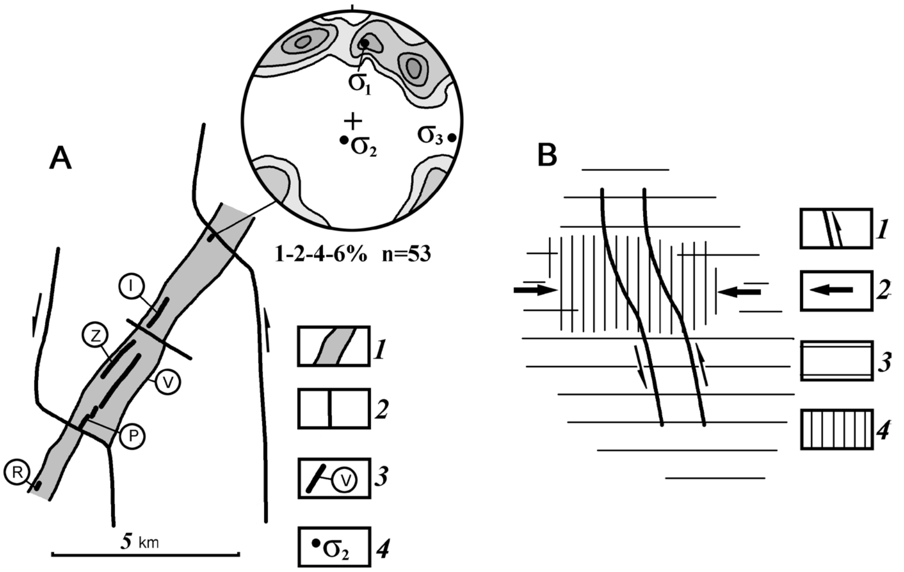

Fig. 3. Structural position of Murtykty deposit (A) and distribution on the curves of strike-slip of local strain areas at the regional compression (B) (Geological and structural methods ..., 1982). Diagrams (Wolfe net, upper hemisphere) of densities in the poles of ore veins. A: 1 – Tungtarovsky upthrow-overthrust, 2 – faults limiting Saytakovsky strike-slip zone; 3 – ore zones: P – intermediate, V – East, Z – West, and I – Ik-Davlyat of Murtykty deposit, R- ore occurrences of Inter; 4 – axes of the main normal stresses (σ_1 – maximum, σ_2- intermediate, σ_3 – minimum). B: 1 –disturbances and the direction of displacement thereof; 2 – direction of compressive forces; 3 – areas of compression; 4 – areas of local strain.

