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TECTONICS OF THE SUROZH GOLD-ORE CLUSTER OF THE NEAR-AZOVIAN MEGABLOCK OF THE UKRAINIAN SHIELD

N.N. Shatalov

(Recommended by doctor of geological-mineralogical sciences L.S. Galetsky)

Institute of Geological Sciences of NAS of Ukraine, Kiev, Ukraine, E-mail: geoj@bigmir.net
Doctor of geological sciences, senior scientific worker.

The results of investigations for the large structural Surozh ore cluster located within the Sorokinskaya graben – syncline of the Near-Azovian megablock of the Ukrainian Shield are presented. The features of fault-block tectonics and its influence on forming the ore cluster are defined. The Sorokinskaya graben-syncline and other fault zones of the orthogonal and diagonal systems and their significance in the localization of the unique fluorite rare-earth deposit are characterized. The manifestation features for magmatism, metasomatosis, mineral and ore genesis are studied.

Key words: tectonics, faults, geoblocks, graben-syncline, dikes, metasomatites, gold, deposit.

ТЕКТОНІКА СУРОЗЬКОГО ЗОЛОТОРУДНОГО ВУЗЛА ПРИАЗОВСЬКОГО МЕГАБЛОКА УКРАЇНСЬКОГО ЩИТА

М.М. Шаталов

(Рекомендовано д-ром геол.-мінерал. наук Л.С. Галецьким)

Інститут геологічних наук НАН України, Київ, Україна, E-mail: geoj@bigmir.net
Доктор геологічних наук, старший науковий співробітник.

Наведені результати досліджень великого структурного Сурозького рудоносного вузла, розташованого в межах Сорокинської грабен-синкліналі Приазовського мегаблока Українського щита. Визначені закономірності розломно-блокової тектоніки та її роль у формуванні рудного вузла. Охарактеризовані Сорокинська грабен-синкліналь та інші розломні зони ортогональної та діагональної систем і їх значення в локалізації унікального Сурозького золоторудного родовища. Досліджені особливості прояву магматизму, метасоматозу, мінерало- і рудогенезу.

Ключові слова: тектоніка, розломи, геоблоки, грабен-синкліналь, дайки, метасоматити, золото, родовище.

ТЕКТОНИКА СУРОЖСКОГО ЗОЛОТОРУДНОГО УЗЛА ПРИАЗОВСКОГО МЕГАБЛОКА УКРАИНСКОГО ЩИТА

Н.Н. Шаталов

(Рекомендовано д-ром геол.-минерал. наук Л.С. Галецким)

Институт геологических наук НАН Украины, Киев, Украина, E-mail: geoj@bigmir.net
Доктор геологических наук, старший научный сотрудник.

Приведены результаты исследования крупного Сурожского рудоносного узла, расположенного в Сорокинской грабен-синклинали Приазовского мегаблока Украинского щита. Определены закономерности разломно-блоковой тектоники и ее роль в формировании рудного узла. Охарактеризованы Сорокинская грабен-синклиналь и другие разломные зоны ортогональной и диагональной систем и их значение в локализации уникального Сурожского золоторудного месторождения. Исследованы особенности проявленного магматизма, метасоматоза, минерало- и рудогенеза.

Ключевые слова: тектоника, разломы, геоблоки, грабен-синклиналь, дайки, метасоматиты, золото, месторождение.

Introduction

A lot of gold deposits were found on our planet. Over the last 30–35 years the large high-grade gold deposits of the world are discovered in the geological formations of the different types such as greenstone, black-shale ones, etc.

Surozh deposit is especial, because it was found within the unique, exclusive, no equals in the world the ancient Precambrian structure. This structure is known as “Sorokinskaya graben”, “Sorokinskaya fault tectonic zone”, and “Sorokinskaya greenstone structure”. Gold deposit was formed at the depth of about 5 km within the rather complicated Surozh ore cluster. The significant feature is not only tectonic position of this deposit, but also the duration of evolutionary development of this graben-syncline, i.e. at least 1.5 billion years. Within the boundaries of the structure in addition to Surozh gold deposit it was discovered the large deposit of rare metal pegmatites “Balka Crutaya” [Розанов, Лавриненко, 1979].

Thus the data presented in the article give ground to categorize the Sorokinskaya graben- syncline as the ***geological exclusive***. Such exclusives include, for example, the geological structure and the largest Witwatertsrand gold-uranium field in South Africa, the analogues of which so far haven’t been found on Earth. The formation of these exclusive structures and deposits in the author’s opinion are connected with the long and unique evolutionary and geodynamic development of our planet, resulting in the unique geological structures occurred in certain its parts and consequently the exclusive deposits.

Geologic-structural position and Sorokinskaya graben-syncline structure

This original geo-tectogene [Глевасский, 1996] is the tectonic boundary between the two lager plicative Precambriant structures having a different age from the Near-Azovian - Manhush synclinorium and Saltychansk anticlinorium, in the center of which same-name dome fold is identified. Some investigators describe this structure as the deep linear zone of rifting embedded in the Achaean (more 3.3 Ga.) on the Precambrian granulite-gneissic basement. In the plan this is the narrow local strip of the Precambrian supracrustal units continued down to 35–40 km at the maximum width (in the bulges) to 2 km. Graben-syncline is cut off from the “frame” of rocks by subparallel deep faults having North-Western spread direction (320-330°) and South-West steep dip (75-85°). In its northern part the strike of structure changes from the north-western direction to sub latitudinal one and there its knee-band is created. The level of erosional truncation within the structure can reach up to 5-6 km. Thus at the present time only the abyssal features remained on the comparatively large fissure-like, fosse-shaped trough-suture (graben-syncline) (Fig. 1, 2).

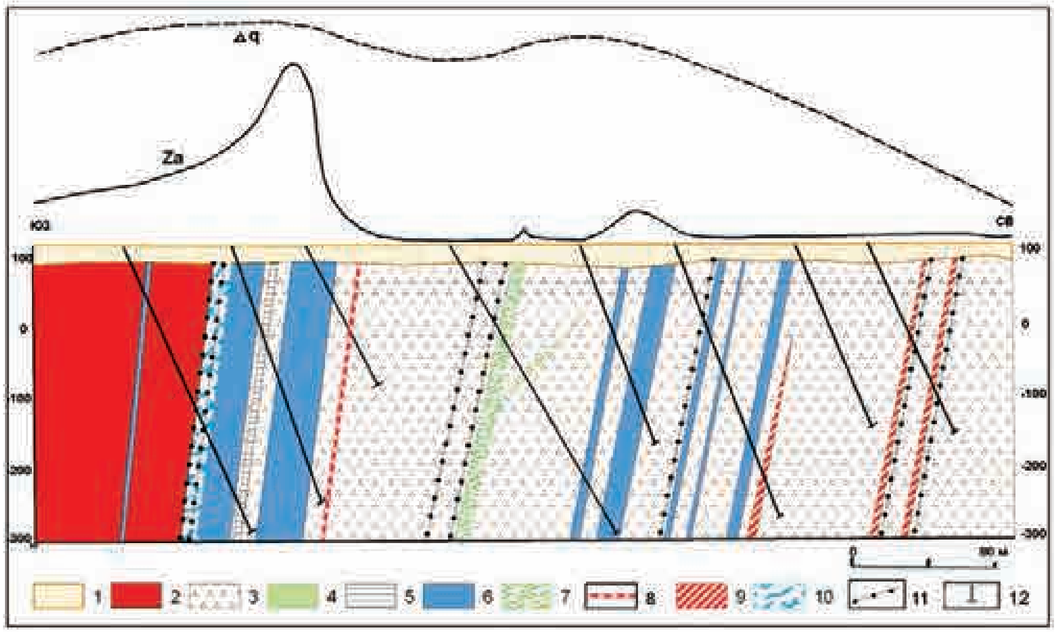

Fig. 1. Geologic-geophysical cross section for the Sorokinskaya trough structure drowned by the author according to the Artiemovsk Geological Survey Expedition data (N.F. Rusakov et al., 1981)

1 – sedimentary rocks; 2 – gneiss and migmatite of the Western Near-Azovian, Archaean series; 3 – gneiss and migmatite of the Central Near-Azovian series; 4 – rocks of the Osipenkovian suite; 5 – ferruginous quartzite; 6 – metabasite dykes; 7 – dolerite dykes; 8 – quartz veins; 9 – pegmatite veins; 10 – cataclasis and mylonitization zones; 11 – faults; 12 – boreholes

