Ore-geochemical zonality and gold complex potential of Muruntau

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This work considers features of genesis, a deep structure and a prospective value of the Muruntau ore field and its flanks, a spatial relation of various classes of gold ores in the operational condition, changes of an industrial ore concentration of gold through time and conditions of its production from technogenic sources. Allocated in the Central Tamdytau on zones of a real ore content (Hg, Au, Ag), to geochemical anomalies (to Ag, Au, W, Hg, Sb, As) and to thin-section blue cap of gold, a scheelite, cinnabarite, diaspore, etc., the expected and search area is estimated as the indicator of the covered and bridged over large-scale gold complex of ore grade mineralization. *KEYWORDS:* Muruntau; ore field; gold zone; geological-genetic model; Tamdytau; geochemical zonality; Au, Ag, Sb, As, W, Cu, Sn.

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Introduction

Gold ore deposit Muruntau, explored in 1958, always was and remains a subject of close attention of the geologists studying gold provinces and deposits of the world [*Cher*, 1972].

According to D. V. Rundkvist the world reserves of ore metal have been focused on more than 80 percent in comparatively few deposits of gigantic size, containing less than 5 percent of total amount [*Rundkvist*, 1981].

Therefore, the problem of origin of gigantic deposits is related to key problem in learning about ore deposits. The difficulty is that scale of these deposits suite with the scales of formation of magnetic rocks that is unexplainable based on traditional processes of ore formation (magmatic and hydrothermal). For their genetic interpretation, it is required to involve main models in which ore formation will be in one range with petrogenetic processes, in one way or another approximate to them in scale. This causes the name petrological for model of this kind of ore formation [*Marakushev et al.*, 1998].

It underlines the specificity of reviewed ore formation its relation not only with the sources ore substances, as with the development process of its concentration under the influence of determined factors which in the first approach is divided into exogenous, endogenous and complex. In recent years among the exogenous factors revealed emphasis of bacterial concentration of ore metals, leading to formation of deposits of gold, iron, uranium and rare earth-niobium ores. In Tomtor (Russia) carbonatite deposit during development of oxidation zone originated microbial mat which served as sorption of geochemical barrier in the way of migration of rare earth and niobium and promoted formation of large deposits of bonanza. Bacterial concentration of platinum, gold and many other metals played a great role in the formation of stratiform deposits, subordinated black shale formations [*Konstantinov et al.*, 2000].

Relating to ore deposits in black shale formations, barrier (concentration) function of accumulation of substance directly proves the existence of metalliferous carbon residue, coal, bog muck, solid bitumen and located in the range of important factors of uranium concentration in the sedimentary process (barrier function of phosphate, titan and vanadium deposits). However, efficiency of these factors incomparably grew when entry of ore metals to the basin of sedimentation increased. Herein there is a connection of exogenous and endogenous factors of formation not only uranium but also ore deposits formation in the basins of sedimentation.

Main Results of Researches

In opinion of A. A. Marakushev metalliferrous basins originate mostly due to explosion ring structures, impulse of activity of which is determined stratiform character of metalliferous residue formation performing numerous depression of crystal foundation platform [*Marakushev et al.*, 1998].

The size of ore deposits of magmatic genesis is limited with slight solubility of ore metals in silicate melt. These limited parameters multifunctional approves in the process of crystallization and proper magmatic (liquation) differenti-

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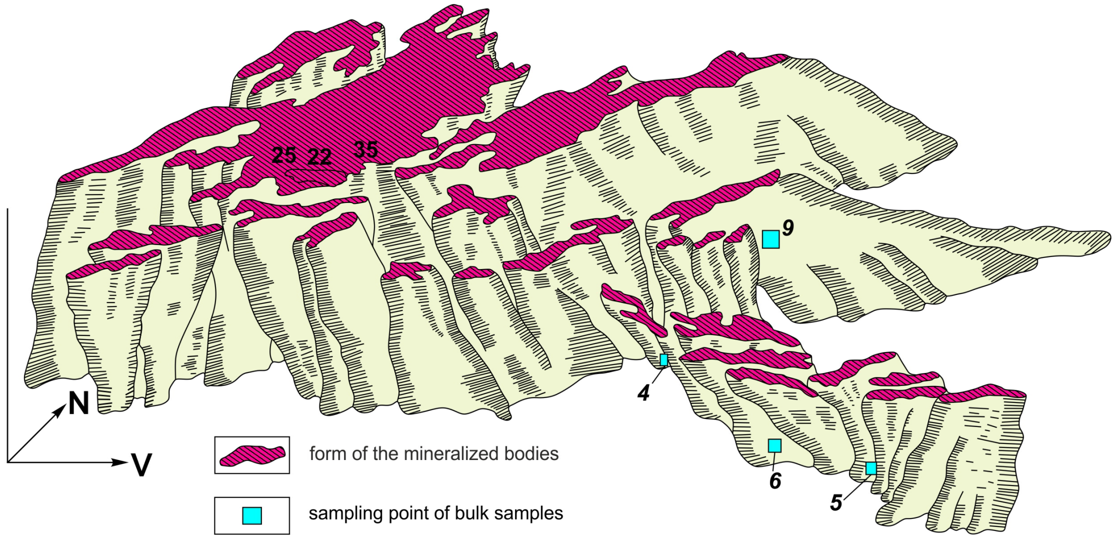

Figure 1. Block diagram of the gold-bearing area of the Muruntau ore field and its satellites (according to [*Vixter et al.*, 1983]).

ation preventing formation of gigantic deposits that because of it are considered rare (unique). Their formation is linked with the special processes that we named transformation of magmatic system. On the basis of them there is transformation of eutectic crystallization systems in liquation system of liquid immisiblity in which ore-bearing melt phase (oxidic, sulfide, carbonate, phosphate etc.) that not having sizable limited parameters have been determined.