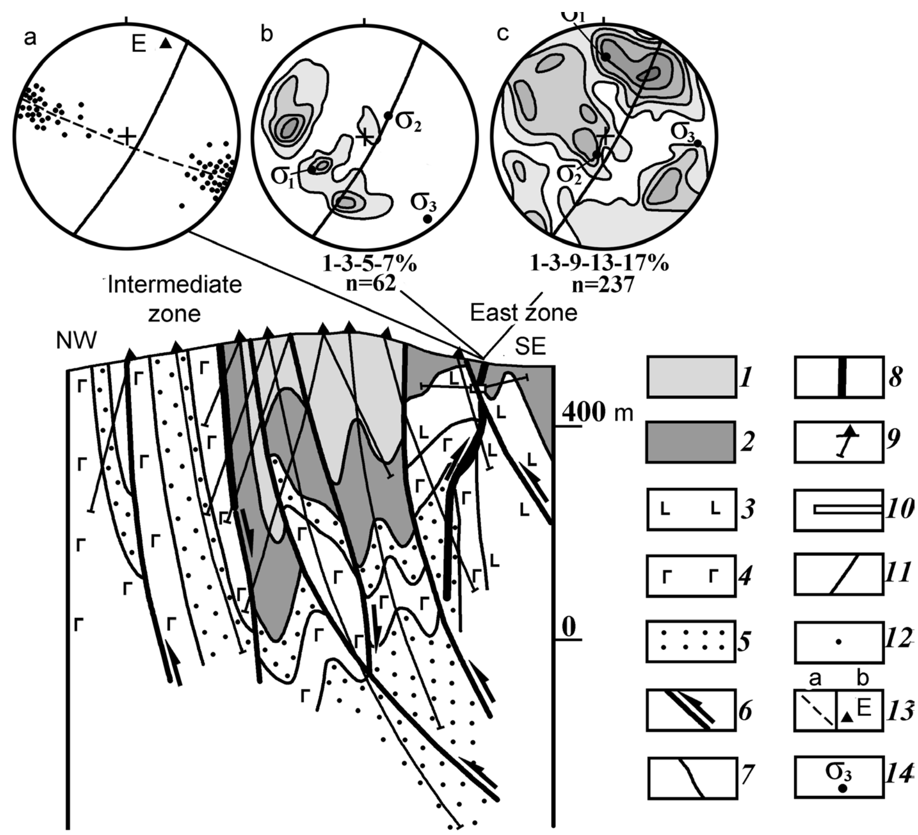

Fig. 4. Geological section of Murtykty deposit for 53 profile. Diagrams (Wolfe net, upper hemisphere) of densities in the poles of lamination (a), gold-sulfide (b) and postmineral carbonate-quartz (c) veins. 1 – terrigenous-siliceous sediments of Ulutauskian suite (D_{2-3}); 2-5 – Karamalytashskian suite (D_2): 2 – tuffs and tuffites of basic composition, 3 – basalts and andesite-bazalts, 4- diabases, 5 – tuffites of mixed composition and siliceous shale; 6 -faults and the direction of displacement thereof; 7 – geological boundaries; 8 – ore zones; 9 – wells; 10 – mine workings; on the diagrams: 11- the main plane of the fault; 12 – poles of lamination; 13– plane of lamination zone (a) and reconstructed folding hinge (b); 14 – axes of the main normal stresses (σ_1 – maximum, σ_2– intermediate, σ_3 – minimum).

Features of the structural evolution of the ore-bearing faults can be illustrated on the example of eastern-vergent upthrow that includes ore body No. 1 in the Eastern zone. Observations were made in the hanging wing of the fault in layered tuffites of the basic structure, which are crumpled into small drag folds. Statistical processing of massive elements measuring (Turner, Weiss, 1963) allowed us to reconstruct the position of the folding axis (diagram a in Fig. 4). Its orientation indicates upthrow displacement along the fault. Drag folds intersect sulfide (pyrite-copper pyrite-sphalerite) and later carbonate-quartz veins.

Gold-bearing sulfide veins carry ex-meridian R- and sublatitudinal R'-chips (Silvester, 1988), steeply dipping detachments of the NW-strike and subhorizontal fractures of unclear genesis (diagram b in Fig. 4).

According to them we restored strike-slip paleo-stress field with northwestern axis direction σ_3. The reconstructed stress field is characteristic for the left upthrow-strike-slips. Formation of late quartz-carbonate veins occurred in sub-latitudinal compression mode (diagram c in Fig. 4) and right upthrow-strike-slip displacements along the main fault.

Thus, in the placement of gold mineralization of Murtykty deposit tectonophysical control of the local strain zone is clearly expressed. It arose at the intersection of Tungatarovsky upthrow-overthrust by left strike-slips of the NVBF. Within the structural node, the gold-sulphide mineralization is localized in the secondary disturbances of the Tungatarovsky fault that experienced strike-slip movements.

The leading role in the structural control of the gold-sulfide-quartz mineralization play transtensional duplexes formed on the stepped overlaps of ex-meridional shifts at the site of compression strike-slip duplexes. In such a structural situation, for example, Ganeevsky deposit and Oktyabrsky ore occurrence on the Buydinsky site (Znamensky, 2014) were formed, as well as gold-ore portion of Krasnaya Vein area.