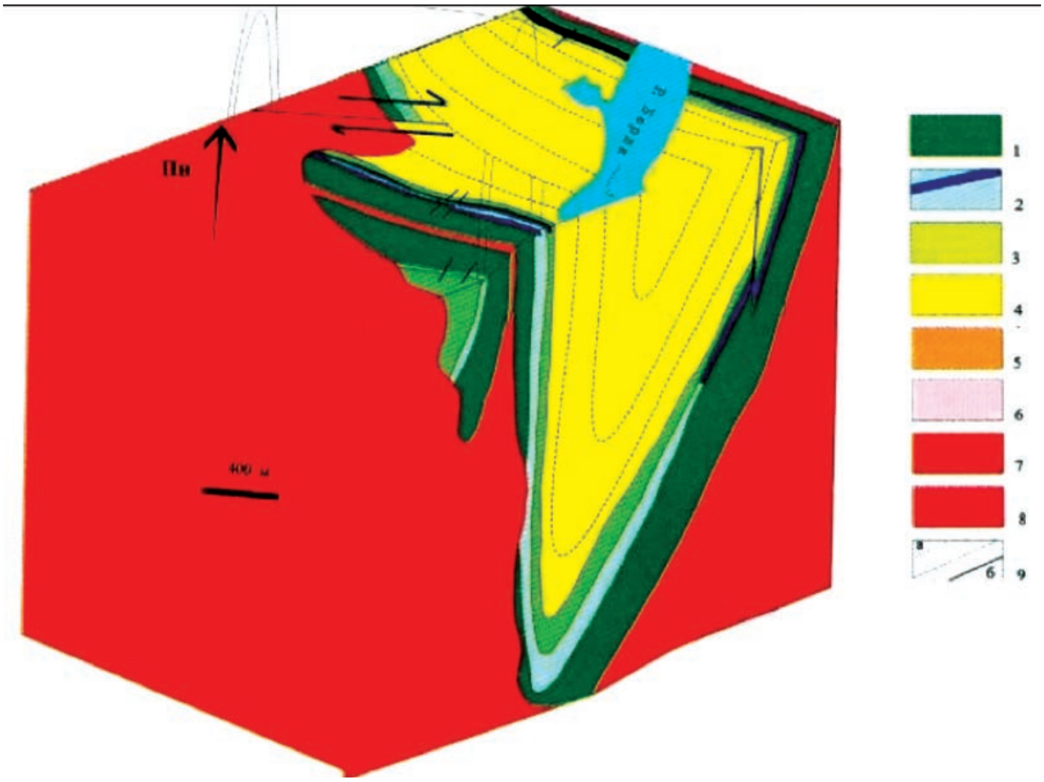

Fig. 2. Three-dimensional map for the Surozh part of Soronskaya graben-syncline [Чорнокур, Яськевич, 2010]

1 – metabasites; 2 – metaultrabasites; 3 – upper metabasite part; 4 – metaconglomerates, sandstones, alumina slate; 5 – lava – subvolcanic material of the Surozh Formation; 6 – hypabyssal material; 7 – intrusive plagiogranitoids from the Shevchenkovsky complex; 8 – two-feldspar granites; 9 – junctions and structural lines

Sorokinskaya graben-syncline has revived multiply. This is proved by the numerous predominantly concordant dykes, compression zones, as well as cataclasis and milonitization ones. In addition to the longitudinal (against the structure) fault tectonic zones, here there are also the transverse (north-eastern) and transcurrent (sub-meridional and sub-latitudinal) faults. Graben-syncline is dissected by the systems of orthogonal and diagonal faults into the discrete small-sized blocks (Andriievskiy, Sorokinskiy, Osipenkovskiy, and Sadovyi ones), which have undergone the shift along the lateral and vertical directions. As a result it turned into the peculiar “keyed” structure, where the rock complexes of the different depths (density) appear at the recent erosion truncation level. Such block structure is a base of atypicality for its anomalous gravitational and magnetic fields (Fig. 3). In the direction from north-west to south-east the erosion truncation depth within the graben-syncline considerably decreases that can be seen from the compositions of metamorphic rocks of the different its parts, as well as on the degree of their metamorphism. Thus, within the Andriievskaia magnetic anomaly manifested to the most elevated block the relics of highly-metamorphic volcanosedimentary formations of granulite facies are defined, and in south-eastern graben-syncline at the Sadoviy site (downthrown block) the most complete section of low-metamorphic rocks (epidot-amphibolitic facies) are revealed. Geoblocks occupy the intermediate position at which the Surozh deposit and Sorokinskiy site are located, where diaphthorites are well represented along the rocks of amphibolites facies [Кравченко, Сахацкий, 1988; Глевасский, 1996].

The thickness of rocks building up the graben-syncline is 1.2 km [Глевасский, 1996]. In the present stratigraphical sectional planes they are divided into the Lower and Upper Osipenkovian suite associated with the Achaean and Lower Proterozoic. The thickness of the lower “greenstone” suite is 700 m. It is composed of amphibolites, green sheets, metaultrabasites, ferruginous quartzites and intruded by numerous metamorphosed dykes of ultrabasite – basite and acidic compositions. In the north-eastern slope of graben-syncline in the section of Lower Osipenkovian suite the high alumina and two-mica gneisses are wide-developed. The Achaean age of Lower Osipenkovian suite is proved by geological and structural data and the dating on the minera

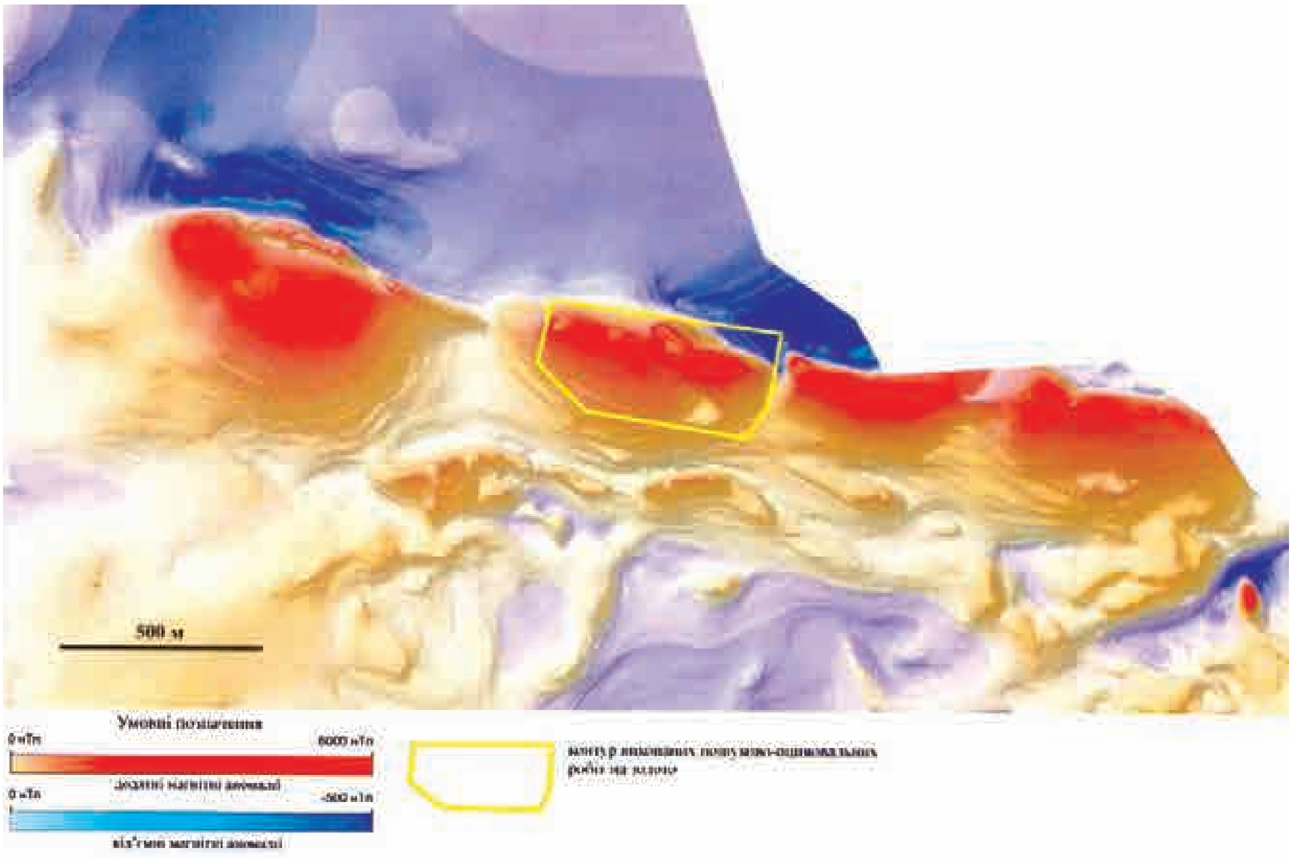

Fig. 3. Earth's magnetic field model for the site of Surozh gold deposit [Лисенко та ін., 2005]

l zircon from both the Osipenkovian granodiorites having the sharp active contacts with amphibolites and metamorphosed quartz porphyrys, i.e. 2.79 and 2.66 b.y.a. [Глевасский, 1996; Кравченко, 1999].