Reviewed petrologic models of formation of different gigantic deposits are considered to be schematic that requiring detalization of further development and substantiation. Nevertheless, they exactly indicate that the problem of gigantic deposits is urgently solved only on the way of petrogenetic construction determined by the processes of formation of geological structure and characteristic for their rock with which deposits are genetically linked. From this, it is required important conclusion relating to exploration criteria of gigantic deposits that should include mineral petrological factor.

Alkalization of melting is related to effective factors of transformation of magmatic systems during their development in way of magmatic replacement of hyperbasites. As a result of this process the primarily homogeneous (perfect) magmas lose ideality, which controls the formation of alkalisilicate melts and immiscible with them ore concentrating melts (carbonatites, carbonate-chloride, carbonate, fluoride, sulfate, and others) on that base giant deposits of phosphorus, uranium, gold, rare metals are formed, including long distant from matrix magma chambers.

Among the giant deposits, Muruntau deposit is characterized with unusual high-fineness of gold (its natural refinement) and a huge scale of gold mineralization (Figure 1). It is satisfactorily explained in the framework of the well-known hypothesis [*Marakushev and Hohlov*, 1992] of infiltration magmatic replacement of carbon meta-siltstone with the participation of alkaline potassium lamprophyre melts intruded in ore field mainly along the deformation zone at the base of slate-carbon thickness with a concentration of Au-W-RM mineralization along the folded structures. The largest of these ones is the synclinal deformation structure – region of localization of Muruntau mega ore bearing zone, lean and plunging to the east.

The same deformation ore localizing structure is shown in the composed by us depth section of Muruntau deposit along the line of Mine-M borehole SG-10 (Figure 2). Here, in the area of its core zone, the structure is "faulted" with a series of pillar bodies occurred also in the deeper horizons.

At the bottom of the depth section, it is shown the uncovered apical zone of Sardarinsky granite pluton – the source of ore-bearing transmagmatic fluids representing infiltration of hydrogen-hydrocarbon stream flows without participation of hydrosulfuric solutions. Active dynamic and chemical-reaction effect of flows on terrigenous-layered carbon thickness lead to their fluid-magmatic replacement in a strongly reconstructive carbon conditions.

In this regard, the actual concentration of gold happened without noticeable accumulation of silver, copper, antimony, bismuth, mercury and other chalcophilic metals formed in the volume of deposit region of negative ore geochemical anomalies.

According to *Marakushev and Hohlov* [1992], it is happened removal of metal infiltration with flow of fluids, controlled the origin of a unique process of refining gold.

The concentration of the noble metal in the melt-fluids are being introduced in petrogenetic scale in gold-bearing carbon content thickness of high sorption capacity, and defined unusually large volume of gold mineralization of Muruntau.

Intensive large-scale replacement of black schist rock strata in over intrusive zone of Muruntau controlled emergence of excess quartz, which permeated all of its space.

Silicification reached special intensity in the thick zones of ore transportational structures of the Southern and North-eastern faults (see Figure 2).