Within the Krasnaya Vein area, deposit of the same name and occurrence Rytovskie Veins are located (Fig. 5). The plot is complicated with effusions of the basic structure (O_3-S_1), clastic- siliceous strata of Mansurovskian strata (D_1) and serpentinite, intruded by dikes of gabbro and gabbro-diorite of unknown age. Structurally, it is a left-stage overlap of two faults of meridian strike, by which the early movements are set with the left sign and later movements with the right sign. Left- strike-slip dislocations along faults, which can serve as an indicator of drag folds (diagram b in Fig. 5), are associated with the formation of transpression duplex on the stepped overlap. Its internal parts are disturbed by scaly left strike-slip-upthrows of the steep fall, including serpentinite and listvenite. During the late right displacements the duplex structure of compression was transformed into a

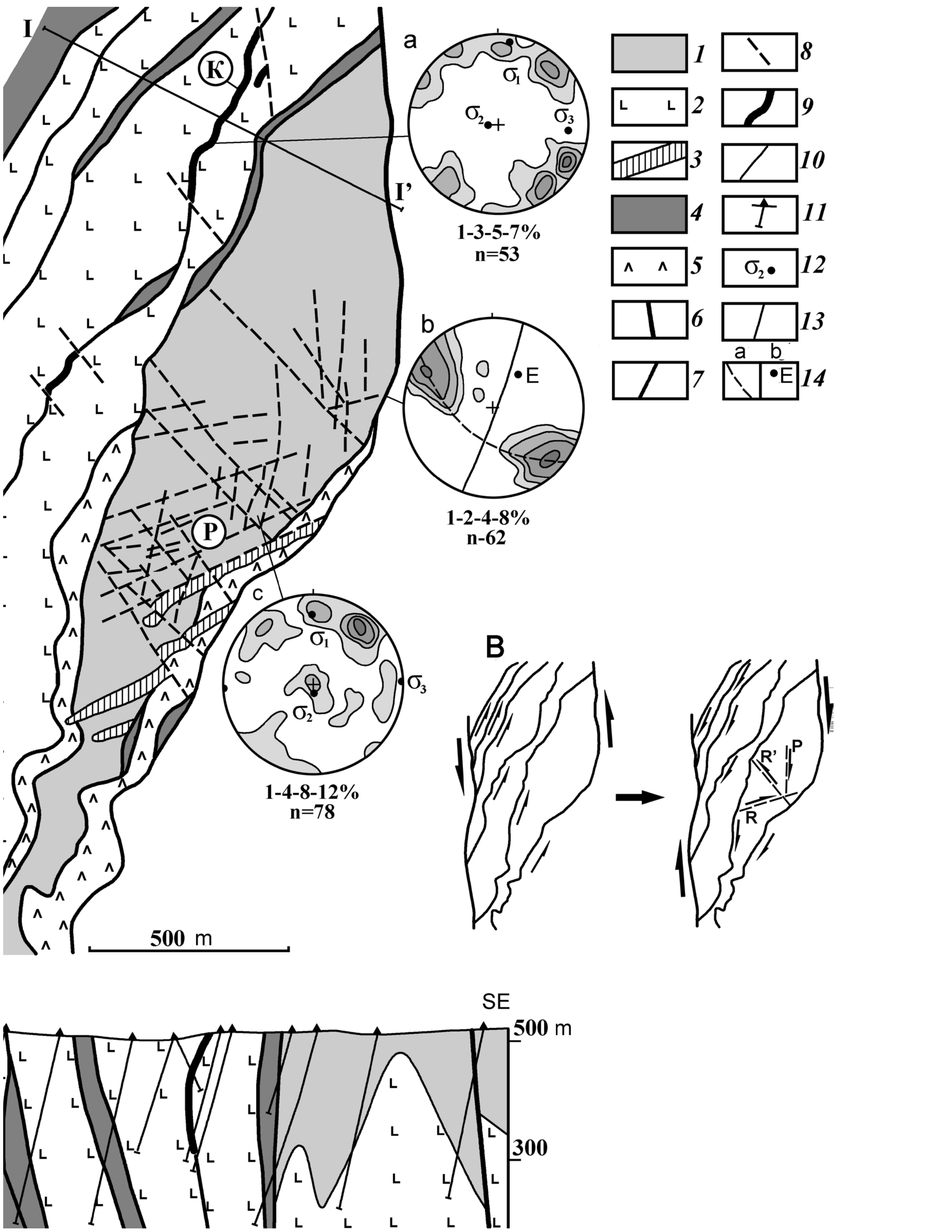

Fig. 5. Geological and structural scheme, section (A) and model of the structure formation (B) of the Krasnaya Vein area. Diagrams (Wolfe net, upper hemisphere) of densities in the poles of gold-sulfide-quartz veins (a,c) and lamination (b). 1 – Terrigenous-siliceous rocks of Mansurovskian strata (D_1); 2 – basalt, andesite-balalt and tuffs (O_3-S_1?); 3 – dikes of gabbro and gabbro-diorite; 4 – serpentinite; 5 -listvenite; 6 – major strike-slips; 7 – secondary fractures, destroyed the duplex; 8 – secondary ore-bearing strike-slips; 9 – ore deposits of the Krasnaya