The Upper Osipenkovian suite at the thickness of about 500 m is composed essentially of terrigene formations and broken by the dykes of lamprophyres, diabases, and younger dolerites. Its rhythmic structure can be observed at the exposed areas of graben-syncline along the Berda River as an alternating two-mica gneisses or schists with the relicts of meta-detritus structures and high aluminous (staurolite-, andalusite-, cordierite-, and sillimanite-bearing), garnetiferous, graphitic and other gneisses and schists.

In the southern Sorokinskaya graben-syncline the low-thickness (about 200 m) sedimentagenous package including marbles, meta-conglomerates and grafite-bearing schists ("Sadovaia suite") lies at the rocks of the lower and upper Osipenkovian suite. In the graphitic schists of Sadovaia suite the geologists have determined the complex of microphytofossils typical of the rocks of the Hdantsevian suite for the iron-ore Krivoy Rog belonging to the early Proterozoic.

The characteristic feature for the lower and upper Osipenkovian suite and particularly "Sadovaia suite", developed within the Sorokinskaya graben-syncline is weak metamorphism (epidote – amphibolitic stage) relatively to Achaean – Proterozoic kratogen and a lot of dykes with the different compositions and ages indicated the ertain stages of tectonomagmatic activation and destruction of the Earth's crust [Шаталов и др., 1982; Шаталов, 1986, 1990, 1991].

The history of deposit discovery

The story of discovery of the Surozh gold ore deposit goes back to the 1970s. The first finely-dispersed gold [Усенко и др., 1973] and then visible [Кравченко, 1988] free gold in the parent rocks of ore occurrence sites of the Sobachia Gulch and the Berda River were found by the specialists of the Institute of Geochemistry and Physics of Minerals of the Academy of Sciences, UkrSSR (now the Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences, Ukraine) in studies of mineral composition of rocks and mineralization of the Western Near-Azovian.

The Surozh deposit was found in the 1993-1996 by the "Kirovheolohiya" State Geological Enterprise on the recommendation of H.L. Kravchenko and N.N. Shatalov.

The prehistory of the Surozh gold deposit discovery is such that the large Production Geological Association (PGA) "Kirovheolohiya" (now "Kirovheolohiya" State Enterprise) was organized in the post-war years and based at the beginning in Krivoy Rog Town and then in Kiev City. Despite the location "Kirovheolohiya" PGA had the All-Soviet Union subordination and specialized in prospecting for uranium ores not only in Ukraine but in Moldova and Russia. The PGA"Kirovheolohiya" didn't explore the Near-Azovian area on uranium ore, because this region was considered as little promise on this mineral. It must be emphasized that in the 1960s – 1990s the PGA"Kirovheolohiya" have got everything, i.e. money, staff, transport, boring rigs, laboratory facilities, funds, library, and most importantly, there were the promising geological objects for exploration.

And suddenly there was a collapse of the Soviet Union in 1991. The new "Kirovheolohiya" State Enterprise (SE) have been survived both the financial crisis and geological one, since the set of promising objects for geological exploration significantly reduced. But the prominent experts–geologists, the boring rigs and classy laboratory facilities have remained. It might be no accident that in this period the idea to prepare the recommendation on prospecting for gold in the Near-Azovian for "Kirovheolohiya" SE came up to two scientists – H.L. Kravchenko and the author of this article. It often happens in science, when the similar ideas came to mind to two scientists independently and simultaneously, as it was with Boyle and Mariotte or Joule and Lanz and their laws in physics. And why the similar ideas can't come to geologists?

So in 1991 the "Kirovheolohiya" SE management has received simultaneously the recommendations of H.L. Kravchenko (Candidate of Geological and Mineralogical Sciences, Senior Researcher at the Institute of Geochemistry, Mineralogy and Ore Formation, National Academy of Sciences, Ukraine) "On the prospects of the search for gold in the Sorokinskaya zone" and two ones of N.N. Shatalov (Candidate of Geological and Mineralogical Sciences, Senior Researcher at the Institute of Geophysics, National Academy of Sciences, Ukraine) "On the prospects of the search for gold deposits in the Near-Azovian in relation to the dyke complex" and "The prospects of the search for rare metal deposits in the Near-Azovian in relation to the dyke complex". Every recommendation was heard in the same Scientific and Technical Council (STC) of "Kirovheolohiya" SE and done to implement (Minutes №55 dated 28.02.1991). The one of promising object of the search for gold in the Shatalov's recommendations was the Sorokinskaya graben-syncline, where many dykes are mapped including golden ones [Шаталов и др., 1982; Шаталов, 1986, 1990, 1991, 1993]. Therefore the "Kirovheolohiya" SE immediately got the primary object of research from the hands of scientists – geologists of the National Academy of Sciences of Ukraine in the Near-Azovian as the Sorokinskaya graben-syncline.

It is encouraging to note that in spring 1991 the 47th Geological Exploration Crew (GEC) "Kirovheolohiya" SE started exploring the Sorokinskaya zone structures promising for gold. In particular, the top layers of ore bodies were uncovered with the bulldozers along the Sobachia Gulch and the deeper their sites with wells. In the subsequent two years the deep core drilling, laboratory research, and primary reserves estimate were carried out for this deposit. So the unique Surozh deposit was discovered. It needs that the discovery of this deposit is an outstanding example of a fruitful collaboration between the scientists – geologists of the National Academy of Sciences of Ukraine and practicing geologists from the "Kirovheolohiya" SE.

H.L. Kravchenko (the Institute of Geochemistry, Mineralogy and Ore Formation – IGMOF, National Academy of Sciences, Ukraine), N.N. Shatalov (the Institute of Geological Sciences, National Academy of Sciences, Ukraine), and V.F. Bakarzhiev, N.A. Beluch, A.A. Lysenko (GEC at the "Kirovheolohiya" SE) should be recognized as the discoverers of the Surozh gold ore deposit.

In 1994–2015 the Surozh deposit was studied by H.L. Kravchenko, I.I. Sakhatsky, E.B. Hlevassky, V.N. Kvasnitsa, I.K. Latysh, S.N. Bondarenko, I.N. Bondarenko, et al. (IGMOF NAS of Ukraine), O.B. Bobrov, A.O. Sivoronov, B.I. Maliuk, T.B, Yaskevich, Yu.V. Liakhov, M.M Pavlun et al. (Lviv State University), O.B. Bobrov, O.A. Lysenko, B.I. Maliuk, I.E. Merkushin, O.M. Tysiachna, S.V. Hoshovsky, et al. (UkrDHRI), D.S. Hursky, N.I. Lebed et al. (Ministry of Ecology and Natural Resources, Ukraine), L.S. Haletsky et al. (IGS NAS of Ukraine).

In the following years the 47th Geological Exploration Crew from the "Kirovheolohiya" SE has explored Andriievskiy, Sorokinskiy, Olhinskiy, and Sadovyi and other prospecting sites within the Sorokinskaya graben-syncline for gold. Now all of them require further investigation and assessment.

The features of geological deposit structure

The Surozh gold deposit is located in the pretty beautiful place, in the valley of Berda River near the water reservoir of the same name about 30 km north of Berdiansk City in the central Sorokinskaya graben-syncline. As far as tectonics this deposit is confined to the western geoblock of the Near-Azovian megablock of the USh, to the south shoulder of graben-syncline. As a result of sublatitudinal and north-eastern fault zones at the area where the deposit was found the significant "bulge" of graben-syncline arose and the large ore cluster was formed (Fig. 4). Here the size of formed structural ore cluster is about 2×2 km. The extension of gold ore deposit is around 1.5×0.2 km and the area is 3-4 km^2.