Another characteristic feature of depth levels composed

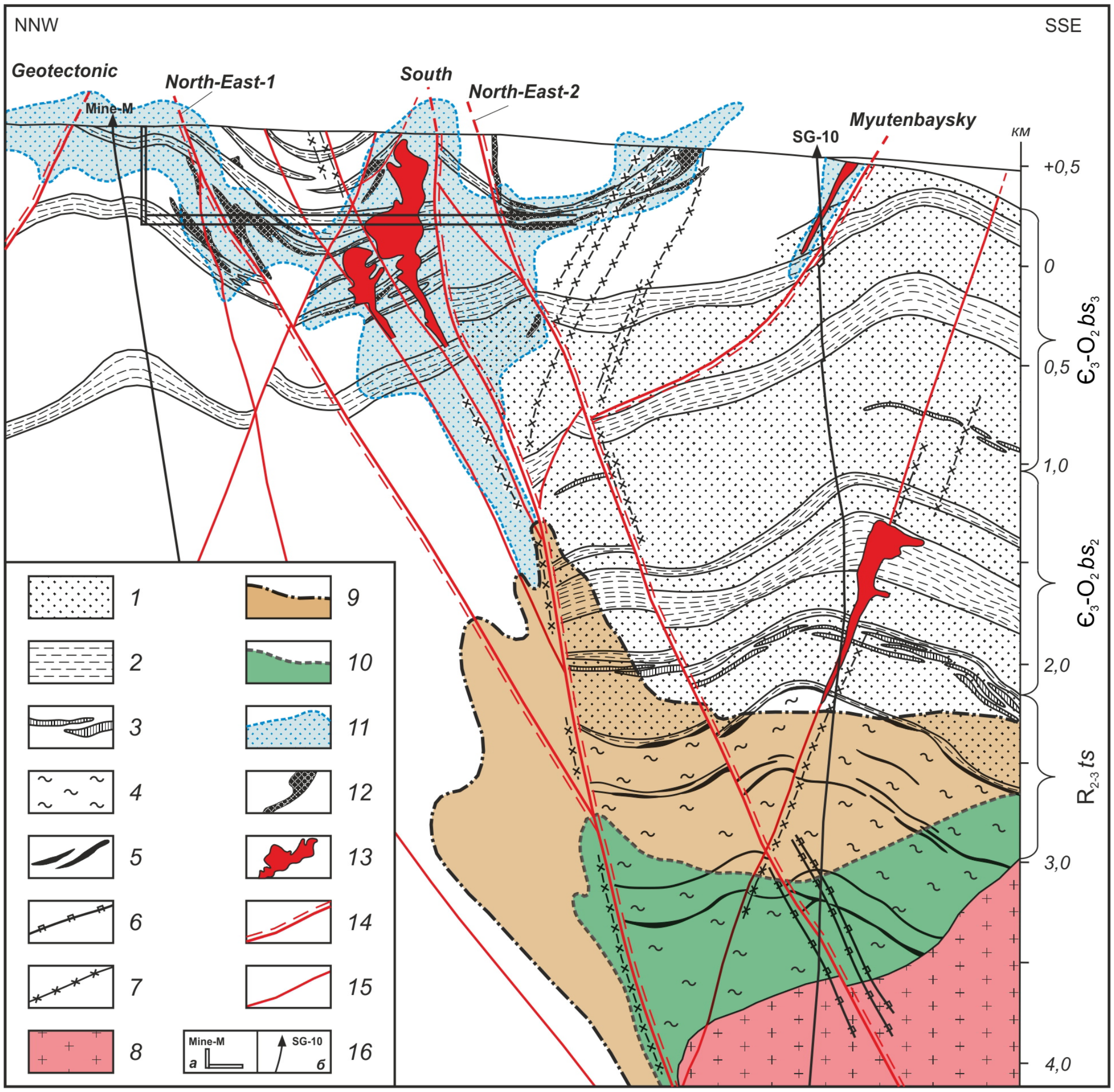

Figure 2. Depth section of Muruntau deposit along line Mine M – SG-10 well. 1 – metasandstone, silty sandstone; 2 – aleurolite, aleuropelite; 3 – albite-quartz schist; 4 – crystalline and carbonaceous-albite-quartz schist; 5 – siliceous and quartz rocks; 6 – quartz-feldsparic-micaceous pegmatites; 7 – granosyenite, quartz-porphyry and etc.; 8 – granite leucocratic; 9 – "dome fold" of biotititated (porphyroblast) quartz-two-feldspar contact-metasomatic rocks; 10 –zone of scarn (actinolite-clinozoisite and diopside-garnet-actinolitic assemblages); 11 – zone of massive linear-vein and lens shaped quartz-feldspar mineralization; 12 – Au-metalliferous deposits and stoops; 13 – ore bodies eroded and supposititous; 14 – aggregate ore transport faults; 15 – ore-hosting and blocking faults; 16 – minings: a) mine-M, b) boreholes. Enclosing rocks: R_{2-3}ts – crystalline and carbonaceous-albite-quartz schist with assise of quartz and siliceous-carbonate rocks. G_3-O_2bs$_2$ – metasandstone metaaleurolite of puckered and schistic structure, micaceous-albite-quartz schist with adit levels and lense of chalcedony. G_3-O_2bs$_2$ – aleurolite-microschist with assises of carbon-micaceous-quartz schists with adit levels and lense of siliceous rocks and carbonates.

geological and structural section is the emergence of a thick "dome fold" biotitized porphyroblastic quartz-difeldspar metasomatic rocks, exchangeable with approaching to the apical surface of intrusion covering it with skarn plume with dominate actinolite-clinozoisite and diopside-garnet-actinolite mineral associations.

The spatial distribution of gold-bearing (gold extracting) blocks in the ore hosting thickness of central part of the deposit was studied in detail and presented by *Obraztsov* [1998].

In the plan of operational exploration within the boundaries of the ore zone, according to exploration in detail clearly occurred transversal sickle semicircular structure with central (diametrical) core (morphology "inclined mushroom"), formed by the series of focal mergers ore grade gold pillars and feathering their zones (Figure 3).