Vein body; 10 – geological boundaries; 11 – wells; on the diagrams: 12 – taxes of the main normal stress (σ_1 – maximum, σ_2- intermediate, σ_3 – minimum), 13 – the fault plane, 14 – the plane of the lamination zone (a) and folding hinge (b). Letters in the circles mark: K – Krasnaya Vein deposit, P – Rytovskie Veins ore occurrence.

transtensional duplex and scaly faults are converted into the right strike-slips. The model of the structure formation in the Krasnaya Vein area is shown in Fig. 5 B.

In connection with the right strike-slip dislocations in the clastic-siliceous rocks of Mansurovskian strata, located on the southeast flank of the area, three systems were formed of small strike-slip disturbances of the northeastern, northwestern and ex-meridian strike, enclosing vein gold-sulfide-quartz mineralization of Rytovskie Veins occurrence. By the kinematics and orientation these systems of gold strike-slips are approximated by R-chipped, R'-chipped and P-strike-slips, respectively. On the Krasnaya Vein deposit gold-sulfide-quartz mineralization is localized in the fault limiting the tectonic plate and spatially aligned with pyrite mineralization of chalcopyrite-pyrrhotite-pyrite structure.

Tectonophysical reconstructions showed that the formation of gold-sulfide-quartz mineralization in the area Krasnaya Vein took place under conditions of strike-slip paleo-stress field that is characterized by sublatitudinal axis orientation of minimum major normal stresses (diagrams a and c in Fig. 5).