The key elements of tectonics for the considering region are the faults. They are responsible for heterogeneity and patchiness of the Sorokinskaya graben-syncline Surozh structural ore cluster as well as the block character of the structure for the gold ore deposit and Western Near-Azovian megablock of the USh on the whole. The faults in this region differ in the direction, laying depth, extension, amplitudes of the vertical and lateral displacements and other kinematic features. They form the orthogonal and diagonal systems here, which consist of a series of sub-parallel zones dissecting the above mentioned structures into the different-sized geoblocks. The fault systems are most developed for the following directions: NW 315-325°, NW 280-290° and NE 60-70°. The faults of sublatitudinal orientation

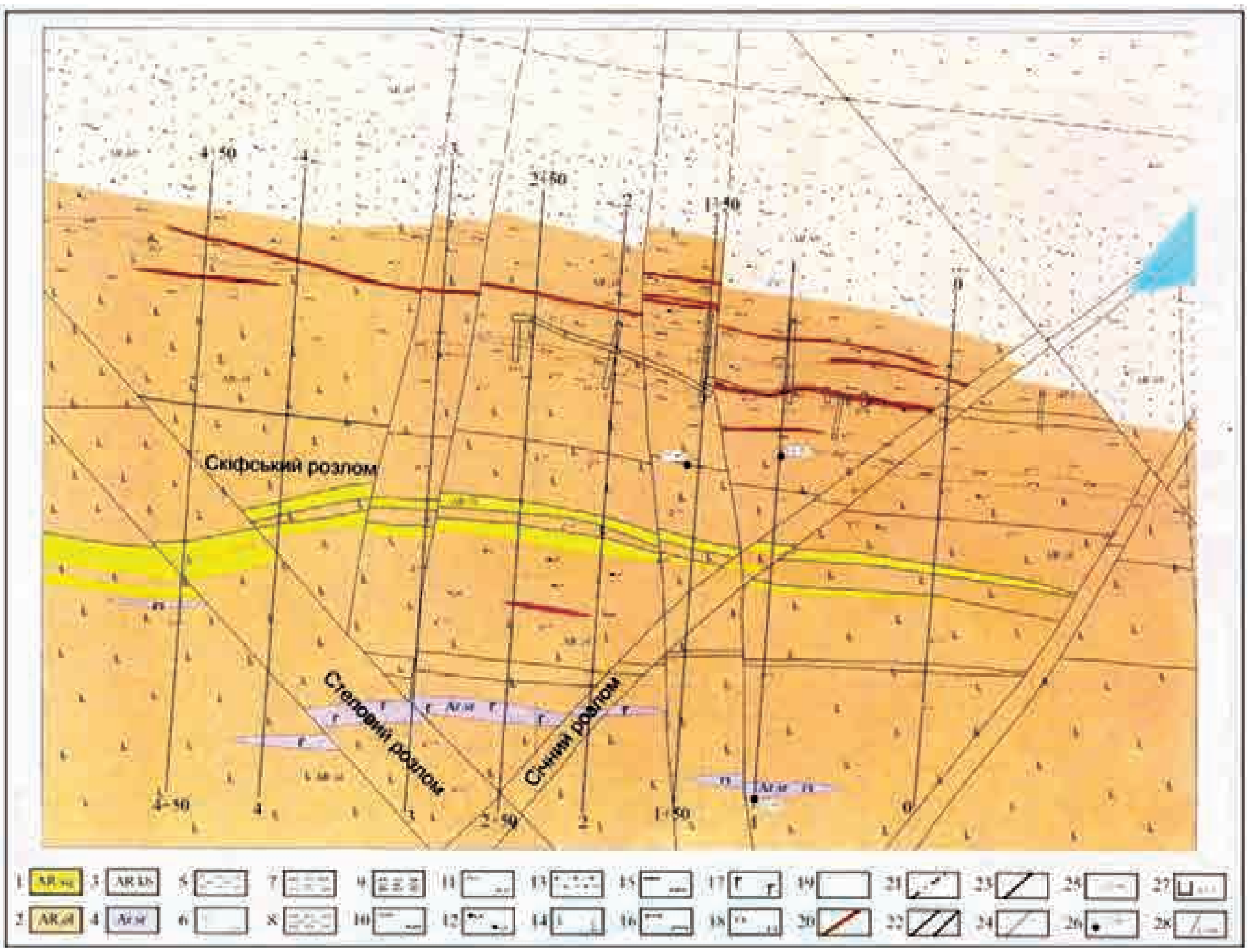

Fig. 4. Geological map for the Central Surozh deposit [Лисенко та ін., 2005]

1 – Surozh Formation; 2 – Olginsk Formation; 3 – Kruta Bulka Formation; 4 – Sorokinsky complex (yiroxenites, peridotites, gabro); 5 – loams and sand clays; 6 – crust of weathering; 7 – metsiltstones; 8 – metasandstones; 9 – metaconglomerates; 10 – biotite slates; 11– alumina slates; 12 – amphibolic slates;13 – ferruginous quartzite; 14 – metabasalts; 15 – tremolites; 16 – actinilites; 17 – gabro; 18 – dunites, peridotites; 19 – milonites; 20 – ore bodies; 21 – faults identified by geophysical data; 22 – essential faults; 23 – minor faults; 24 – geological boundaries; 25 – deep boreholes; 26 – deep test holes; 27 – bulldozer trenches; 28 – profile line and its number

are common here, the submeridional ones are rather rare. The most faults have arisen in the Archean and they are active up to present. It can be seen on the character of Berda River confinedness and the change of orientation for its river-bed. These fault tectonic dislocations are characterized by all typical features of deep faults. The series of differently oriented faults of orthogonal and diagonal systems control the character of edged and inner parts of graben-syncline and define the direction of strike for the thicknesses, which compose it. The segments of faults connecting with each other form a complex framework for the recent configuration of graben-syncline. At the stage of subsidence of the foundation geoblocks the faults served as the supply channels for erupted lava and the other product of volcanism, as well as accumulation of volcanosedimentary formations in graben-syncline. In the vicinity of Surozh structural ore cluster the mentioned faults have caused the split-block "keyed" construction. The sizes for the separate geoblock segments here, for example, may be 1×1 or 1×2 km.

The ore-bearing bodies of the Surozh deposit are confined to the fault intersection node for the three directions: NW (320-330°), sublatitudinal (275-280°) and NE (60-70°). The ancient near edge fault of north-western strike restricts the Sorokinskaya zone and deposit to the north-west named Stepovoy, the sublatitudinal Scythian fault restrains to the south, and the north-western Transversal fault coincides in the direction of the Sobachia Gulch. The latter, i.e. the fault crossing Sorokinskaya graben-syncline by H.L. Kravchenko [Кравченко, 1999] is more recent. The tectonic significance, the features of geodynamics and magmatism as well as mineragenetic characteristics prove the great importance of the near edge Stepovoy deep fault in the forming very complex structural ore cluster. This tectonic zone in our opinion is the primary among the faults. Within Sorokinskaya graben-syncline (along the lateral and in the depth) this zone is certainly magma- and ore controlling structure. The Scythian fault plays a key role. Here metabasites, ferruginous quartzites, and ore-bearing metasomatites coincided just with it. This fault during the formation of gold deposit was probably undergoing the geodynamic expansion (fault-rupture). The Transversal fault is an ore controlling structure. In the opinion of Kravchenko [Кравченко, 1999] the main ore-bearing zones and ore bodies from the Surozh deposit are confined to this fault. The diagonal Transverse fault located in the deposit area (possibly, oblique-slip fault) divides the all defined types of the faults into the two lateral geoblocks at the different level of erosion truncation. The level of erosion truncation for the rocks is significantly lower to the east. The Scythian, Transverse, and Stepovoy faults overlapping here create the structure-ore cluster and the frame for the Surozh deposit. They are accurately found and studied by the geological and geophysical methods not only within the deposit and graben–syncline on the whole, but also far beyond their borders. The intercrossing of above mentioned faults creates a "triangle" with sides of 450-550 m. [Лисенко та ін., 2005]. This triangle mainly controls the gold deposit. In addition to the primary fault zones the systems of secondary rupture anomalies, contiguous fractures, as well as the dykes varying in the compositions and ages are widespread. Perhaps, during that period of the Earth's evolution the fracturing and extension of the formed, rather thick, compact, solid, and crystalline crust have taken place within the Western Near-Azovian Archean "craton" at the knot of above mentioned zones of the deep faults. In course of tectonomagmatic activation in the Archean and Proterozoic the Sorokinskaya graben-syncline was formed here, the numerous magmatic intrusions of basic and ultra-basic compositions were enforced, the skeleton frame for the structural-metallogenic and smaller ore cluster were "shaped", where the gold deposit was localized subsequently.