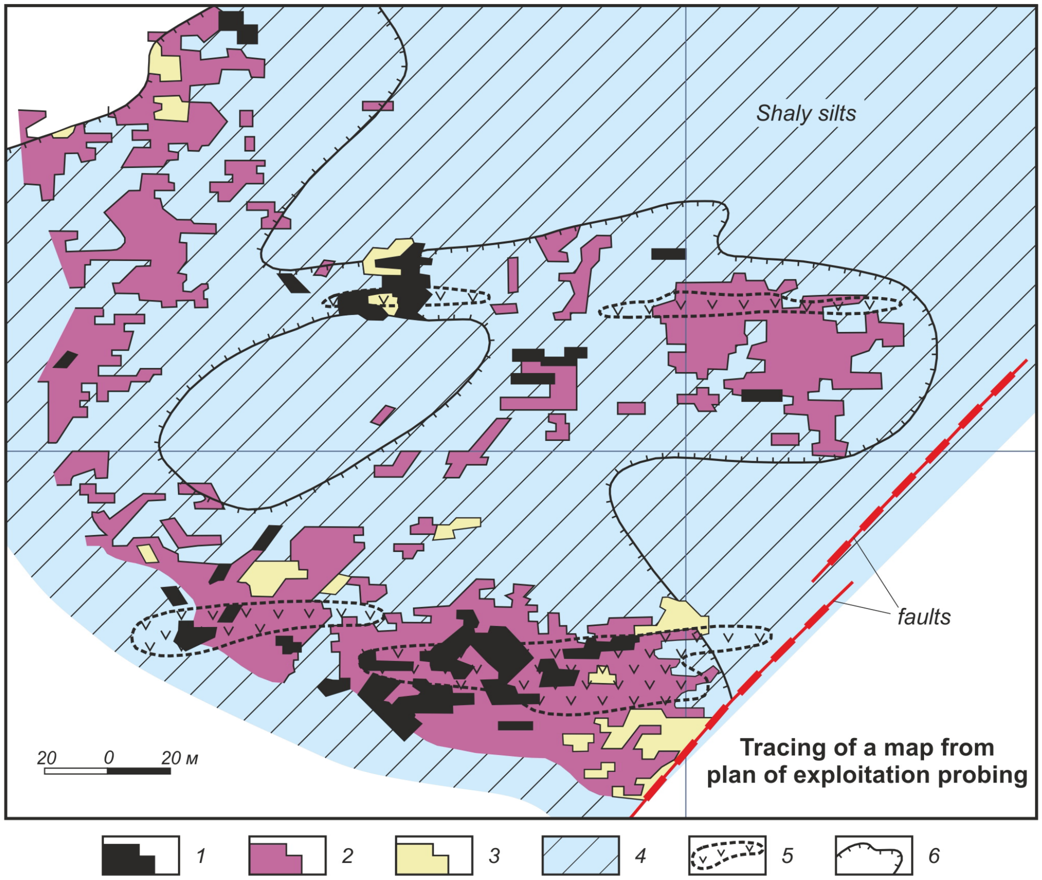

Figure 3. Nature of distribution of gold on Muruntau deposit in an ore zone (detailed exploration), according to operational exploration [*Obraztsov*, 1998]: Ores: 1 – bucking, 2 – run of mine; 3 – barren rock; 4 – interstratified shaly silts; 5 – zone of quartz vein; 6 – borders of ore zone according to data of detailed exploration.

Previously, [*Ezhkov et al.*, 2009] the important geological and structural information has been got by A. I. Obraztsov from the analysis of a longitudinal section through the Muruntau deposit [*Obraztsov*, 2001]. It clearly occurred the block structure and shielding role of the second assise of Besapan suite with carbonaceous schist at the base. Directions and vertical displacement amplitude have such a scale that, despite the overall eastern decline and dipping of ore-bearing zone, each subsequent ore block is uplifted relative to the preceding, and is located at a depth that permits the total eastern decline and dipping of ore-bearing zone, as well as an effective exploration and open development work. Then it was proved with three boreholes the presence and depth of ore occurrence in the “third block”.

For clarification of morphology of the ore field A. I. Obraztsov constructed a cross-section (profile 136) through the eastern flank of Muruntau field and deposits Myutenbai (Figure 4) [*Obraztsov*, 2001]. The testing results on adjacent with the MS-2, 13706, 7341 boreholes have been contaminate to it. East ore blocks of Muruntau have been explored from the surface with exploration boreholes, traced to a depth with mine workings up to horizon 00 m, and opened with the MS-2 borehole below to the dip. The total scope of mineralization vertically approximately is 1800 m. Dip of zone is cragged in the south direction, and with the block movements – subvertical. Ore bearing zone of Myutenbai deposit have general north-north-east dip. It is also divided into blocks with successions in south-east direction, many of which are developed with post-ore dikes of granite porphyry, microdiorites. Its step nature in the section is not defined by the exact knowledge of the displacement amplitude, but with separate contouring of ore according to sampling within each tectonic block. Analysis of the spatial position and orientation of successions in deposits concerning to the layered and folded structure (see Figure 4) shows the symmetrical nature of the ore-bearing complementary successions and explains natural north (towards the root side of the ore field) dip of generalized ore zone of Myutenbai deposit. A certain symmetry is observed in the orientation of flatness of the ore-bearing fault.

Morphological and structural proportions, which is characteristic for Muruntau ore field (MOF), make it unlikely attenuation Myutenbai ore zone below the dip from 7341 borehole (see Figure 4). Therefore, acceptable and very likely assumption that the ore zone Myutenbai and Muruntau converge in a single part of the root – the “principal zone of mineralized fluids migration”. If the displacement of contacts suites is gray and variegated besapan on Southern