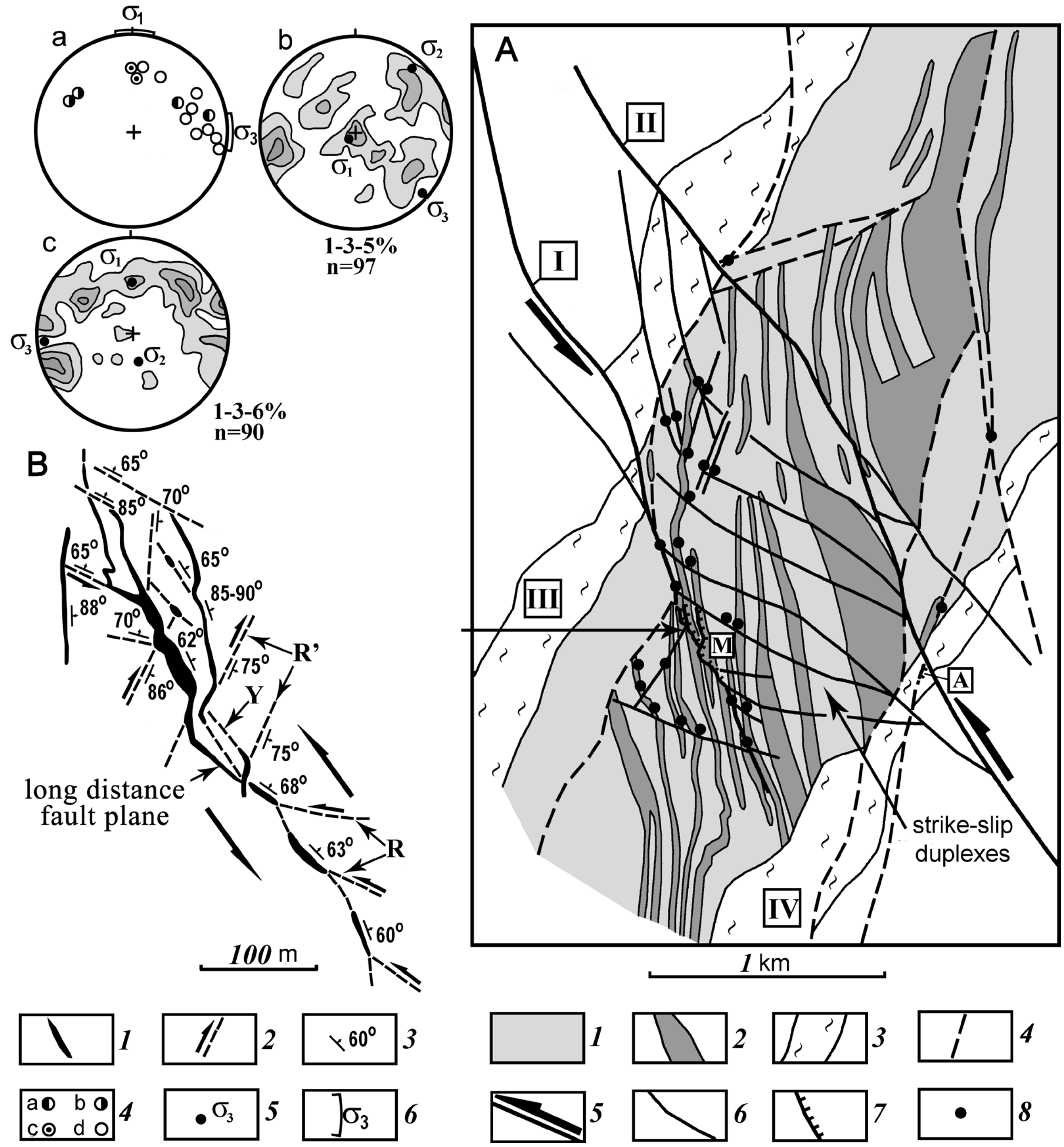

Fig. 6. Structural scheme Malokaransko-Aleksandrovsky area (A) and Maliy Karan deposit (B) (compiled using the data of "Bailzoloto" multicorporate group and N.I. Borodaevsky (1938)). Diagrams (Wolfe net, upper hemisphere): a – disturbance poles, enclosing eysite zone, 6 – density poles of albite-quartz veins, c – density poles of sulfide veins. A: 1 –volcanic-sedimentary rocks; 2 – intrusive bodies of Balbuksky syenite-granite-porphyry complex (C_2-P); 3 – zone of serpentinite melange; 4 – magma-controlling strike-slips; 5-6 – ore-controlling strike-slips; 5 – the main ones and the direction of displacement thereof, 6 – the secondary ones; 7 – ore zones for deposits Maliy Karan and Aleksandrovsky; 8 – small ore occurrences. Roman numerals in squares designate faults: I – Malokaransky, II – North Aleksandrovsky, III -Aushkulsky, IV – Malokumachinsky; Letters mark – deposits: M – Maliy Karan, A – Aleksandrovsky. B: 1 – eysite zone with sulfide-albite-quartz stockworks; 2 – disturbances (arrows show the horizontal component of the displacement of wings); 3 – elements of disturbances occurrence; on the diagrams: 4 – poles of disturbances, enclosing eysite zone (a- left strike-slip, b – right strike-slip, c – throws, d –disturbances of indefinite kinematic type), 5 – axes of the main normal stress (σ_1 – maximum, σ_2- intermediate, σ_3 – minimum), 6 – sectors of the possible orientation of the axes of main normal stresses.

The gold-sulfide deposit Karagaily, as well as gold-sulfide-quartz deposits and occurrences Malokaransko-Aleksandrovsky area are confined to the structures of combined type. Malokaransko-Aleksandrovsky area is the intersection node of faults in three age groups (from early to late) (Fig. 6A.): 1) the tectonic plates of volcanic-sedimentary rocks, limited by areas of serpentinite melange of Aushkulsky and Malokumachinsky upthrow-overthrust of the southeast fall; 2) strain magmatic duplexes that are localized in the left strike-slip zone of ex-meridian strike relating to NVBF; 3) sin-ore left strike-slip zone of the northwestern direction, having a duplex structure (Znamensky, Znamenskaya, 2011). Magmatic duplexes are made of syenite-porphyry and granosyenite-porphyry of Balbuksky complex of the Late Paleozoic.