Metavolcanic, metamorphous igneous-sedimentary and sedimentary rocks composing the graben-syncline have the maximum lateral thickness to 2.0-2.3 km due to the "bulge" at the Surozh area. The strike of metamorphous rock is north-western (NW 325°) here, the inclination is steep, south-western under the angle of 75-85° [Кравченко, 1999]. As far as the geological setting the opinions of scientists-geologists were divided. Some researchers consider it as the diaphtoric fragment of the ancient basement, while others believe that it is the typical greenstone structure [Глевасский, 1996; Лисенко та ін., 2005].

In the Sorokinskaya graben-syncline and within the deposit the aluminous and biotite gneisses are widespread, which are occurred both the separate benches and the interlayers among metamorphoused volcanites of basic and ultrabasic compositions. A genesis of these rocks due to the high degree of metamorphism remains unclear. The relicts of porphyritic structures are found at the gneisses that is evidence of volcanogenic genesis. However, zircon from these rocks has the marks of roundness that allows interpreting them as metamorphoused sedimentary ones [Шаталов, 1992]. A degree of metamorphism for rocks from the Sorokinskaya graben-syncline is rather diverse: to the north (Andreevskyi geoblock) it is granulite facies of metamorphism and on the south flank, i.e at the Sorokinskaya and Surozh areas, rocks were metamorphosed under conditions of amphibolitic and epidot-amphibolitic facies [Глевасский, 1996; Kravchenko, Sakhatsky, 1988].

Compositions of rocks well represented at the deposit are heterogeneous: to the south there are metabasites mainly, ferruginous rock and calcareous skarns from the Lower Osipenkovian Formation (AR_2) and to the north-east the megapelites from the Upper Osipenkovian Formation (AR_2) of the Central Near-Azovian series [Кравченко, 1999]. To the south-east from the Surozh deposit the Osipenkovian massif of hornblende-biotite granodiorites was mapped as well as its active cross joints with metamorphic rocks containing gold mineralization. Granites developed here have the clear junctions both with amphibolites and metapealites. The thickness of their concordant veins ranges from 1 to 10 m.

According to research [Кравченко, 1999] the deposit area is composed by greenstone rock of the Olzhinsk, Kruta Bulka, and Surozh Formations, which are incorporated in the Osipenkovian series of the Middle Archean. Metamorphosed igneous and volcanosedimentary rocks from the Olzhinsk Formation are classified as metakomatite – tholeitic assemblage, while ferruginous quartzite and schist of the different mineralogical compositions are attributed to schist – jaspilite – metatholeite one. The vein-shaped and sheet-like bodies of metarhyolite and metarhyodacite from the Surozh Formation [Лисенко та ін., 2005] are identified as rhyodacite-plagiogranite volcanic-plutonic association.

In the vicinity of the Surozh deposit in the righ slope of the Bulka Krutaya early it was found the rather large field of rare metal pegmatites. In geological literature it is known as the Bulka Krutaya deposit of rare metal pegmatites [Розанов, Лавриненко, 1979; Чорнокур, Яськевич, 2010]. The deposit are composed of the flat dipping veins (at the thickness of 0.5 to 7 70 m) of quartz-microcline-albite composition with muscovite, tourmaline, biotite, garnet, magnetite, apatite, beryl, spodumene, tantalite, and columbite.

Material composition of gold-hosting rocks

The Surozh gold is hosted in the metamorphic rocks from the Lower Osipenkovian Formation. These rocks are presented by amphibolites. The thickness of dyke-like amphibolite bodies reaches 500-600 m. Among amphibolites there are the bodies of magnetic quartzite (thickness to 10 m), lime skarns, as well as garnet-biotite, two-mica and other schists and gold-bearing sulphidized metasomatites. Quartziferous and sheeted plagioclase amphibolites are most widely represented. However, feldspar-free amphibolites close to hornblendites are rather common. As far as the chemical composition the latter belongs to the varieties of picrobasalts and picrodolerites, and plagioclase amphibolites together with amphibolitic schists may be referred to the ferriferous kinds of basalts and dolerites. Ferriferous-silicified rocks of the deposit are present by actinolite-cummingtonite-magnetitic schists, sometimes by biotite- and garnet-bearing ones. In amongst meta- and ultrabasites and magnetite-bearing quartzites there are skarnification zones at the thin thickness up to 10 cm. The scarnified bodies are enriched by the iron and form predominantly the concordant zones [Кравченко, 1999]. Among host rocks besides lime skarns there are also aluminous (garnet-biotite) schists.

Rocks of the upper Osipenkovian suiteat the deposit are mainly represented by metapelites, among which the schists with the different mineralogical compositions such as garnet-biotite, muscovy, two-mica, tourmaline-garnet-biotiter and other ones.

Magmatic rocks at the deposit are quite diverse. There are ultrabasites, granodiorites, acid effusive, aplite-pegmatoid granites and pegmatites. Among metabasites it is observed the dyke-shaped bodies of ultrabasites at the thickness of 1 to 50 m. They are amphibolized, chloritized, serpentized intensively everywhere, sometimes carbonatized and talcous. Acid effusive rocks are observed here as the concordant bedded deposits (or dykes) among amphibolites. Their contacts with amphibolites are sharp, the thickness of bodies are from centimeters to 25 m. Among the acid effusive rocks it is separated the gold-hosting dykes of high-alumina quartz porphyries of potassic-sodic series from the set of rhyolites and low-alkali rhyodacites [Кравченко, 1999; Лисенко та ін., 2005].

Structure and morphology of ore bodies

According the results of exploration carried out by the 47th GEC "Kirovheolohiya" SE within the Surozh deposit the five ore bodies with the industrial gold contents were uncovered [Кравченко, 1999]. The ore-glade gold mineralization within the deposit is traced to 1.5 km on the strike and to 0.2 km transverse to the strike. The deposit is prospected to the depth of 400 m. The tailing out of mineralization at a depth wasn't identified. The gold mineralization evidences are identified for the profiles of № 0 to № 15 (Fig. 4-7). The gold ore process covers the rocks from the Olginskaya Formation along their whole thickness. Gold mineralization is located in the development stripe of metaultrabasites and amphibolites, in the contacts of which there are quartzites and metapilites. In the authors' opinion [Лисенко та ін., 2005] the productive ore-hosting rocks are controlled by zone of the large Scythian fault, the main joints of which are located 60-00 m to south and aligned with the axial part of the Surozh anticline. The location of ore bodies here are controlled by the joints and mylonites of this fault. The bended iron formation and high quartzous rocks are the most favorable for the ore emplacement within the deposit. Development of the ore mineralization in the eastern direction is restricted by the Transverse fault. The industrial gold contents near the Transverse fault were mapped by means of wells at the deep horizons only. Simultaneously the western side of the Transverse fault shows the maximum aggregation of ore bodies at a distance to 200 m. Without a doubt, the set of gold-hosting bodies form a so-called ore metallic "column" at the eastern flank of the deposit, which is extended downward into the long distance at least for several kilometers. To the west from the Stepovoy fault there is the western flank of deposit.