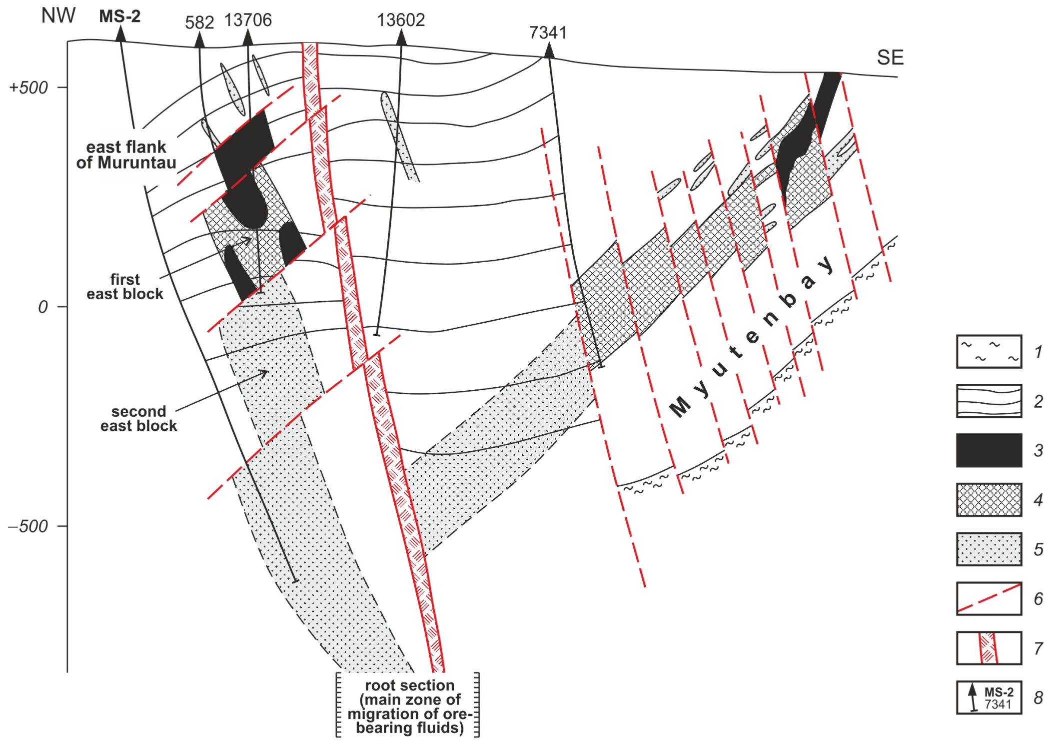

Figure 4. Longitudinal model of a ratio of gold blocks of Muruntau east flank and Myutenbay deposit (GE line 136). According to [*Obraztsov*, 2001]. 1 – carbon-micaceous schist; 2 – interstratified micaceous-quartz schist and metaaleurolites; 3 – balance ore; 4 – outbalance ore; 5 – lean and underexplored ore zones; 6 – faults; 7 – tectonic zone; 8 – boreholes.

fault with an amplitude of about 1000 m in plan caused by raising the southern block, for reconstruction of the original structure, it must be lowered to 500 m. In this case, the root portion of fields spatially coincide in a single field, conventionally shown in section. All this allows to continue the reconstruction of three-dimensional model of Muruntau ore field, which is crucial for the correct direction of exploration and evaluation of its fullest metal resources.

Continuing the theme of gold mineralization modeling of Muruntau ore field, we obtained estimation results of prospective gold bearing area of deep space horizons (1.5 km^2) in the contours of Myutenbai deposit, located east-northeast of geological exploration line 136 (see Figure 4), where Navoi metallurgical combine drilled dozens core boreholes. We defined as typical the following boreholes: 13703^a (depth 670 m). 14902 (depth 610 m) and 15100 (depth 680 m).

For the purpose of orientation in space it was selected the following plugs for the boreholes: 13703^a – near borehole 13602 (geological exploration line 136) 14902 – 260 m east of borehole MS-2, 15100 – 260 m southeast borehole MS-3.

Analysis of the model distribution of Au content classes in the near-ore mining and cross-sections of typical boreholes showed that the weighting of Au classes is over 1.0 g/t (total) is in the range 15–37%, with an average of just over 24% that is high enough for the reserve estimation characteristics of forecast resources (Figure 5).

Drafted a database of more than 10,000 samples were processed by GEMCOM program, which showed that in the area of calculation oval gold reserves of P$_1$ category (with onboard 1.0 g/t) reach high-volume values of the gold object.

Thus, the gold bearing potential of Myutenbai deposit has many reasons for its increase.

Initially ores with content (g/t) belongs to off-balance ore $2.0 < C_{\text{off-balance ore}}\ 2 < 2.5$ that laid in storage # 2 and ore with content $1.5 < C_{\text{off-balance ore}}\ 3 < 2.0$ (storage # 3). Then they started to allocate to separate traffic flows and ore containing $1.0 < C_{\text{off-balance ore}}\ 4 < 1.5$ (storage # 4), and ore with content in the subsoil more than 1.0 g/t has been reviewed as perspective raw material base Mining and Metallurgical Integrated Works-2. Mountain mass with content less than 1.0 g/t refers to the uncovering and are not separately stored. This led to the fact that the rock in barrows has an average gold content 0.35 g/t, and its quantity to 2005 reached $\sim$ 1500 mln t. According to preliminary estimates, among these rocks in the barrows may be isolated areas with a high content of gold (not less than 0.5 g/t) and total reserves 250 mln tons. Besides that, the allocation of a separate cargo traffic of rocks with a gold content less than 1.0 g/t it is possible to extract for 20–25 years annually 5–6 mln. tons of rock mass containing 0.7–0.8 g/t from the open pit.