The main ore-controlling structure of Malokaransko-Aleksandrovsky area is a left strike-slip zone of the northwestern strike. Limiting North-Aleksandrovsky and Malokaransky faults form left stepped overlap. On the southern flank of the stepped offset there is a strain duplex of lenticular configuration. Tectonic lens is disturbed by additional left strike-slips of the west-north-west strike, corresponding in position and kinematics to R-chipping. In the northwestern strike the duplex gives way to the additional left strike-slips and upthrow-strike-slips of the northwestern strike, apparently related to synthetic secondary strike-slips. Ex-meridian faults of the second age group, transformed in the ore stage into right disturbances, do not play a significant role in the distribution of gold mineralization.

Strike-slip strain duplex includes Malokaransky and Aleksandrovsky deposits, as well as a significant part of the occurrences. Mineralization is represented here by metasomatite of eysite composition containing sulfide-albite-quartz stockworks. The largest object of Malokaransko-Aleksandrovsky area is Maliy Karan. It lies near the southwest corner of the duplex in the same fault zone in the range of coupling it with additional strike-slips of west-northwest strike. Ore-bearing interval is characterized by a small deviation (at 5-10°) counterclockwise relative to the total strike of fault zone and is stretch bending. Probably, this bending was the main ore channel, as most occurrences of Malokaransko-Aleksandrovsky area are centered around it.

Formation of gold eysites in the area of Malokaransky fault occurred in a pulsating mode of lateral compression during the three main phases. At an early phase of sub-latitudinal compression and intensive dynamometamorphic transformations of host rocks, main seam and mesh of disturbances of the secondary paragenesis were formed (Fig. 6 B), and areas of metasomatite of eysite composition (diagram a in Fig. 6 B). During the second phase, after the cessation of active stress, changed by biaxial stretching in the vertical and horizontal north-east direction, small veins of albite-quartz composition were formed in eystite areas, localized in the cleavage cracks and less detached cracks (diagram b in Fig. 6 B). At a later phase, in a renewed near-latitude compression gold-bearing vein-nodule sulfide mineralization was formed (diagram c in Fig. 6 B). It is developed mainly in eysites and placed in the cleavage cracks, thin zones of mylonitization and shearing planes.

Conclusions and practical recommendations

Thus, strike-slip deformations were the leading ore controlling factor in the formation of gold-sulfide and gold-sulfide-quartz mineralization in the NVBF zone. Disturbance intersection nodes, transtensional duplexes and combined structure, combining disturbance intersection nodes and strike-slip strain duplexes are the most common structures that determine the position of gold deposits and occurrences of both types. The research results allowed us to identify areas in the fault zone, promising for gold mineralization. Structurally, intervals of Tungatarovsky fault associated with the structural node that includes Murtykty deposit are promising areas for the detection of gold-sulfide ores (Fig. 2).

As noted above, in the surrounding geological space local strains favorable for the mineralization process could occur during the formation of the deposit? (Fig. 3 B). The gold-sulfide ores indicate the existence of deposits on the flanks of tectonic strains (Inter, Evgenevsky vein). Flanks of the gold-sulfide deposit Karagaily are also promising (Fig. 2). The deposit is localized at the intersection of scaly upthrow-overthrust of the southeastern fall by two ex-meridian strike-slips within the system of NVPF dislocations.

In the context of early left shifts between strike-slips transtensional duplex was formed, dislocated by secondary disturbances of the northwestern strike. The mechanism of its formation is similar to the experimental model of duplexes “Riedel” formed on straight-line areas of strike-slips when overlapping to the R-chips of Y-strike-slips (Woodcock, Fisher, 1986). The largest in the Southern Urals Kochkar deposit with gold reserves of about 300 tons is located in the duplexes of this type (Znamensky, Seravkin 2005). Search prospects in the NVBF zone of gold-sulfide-quartz mineralization appear to be quite limited.

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