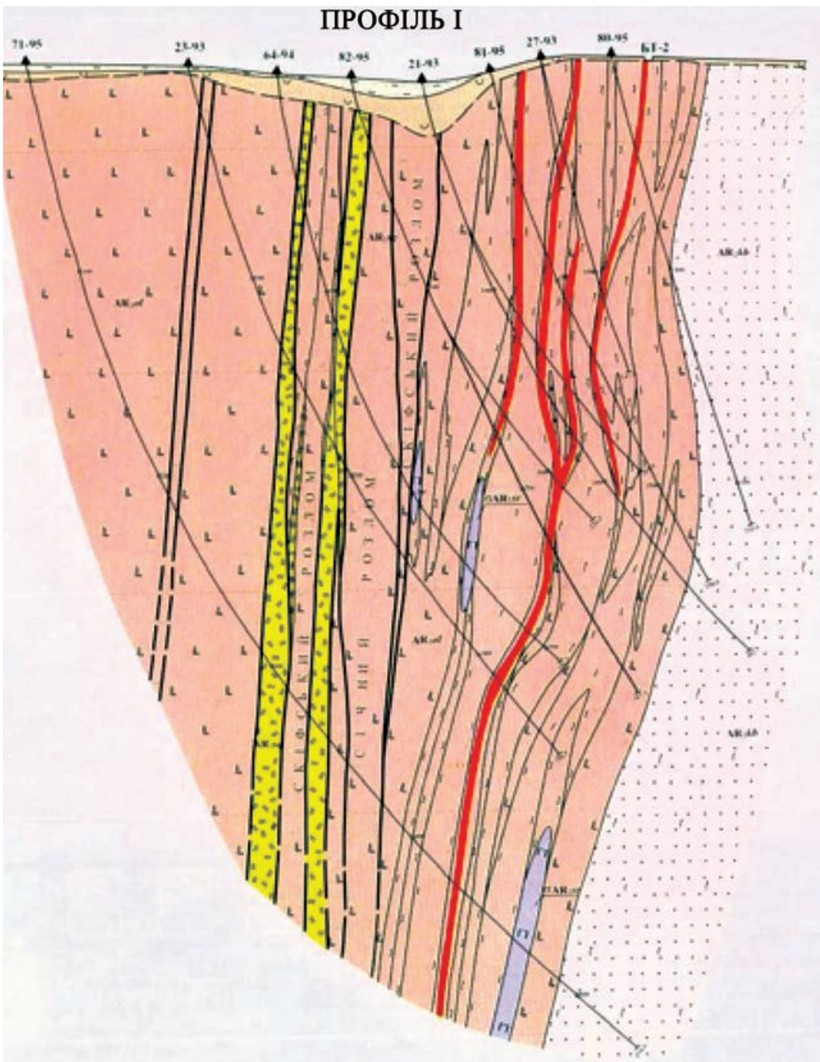

Fig. 5. Section of geological profile for the Central Surozh deposit [Лисенко та ін., 2005]

The central block of deposit is the most investigated [Кравченко, 1999; Лисенко та ін., 2005]. From the surface the ore zone was opened by the bulldozer trenches, passed perpendicularly to ore body strike at interval of 5-100 m. The main ore body was opened along strike by the trench at interval of 250 m (Fig. 4, 5). Between the profiles of № 0-3 the gold mineralization is explored by the deep angle holes to the depth of 400 m at 50-100 × 50-100 m grid. At section from profile № 3 to № 6 the holes are drilled at intervals of 100-150 m. The western flank of deposit (profiles of № 9-12) is explored by the rarer grid of the deep angle wells. The productive mineralization was identified at the distance of 300 m. The ore bodies (two or three) here is associated with ferruginous quartzites and contact with Olginskaya Formation together with metasediments from the Krutaya Bulka Formation. Ore saturation for the southern flank of deposit is far less. This area was studied by the coring wells and deep boreholes. As a result it was detected the individual bodies, discrete ore occurrences, the points of mineralization and gold anomaly.

The shape of ore bodies are bedded, podiform, more rarely veined. The real thickness of ore bodies ranges from 0.2 to 3.1 m (mean one for the deposit is 1.9 m). The internal structure of ore bodies is very composite. However all of them are distinguished by the high mineralization continuity [Кравченко, 1999]. The low-grade gold mineralization (to 4 g/t) is confined to the hanging sides of ore bodies (where amphibolites and slates are developed), and the most grade gold mineralization (to 66 g/t) coincides with the laying walls, where the common ferruginous quartzites are well represented.

The ore zones and ore bodies within the deposit are the ore sulphidized metasomatites. They are formed as a result of quartz – sulphide metasomatosis along cataclastic, brecciated, and silicified slates, amphibolites, magnetite-bearing quartzites and actinolites. The ore–bearing zones, as a rule, are occurred relevant to the host rocksand confined to the region of geological contact between two packages differed from each other by their mechanical properties: on the one hand amphibolites, metaultrabasites and magnetite quartzites, and other hand metaterrigenous, semisulphidized, garnet-staurolite-biotitic silicified slates, sometimes with tourmaline and graphite [Кравченко, 1999]. The gold ore bodies within the deposit are frequently controlled by tectonic fault-joints located like wings, dukes, as well as the zones of cataclasis and mylonitization.

Gold ore metasomatites of the Surozh deposit are microscopically inequigranular, often lenticular-banded and brecciated, silicified and sulphidized at varying degrees, as well as carbonatized and chloritic rocks. Their mineral content in % is the following: 25-50% of pyrrhotine and pyrite; 5-40% of qurtz of two generations; 10-40% of cummingtonite, as well hornblende, actinolite, garnet, biotite, chlorite, carbonite, magnetite, and chalcopyrite [Кравченко, 1999].

Early quartz in ore metasomatites is well crystallized, medium-grained. It composes the bands (to 5 mm) and lenticular-pockety segregations. Extinction of early quartz is quiet, often strongly-pronounced wavy, aggregate. In the geodynamical brecciated zone of weakness there are thin alternation of the parts with broken early quartz and latter low-temperature, sometimes flint.

Ore mineralization of productive zones

Mineralization of the productive zones in the Surozh deposit is varied. Ore minerals are here represented by the nuggets, as well as sulfides, tellurides, arsenides, sulphoarsenides, oxides and tungstates of hydastogenesis and metamorphogenic-metasomatic origin. Sulphides are the most wide spread among those pyrrohtine and pyrite are distinctive.

G o l d in the Surohz deposit (Fig. 6, 7) is concentrated in sulphidized metasomatites, which compose the main ore bodies and are controlled by the wing-like tectonic joints and cataclasis zones. The bulk of gold (60-70%) is connected with quartz (to 114 g/t of gold at its content of 3.24 g/t in ore-bearing magnetite quartzite and less with pyrrhotine and pyrite (to 41 g/t of gold at its content of 35.4 g/t in ore metasomatite). Iron sulphides contain 20-30% of gold. The bulk of apparent (free) gold is located in very fine-grained crush quartz, rarer in its coarse-grained pockety-lenticular varieties [Кравченко, 1999].

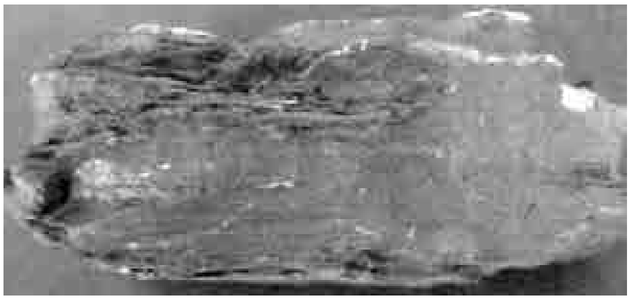

Fig. 6. Oxidized ferruginous quartzite with the ore gold-bearing veinlets [Квасниця, Латиш, 1996]

P y r r h o t i n e relative to the frequency of occurrence gives way to magnetite. The highest its concentrations are observed in the gold-bearing brecciaed zones and silicified amphibolites. It is less common in amphibolites and quartzite contained

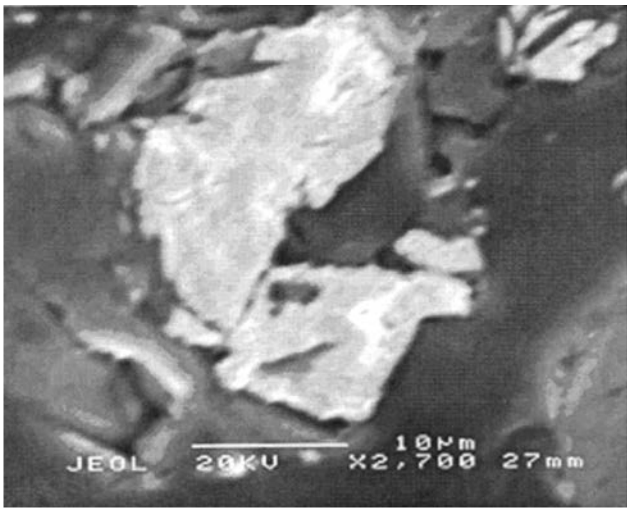

Fig. 7. Native gold in a matrix of quartz, Surozh deposit [Квасниця, Латиш, 1996]

magnetite and in slates, which are different in composition. It composes both the separate aggregations and monomineral streaks and pockets.