For processing by heap leaching method off-balance ore accumulated for over 25 years of existence Muruntau open pit, in February 1992 the company "Newmont" (USA), the State Committee of the Republic of Uzbekistan on Geology and Mineral Resources, Navoi metallurgical combine have found "Zarafshan-Newmont" joint venture. According to

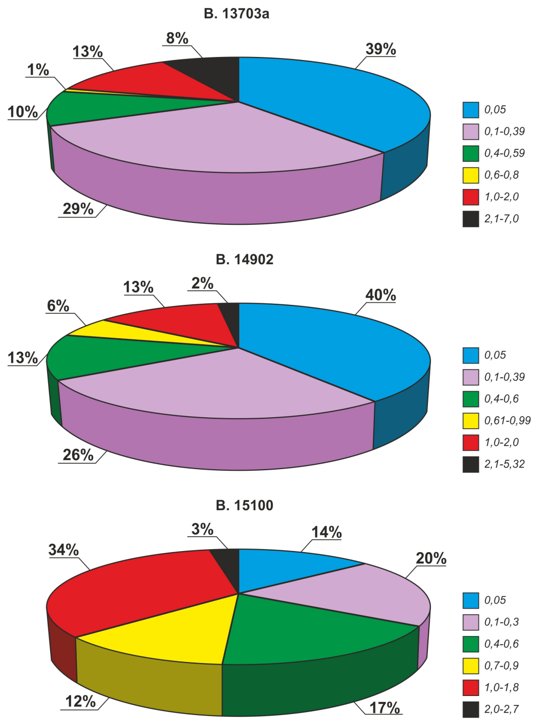

Figure 5. Model distribution of classes (%) of contents (ppm) of Au in ore and wallrocks intervals of boreholes of Myutenbay deposit (the region of deep boreholes of MS-2 and MS-3). Borehole, 15100.

the contract, it was transferred to this company 220 million tonnes of ore at an average grade of 1.4 g/t. Such quantity of ore was planned to process within 15 years, and after completion of the work should remain dump of size 950 × 2250 m and a height of 80 m.

To shorten credit payments period, the "Zarafshan-Newmont" joint venture during the first 5 years (since 1995) processed the ore with an average gold content 1.8 g/t. During processing of such ore, the extracting was 55–60% and more poor ore – 50%. After the finish of the desalination process in the dump is 40–50% of the gold (0.7–0.8 g/t), so it should be considered as a typical technogenic deposit, where the ore material is reground to a grain size – 3.25 mm. Under certain economic and ecological conditions, reserves of this field are raw material base of Mining and Metallurgical Integrated Works-2 and processed by traditional factory technology. As a result, the ore from the dump after grinding and additional recovery of gold at the factory moved to the existing waste storage facility, where and buried with the use of biological remediation methods, techniques of which has already been worked out and implemented.

The proposed technological scheme of processing of mineral raw materials is element to adapt the existing resource base of Muruntau deposit to the new economic situations, when constructing strategies for the use of which applied the principle of cyclic production, when the waste pits (off balance ore) are directed to heap leaching of gold, which is, in turn, processed in Metallurgical Integrated Works-2.

The use of such a scheme of using the heap leaching of waste for repeat processing factory by technology involves partial replacement of the ore from the mine this waste, which, naturally, will lead to some reduction of the content in the processed ore. Therefore, this scheme can be implemented with a certain combination of geological, technical, economic and ecological conditions, the main ones are:

- the inevitable reduction of ore extraction with high gold content due to increasing depth of open cut mining, due to naturally decrease of ore body thickness with depth in Muruntau deposit (Figure 6a);

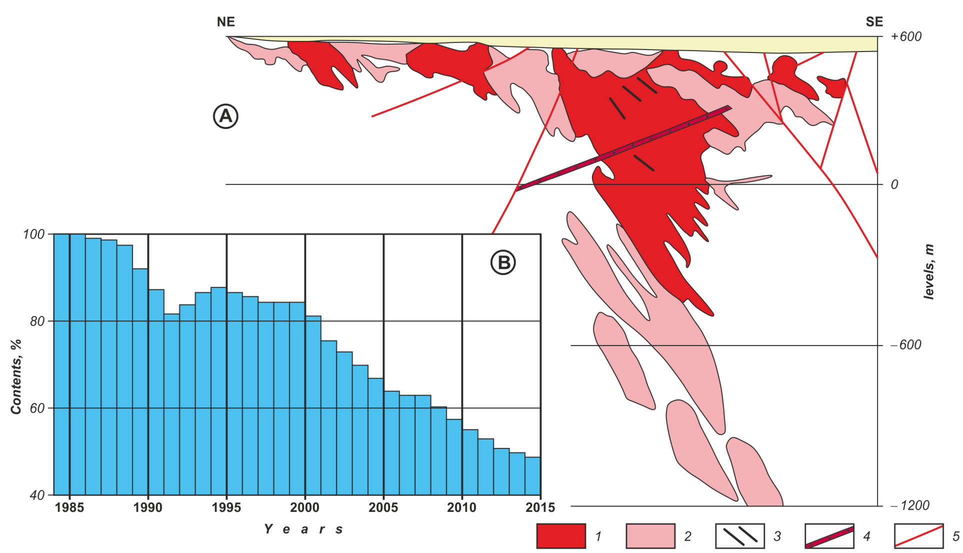

Figure 6. A schematic section and depth of development of the central part of Muruntau deposit (A) and dynamics of gold content change in the process ore in time (B). According to [*Sitenkov et al.*, 2005]. 1 – rich ore columns with ore content > 0.8; 2 – low-grade ore bodies with ore content < 0.3; 3 – gold-bearing quartz veins; 4 – dyke of a plagioporphyry; 5 – faults.