P y r i t e relative to pyrrhotine occupies the subordinate position and is rarely occurred in considerable amounts. Three generation of pyrite have been identified for the deposit, which were connected with metallogenic minerals formed under the action of temperature.

O x i d e s are represented by magnetite and ilmenite. Magnetite is wide spread mineral. It has two generations and presents mainly in magnetite quartzites, ultrabasites, amphibolites, and ore sulphidized metasomatites.

In addition to the above mentioned minerals there are marcasite, chalcopyrite, pentlandite, violarite, mackinawite, millerite, sphalerite, galena, molybdenite, bismuthine, maucherite, niccolite, scheelite in ore metasomatites.

The morphology of virgin gold

The form of virgin gold segregation is an important indicator of the conditions for its formation. Morphology of the gold separation at the Surozh deposit is very different [Кравченко, 1999]. The most frequent xenomorphic segregations of gold are cloddy, cementing, veinlet and other forms. Sometimes it is noted the fine imperfect crystals and hemi-idiomorphic segregations. There are the polyhedrons also. The well-bounded crystals of gold are here occurred rarely (Fig. 6, 7).

The xenomorphic segregations of gold are commonly formed at the late productive stages of oregenesis. Gold fills the free fissures, cavities, intervals between the crystals of the other minerals, i.e. fits into rock structure. The platelets, elongated and lenticular grains of gold with the induced parallel striation of their surface are mainly located along the fissures and among the crystals of carbonates, pyroxene, and amphibole. Hemi-idiomorphic segregations in the deposit are rather common. They have both the xenomorphic and idiomorphic forms. The part of faceted surfaces of gold grains of the first variety evidences the growth of gold at the interface of two surroundings, one of them has supported the free growth of the gold grains. The grains of gold of second variety are characterized by the occurring gold under the conditions of independent growth. The gold crystals from the Surozh deposit are scarcely abundant. They are very fine (to 0.1 mm) and located only in ferriferous quartzite and slates.

Among the visible gold mainly the grains at the size of 0.01-0.02 mm are predominant, there are the colors no larger 0.1-0.5 mm across and even more rarely 1-2 mm across.

The microprobe analysis has shown that gold from the Surozh deposit is high and very high fineness (926-983), only in individual cases it decreases to 869 as a result of gold association with pyrite mineralization. It is found that gold has almost homogenous composition: 948 in the central part; 944 in the selvage [Кравченко, 1999].

The quantitative and qualitative compositions for the element impurities in native gold are rather steady (7.7-12.8%) in contrast to gold associated with quartz (5.1-6.7%). Silver in essence is determined the fineness of gold and is an indicator of the depth of oregenesis. While the gold concentration for the deep deposits ranges from 5 to 15%, for the shallow ones the concentration varies from 30 to 40%. Surozh gold is deep, rather homogeneous at the high rate of gold. The increase of rate for this gold can be induced by its occurring in the carbon-rich areas. The fine imperfect crystals and cloddy equant gold grains are high-grade. The tendency of fineness change against the depth for this deposit didn't identify. The high-grade gold and defined tendency indicate clearly here the occurrence of ore metallogenic column, formation of which was a cause of appearance of crystals under the influence of reducing deep fluids. Among typomorphic element-impurities in Surozh gold there are copper, bismuth, nickel, cobalt, lead, zinc, mercury, arsenic, and iron.

Genesis of gold ore mineralization

According to mineral composition the ores from the Surozh deposit can be attributed to gold-sulphide-quartz type (formation). The thermobaric geochemical study shows that the generation conditions for gold ore paragenesis have proceeded in the following ranges: 1) magnetite and pyrrhotite mineral associations are formed at the temperature from 460-350°; 2) gold-chalcopyrite ones – from 325 to 210°; 3) pyrite post productive one – from 140 to 85°.

The study conducted by Kravchenko [Кравченко, 1999] has shown that the forming productive gold ore mineralization were carried out at the few stages: 1) early oxide one (magnetite-I, ilmenite), where gold is connected with the early alkali phase of metasomatic processes; 2) early sulphide and ferruginous arcenide-sulfoarcenide one (pyrite, pyrrhotine, and chalcopyrite), as well the middle sulphide stage combined with early gold one (pyrrhotine-II, chalcopyrite-II, sphalerite, galena, pyrite-II, molybdenite, gold-I); 3) middle oxide (magnetite-II) mineralization together with the late alkali stage. Gold-I formation temperature was high (about 300°) and pressure in the process of gold mineralization formation has been changed in the range of 350-48 MPa [Кравченко, 1999].

The stages of the following post metamorphic changes (epidot-amphibolitic facies) resulted in the new hydrothermal-metasomatic phases. However this was the phase of low-temperature metasomatic alteration of rocks. At this stage native gold-II, tellurium bismuthinite, pyrite-III, marcasite, goethite, hydrogoethite were formed. Gold-II was developed at the final crystallization stage of late quartz and sometime later. Gold was deposited from the deep heterogeneous hydrothermal-metasomatic fluids at the high salt concentration and weak solutions of volatile constituents such as CO_2, N_2 and CH_4. Thermodynamic parameters of ore-forming fluids were close to P-T parameters for the fluid inclusions in gold-bearing late quartz. Ore emplacement of productive gold-II occurred in almost the same temperature range, where its upper and lower limits are 205 -200°C and 120-100°C, respectively.

Thus two main stages can be defined for the forming Surozh gold. The earliest stage is characterized by the deposition of fine gold and more late one is connected with the forming very fine visible gold. Early finely-dispersed gold is 65% of all reserves in the deposit. It is confined to quartz and much less to pyrrhotine and pyrite.

Age of gold mineralization

Age ogf Surozh gold ca be defined by mean of complex analysis of geological and structural relation for rocks and isotopic data. Geochronological data for the Sorokinskaya graben-syncline show its prolonged development. The morphological features of zircon from the biotite gneisses correspond to clastogene type and the age of Surozh zircon is 3320±30 Ma. Uranium-lead age of zircon from granodiarites intersecting amphibolites and biotite gneisses is 2800±30 Ma and the age of dykes of leucocratic porphyraceous granites intersecting amphibolites is 2680±30 Ma [Шаталов, 1993; Щербак та ін., 1999]. Thus Osipenkovsky granodiarites at the age of 2.8 Ga cut the gold-bearing rocks of the Osipenkovian Formation, whereas acid eruptive rocks at the age of 2.66 Ga containing practically no gold have formed the concordant bedding bodies in these rocks. Granodiorites near the dam on the Berda River in the Osipenko village are dissected by the cataclasis zones, where the small gold particles were detected. Therefore, the gold mineralization age must be younger than 2.8 Ga. Isotopic age for the metamorphism of amphibolites and shales from the Osipenkovian Formation is 2.3-2.0 Ga. About the same time, i.e. 2.24 Ga the rare-metal pegmatites of the Kruta Balka deposit have been formed. Cosequently, the age of Surozh gold in the estimation of H.L. Kravchenko is 2.6-2.2 Ga [Кравченко, 1999, Щербак та ін., 1999, 2006] believe that early finely-dispersed gold in the Surozh deposit may be formed in the Neoarchean and late gold were redeposited in the Paleoproterozoic.

Conclusions

The evidence presented suggests that the Surozh gold deposit is confined to the unique, most ancient and long developed Sorokynskaya graben-syncline structure of the Near-Azovian megablock of the Ukrainian Shield. Just as the host structure, this deposit is the only one on the planet. According to the structural and geological criteria the Surozh deposit in our opinion does not have analogues in the world. It has been formed as a result of the change for rotary mode of our planet 2.6-2.2 billiard years ago. As a result of the rotational strains in that period of the Earth's evolution within the mentioned area of lithosphere the fault tectonic zones of orthogonal and diagonal systems have been intensified, the high gradient dynamic settingt was occurred, where the plots with the maximum fracturing and penetrating of lithosphere became favorable for the localization of the deep magmatic melts, fluids, metasomatites, and ore minerals. The Syrozh structural and metallogenic cluster favorable for ore deposition has been formed as a consequence of network activation for the misoriented faults and deep processes of Earth's energetics within the Sorokinskaya graben-syncline.

The gold deposit has been occurred at the deep depth (about 5 km) due to the activation of tectonic movement, such as fault-block, often thrust- and shift-fold ones as well as the deep tectono-metasomatic processes taking place in the Achaean and Paleoproterozoic time. Assuming the Sorokinskaya zone is the most ancient inland reef was founded over the Achaean granulitic basement, it must be appreciated that the basite-ultrabasite composition of the Achaean folded basement could contribute significantly to accumulation and redistribution of gold for extended time period. The mantel fluids rising along the deep faults have been inducing the substantial transformation of the rocks from the Achaean basement causing their gold enrichment. According to ore mineral composition, the Surozh deposit can be attributed to the gold-sulphide-quartz assemblage. In the universal genetic classification [Смирнов, 1982] this class of the deep deposits among the endogen series of the hydrothermal group isn't designated. The deep and likely mantle fluids have played the important role in oregenesis. As a result of hydrothermal and metasomatic processes in the Earth's crust interior the ore bodies of metasomatites have been occurred, which were superimposed on hosting gold rocks of the Paleoproterozoic such as amphibolites, different shales, ferruginous quartzites, dykes of ultrabasites , and quartz porphyries (Шаталов та ін., 1982; Шаталов, 1986, 1990, 1991, 1993].

The forming productive gold ore mineralization were carried out into the few stages intemperature range from 325 to 100°C [Кравченко, 1999; Лисенко та ін., 2005]. This deposit is characterized by the increase of gold in ores with depth, but the pinching-out of ore bodies isn't identified. The deposit is explored to the depth of 0.4 km. The occurrence of large numbers of small imperfect gold crystals and manifestation of two gold ore stages for the mineralization of fine gold are the indicators of rich deep zones and "ore columns". The level of erosion truncation for the Surozh deposit shows that gold ore "metallogenic column" at the diameter of 50 m can be stretched out to the depths more then 3-5 km. This prediction is provided an opportunity to increase the potential gold resources for the Surozh deposit.

At present the Surozh deposit is the unique and well explored object. As far as its resources it may be attributed to the medium size of deposit. Proved ore is high technological, 86% gold can be extracted from rocks [Кравченко, 1999; Лисенко та ін., 2005]. Gold ore production from the Surozh deposit may be highly profitable. The deposit is located near Berdiansk city, and occupies the abandoned and virgin lands at the northern slope of the Sobachia Gulch. The ore bodies from the most productive central part of deposit are cropped up and at a depth they aren't pinched out. The well-developed infrastructure in this region and favorable geographical, economic, and technological conditions create the uniqueness of the Surozh gold ore deposit and make it attractive for investment.

References

1. ***Глевасский Е.Б***. Зеленокаменные пояса и перспективы поисков золотого оруденения в Приазовье. *Минерал. журн*. 1996. № 4. С. 72-88.

Glevassky E.B., 1996. Greenstone belts and the prospects of the search for ore gold-grade mineralization in the Near-Azovian. *Mineralogicheskiy Zhurnal*, № 4, p. 72-88 (in Russian).

2. ***Квасниця В.М.,*** **Латиш І.К.** Самородне золото України. Київ: Вид-во «АртЕк», 1996. 151 с.

Kvasnitsya V.M., Latysh I.K., 1996. Native gold of Ukraine. Kyiv: ArtEc Publ., 151 p. (in Russian).

3. ***Кравченко Г.Л., Сахацкий И.И.*** Золоторудная минерализация в железисто-кремнистых породах юга Украины. *Докл. АН УССР. Сер. Б.* 1988. № 4. С. 21-25.

Kravchenko H.L., Sakhatsky I.I., 1988. Gold ore mineralization in iron-siliceous rocks of the southern Ukraine. *Doklaly AN USSR. Ser. B,* № 4, p. 21-25 (in Russian).

4. ***Кравченко Г.Л.*** Сурожское золоторудное месторождение (Западное Приазовье) *Минерал. журн*. 1999. № 4. С. 7-19.

Kravchenko H.L., 1999. Surozh gold ore deposit (Western Near-Azovian). *Mineralogicheskiy Zhurnal*, № 4, p. 7-19 (in Russian).

5. ***Лисенко О.А.***, ***Бобров О.Б., Малюк Б.І., Тисячна О.М.*** Геологічна будова та характер локалізації золотих руд Сурозького родовища. *Мінер. ресурси України*. 2005. № 4. С. 9-16.

Lysenko O.A., Bobrov O.B., Maliuk B.I., Tysiachna O.M., 2005. Geological structure and character of the localization for gold ores in the Surozh deposit. *Mineralni resursy Ukrainy*, № 4, p. 9-16 (in Ukrainian).

6. ***Розанов К.И., Лавриненко Л.Ф.*** Редкометальные пегматиты Украины Москва: Наука, 1979. 139 с.

Rosanov K.I., Lavrynenko L.F., 1979. Rare-metal pegmetites of Ukraine. Moskow: Nauka, 139 p. (in Russian).

7. ***Смирнов В.И.*** Геология полезных ископаемых. Москва: Недра, 1982. 669 с.

***Smirnov V.*I.,** 1982. Geology of mineral resources. Moscow: Nedra, 669 p. (in Russian).

8. ***Усенко І.С., Кравченко Г.Л., Сахацький І.І.*** Про золотоносність Сорокинської тектонічної зони (Приазов'я). *Доп. АН УРСР. Сер. Б.* 1973. № 4. С. 322-327.

Usenko I.S., Kravchenko H.L., Sakhatsky I.I., 1973. On gold mineralization of the Sorokinskaya tectonic zone (Near-Azovian). *Dopovidi AN URSR. Ser. B,* № 4, p. 322-327 (in Ukrainian).

9. ***Чорнокур І.Г., Яськевич Т.Б.*** Деякі нові дані щодо геологічної будови району рідкіснометалевого родовища Балка Крута. *Мінер. ресурси України*. 2010. № 2. С. 18-24.

Chornokur I.H., Yaskevych T.B.**,** 2010. Some new data for the geological structure of rare-metal deposit of Bulka Kruta. *Mineralni resursy Ukrainy*, № 2, p. 18-24 (in Ukrainian).

10. ***Шаталов Н.Н., Латыш И.К., Потапчук И.С.*** Золотоносность дайковых пород Приазовья. *Докл. АН УССР. Сер. Б*. 1982. № 6. С. 38-41.

Shatalov N.N., Latysh I.K., Potapchuk I.S., 1982. Gold mineralization of dyke rocks of the Near-Azovian. *Doklady AN USSR. Ser. B,* № 6, p. 38-41 (in Russian).

11. ***Шаталов Н.Н.*** Дайки Приазовья. Киев: Наук. думка, 1986. 192 с.

Shatalov N.N., 1986. Dykes of the Near-Azovian. Kiev: Naukova Dumka, 192 p. (in Russian).

12. ***Шаталов Н.Н.*** О золотоносности дайковых пород Приазовья. *Геология руд. месторождений*. 1990. № 6. С. 101-108.

Shatalov N.N., 1990. On gold mineralization of the dyke rocks of the Near-Azovian. *Geologiya rudnyh mestorozhdeniy,* № 6, p. 101-108 (in Russian).

13. ***Шаталов М.М.*** Золоті самородки України. *Вісн. АН УРСР*. 1991. № 7. С. 106-109.

Shatalov N.N.**,** 1991. The gold nuggets of Ukraine. *Visnyk AN URSR,* № 7, p. 106-109 (in Ukrainian).

14. ***Шаталов Н.Н.*** Тектонические критерии поисков золота в дайках Приазовья. *Тектоника и стратиграфия*. 1993. № 33. С. 13-21.

Shatalov N.N., 1993. Tectonic criteria for the quest for gold in the dykes of the Near-Azovian. *Tektonika i stratigrafiya,* № 33, p. 13-21 (in Russian).

15. ***Щербак Н.П., Артеменко Г.В., Загнитко*** **В.Н.,** ***Степанюк Л.М.*** Возраст золоторудных месторождений Украинского щита. *Минерал. журн*. 1999. № 4. С. 99-105.

Shcherbak N.P., Artemenko H.V., Zahnitko V.N., Stepanyuk L.M., 1999. Age of gold ore deposits of the Ukrainian Shield. *Mineralogicheskiy Zhurnal*, № 4, p. 99-105 (in Russian).

16. ***Щербак Н.П., Артеменко Г.В., Лесная И.М., Пономаренко А.Н.*** Геохронология раннего докембрия Украинского щита. Архей. Киев: Наук. думка, 2006. 241 с.

Shcherbak N.P., Artemenko H.V., Lesnaia I.M., Ponomarenko A.N., 2006. Geochronology of the Early Precambrian of the Ukrainian Shield. Achaean. Kyiv: Naukova Dumka, 241 p. (in Russian).

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