- the decrease of gold content in ore processed (Figure 6b), which is associated with an increase in the ore delivered to the plant, the proportion of low grade ore.

Naturally, the involvement in the processing of waste heap leaching prolongs life by 8–10 years of mining and processing complex, and generally will provide additional quantities of gold. However, this raises questions about the practicability, timing and volume of such replacement, to answer that questions satisfied estimated calculations were provided. Methodical bases these calculations are based on the following assumptions [*Sitenkov et al.*, 2005]:

1. The reduction of gold output due to lowering the content in the processed ore partially is compensated by the increment of factory efficiency.

2. Involvement to the processing of waste heap leaching reduces energy output of ore reduction process in the grinding machine.

3. Return of water from the storage to the factory reduces energy expenses for water supplying of factory.

4. The use of water recycling to the associated transport of waste heap leaching for processing controls lower transport costs.

5. Replacement of part of the produced ore with waste heap leaching will reduce the intensity of underground mining in the pit and the costs of their implementation.

6. The increase in the proportion of waste in the processed ore mass lowers gold production, with the result that the company makes a loss, but at the same time decrease the cost of gold production, because of which company gets additional profit.

7. There is a correlation between the proportion of recyclable waste heap leaching and shares of processed ore from the pit in which the losses from reduce of gold production are compensated with additional profit from reduce of expenses for its production.

However, until the present time there is a problem associated extraction of W, REE, Re, Sc, and other metals from the waste heap leaching, which effectiveness has been proved earlier.

Conclusion

The analysis of position of mineralized structures placement in Muruntau ore field, zoning gold and paragenetic mineralization, conditions of its industrial capacity increase, and others took place at the level of endogenous development processes.

Constructed by us a model of clastogenic migration of minerals with their geographic range contouring in Muruntau mountainous system, showed here, in turn, the intensity of occurrence and epigenetic processes (Figure 7). Zoning in the placing of areal of gold with scheelite from one side, and from another side areal of cinnabarite with aluminate and cerrusite was control by hypergene transformation of bedrock and profile in Muruntau ore field gold and wolfram type of ore, with offset distance from them in the north bearing zones of thermal transformation of sedimentary clastic (with rare volcanic) thicknesses, in the northern strip of “deep” of Muruntau Kosmanachi ore-magmatic system [*Ezhkov et al.*, 2012].

This strip of ore magmatic system, approximately in the border of Central Tamditau, we occasionally published as forecasting of perspective area. We concentrate attention on its ore-formation and geological and structural features again.

Location. Located in Tamdy District of Navoi region, in Tamdy mountains. Linked to a dirt road (15 km) from the Mining and Metallurgical Integrated Works-2 under Navoi metallurgical combine. Electric power line passes through south of 7 km. Absolute elevation figure is 725–775 m; height relationship is 50–70 m.

Prognostic resources of gold (metallogenic potential). 100 t to the depth 300 m.

Geology aspects. Prognostic perspective area is observing along east-west strike in 25 km in average thickness is 2–2.5 km and limited to contact strip of terrigenous rock of Murunkuduk suite (siltstone, argillite, sandstone, gravelite, conglomerate and hornstone) with the carbonate rocks of Belkuduk suite. It is substracted on the basis of occurrences in it not only the mineralized zones and areas, but the 19 occurrences of mercury, as well as two anomalous geochemical fields (AGF) with their blue cup forming complex of ore elements (Au, Ag, Sb, As, W, Cu, Sn). For example, yield of AGF – XXX (g/t per km^2) reaches over an area of 2.4 km 2190 points for Au and 1135 points for Ag. Relating to mega gold-bearing structure of Muruntau ore field in South Tamdy substract prognostic perspective area can correspond to front and pectoral zone of mega gold structure, approaching the lateral ore-geochemical zonation standard of AGF industrial gold deposits. Separate fragments of mega gold structure can plunge in north bearing under carbonate shield and its terrigenous margins. In these conditions, especially complex gold-mercury-silver-lead geochemical blue cup of prognostic perspective area of Central Tamdy obtains meaning of features-indicators of covered by them gold and paragon ore mineralization.

It is attract serious interest very wide-spread occurrence in the prognostic perspective area of stream sediment sample with a high content of water aluminate – boehmite and diaspore – indicators of epigenesis processes not only on the example of arcilla, bauxite crusts, but also transformed carbonate and volcanogenic-terrigenous shale rock enriching aluminates Mn, Mg, Fe. It should be noted that in Australia it is known Buddington gold deposit located in the chimney like structure of bauxite bearing rocks.

The level of knowledge. Geological survey, mercury ore bearing prospecting works and thematic enriching works.

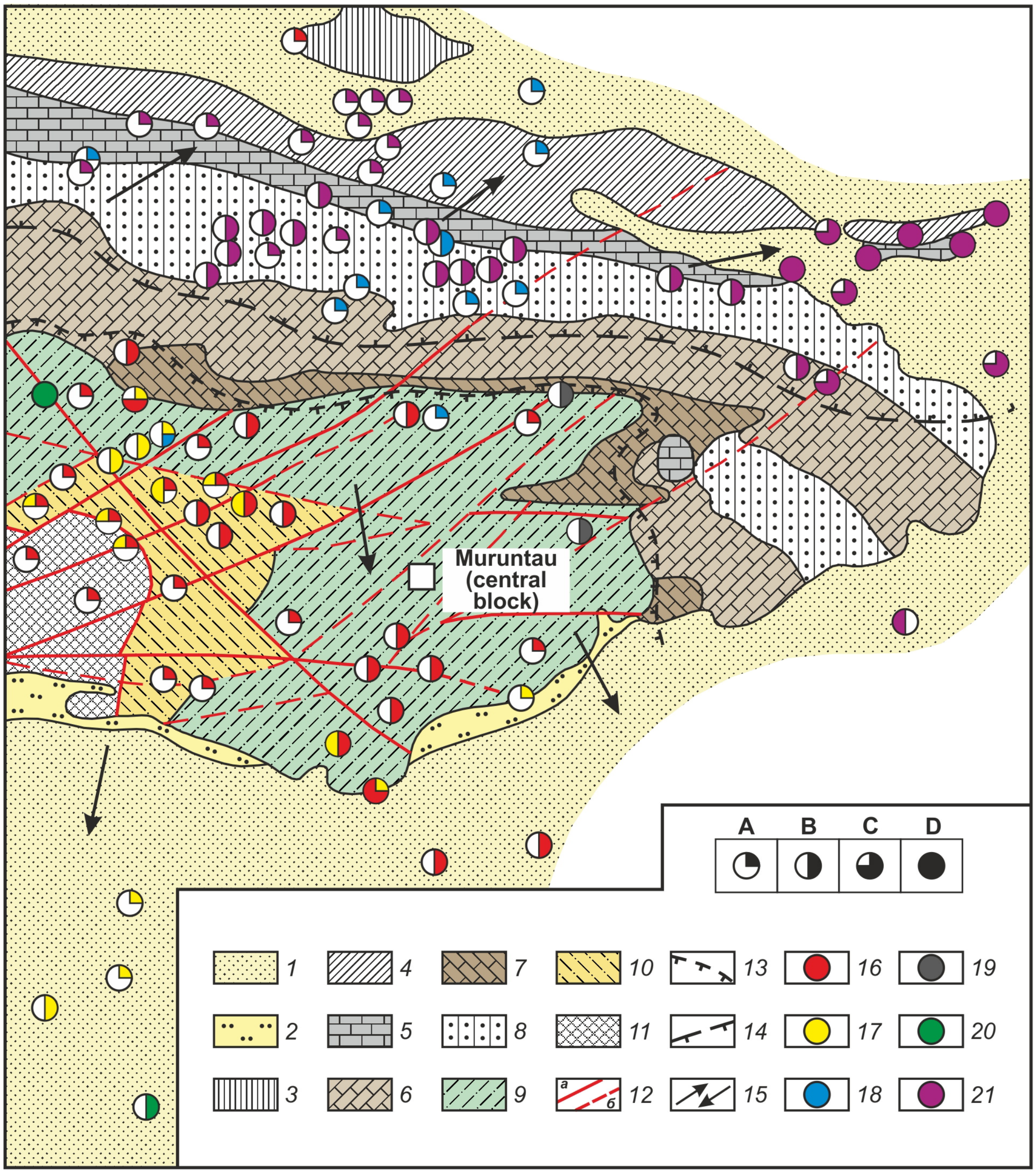

Figure 7. Model of clastic migration of minerals, their areas of Muruntau mountains. 1 – proluvial deposits (Q); 2 – sandstones, alluvium and aleurolites (K_2); 3 – green rocks, conglomerates, sands, gravelites with lenses of chalkstones (C_3); 4 – green rocks, chalkstones (C_2); chalkstones: 5 – C_1, 6 – D_2; 7 – bituminous chalkstones, dolomites (D_1); 8 – quartz sandstones, micaceous-quartz with layers of argillites, aleurolites, tophaceous sandstones (S_1, bs_4); 9 – aleurolites, alluvium, gravelites with lenses of siliceous rock and dolomites, seldom vulcanites of acidic content (O_3-S_1bs_3); 10 – sandstones, aleurolites, argillaceous schist, carbon-quartz-micaceous schist with layers of carbonaceous rocks and gravelites (O_3-S_1bs_2); 11 – carbon-silicic, carbon-quartz-micaceous schist, metaaleurolites, metasandstones (O_2bs_1); 12 – faults (a – actual, b – supposititous). Halo of dispersion: 13 – scheelite, gold, 14 – boehmite, diaspore and cinnabarite; 15 – general directions of ablation of alluvium and migration of minerals. Name and content of minerals in schlich: 16 – scheelite, 17 – gold, 18 – cinnabarite, 19 – vanadinite, 20 – cerusite, 21 – boehmite and diaspore. A – singular marks, B – frequent marks, C – to 10%, D – to 50% of heavy unmagnetic residue.

Extractive enterprise. Mining and Metallurgical Integrated Works-2 under Navoi metallurgical combine.

Proposal on further direction of works and deployment. Prospecting works in noble metals and accompanying rare metal mineralization.

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