| Геолошки анали Балканског полуострва<br>Annales Géologiques de la Péninsule Balkanique | 72 | 101–109 | Београд, децембар 2011<br>Belgrade, December 2011 |
|---|---|---|---|

DOI: 10.2298/GABP1172101A

# The Novo Okno copper deposit of olistostrome origin (Bor, eastern Serbia)

Ivan Antonijević[1]

**Abstract.** The copper deposit Novo Okno, uncovered at present, with non-ore and ore clasts of massive sulphides (from 0.5 to 50 $m^3$ in size), has many distinctive features that indicate its olistostrome origin. The deposit is chaotic in structure, unstratified, with the lower surface unconformable over the underlying parent rock of the basin. It is a lens-like body, with the longer axis directed east and west, variable in thickness from 15 to 28 metres, about 335 metres long and less than 140 metres wide. These and other characteristics of the body indicate a unified, reworked, olistostrome copper deposit formed from primary ore bodies of the Bor mineral deposit and vulcanite, destroyed by volcanic explosion into blocks and rocks of Turonian age and extrusion and concurrent deposition on the land surface. Gravitational massive sliding of the consolidated rocks down the slopes of the volcanic relief and chaotic accumulation of ore and non-ore clasts (olistoliths) in a marine basin evolved in the Upper Turonian and the Lower Senonian.

**Key words:** Olistostrome, copper ore, mineral deposit, ore-clast, olistolith, origin.

**Апстракт:** Данас већ откопано лежиште бакра „Ново Окно“, са нерудним и рудним кластима масивних сулфида (величине 0,5–50 $m^3$), одликује се низом специфичних особености које указују на његову олистостромску генезу. Има хаотичну геолошку грађу, без слојевитости и доњи неравни контакт са подинским матичним стенама басена. Генерално је сочивастог облика. Издужено је по оси исток–запад. Променљиве је дебљине 15–28 m, дужине око 335 m, а ширине до 140 m. По тим, као и другим особинама представља јединствено, редепоновано, олистостромско лежиште бакра. Настало је вулканским експлозивним разарањем примарно образованих рудних тела борског лежишта и вулканита у блокове и комаде туронске старости, њиховим изношењем на површину и синхроним депоновањем на копну. У горњем турону и доњем сенону долази до гравитационог клижења консолидоване стенске масе путем одрона и клизишта низ падине вулканског рељефа и хаотичне акумулације рудних и нерудних класта (олистолита) у морском басену.

**Кључне речи:** олистостроме, лежиште бакра, рудокласти, олистолити, генеза.

## Introduction

The copper deposit Novo Okno at Bor, uncovered at present, is an uncommon type of chaotic assemblage of ore and non-ore fragments, the geology in general and origin in particular of which have not been addressed adequately.

It lies on the "threshold" of the primary massive copper sulphide deposit Jugoistok, near Bor (ore bodies H, J and others). While nearly identical paragenetically to these deposits, particularly to the massive copper sulphide in the central ore zone from which it originates, it differs essentially in being a reworked copper or body of olistostrome origin.

The deposit was discovered in 1979/80 by a local positive gravimetric anomaly in the first exploratory borehole, B 128, in a Senonian epiclastic deposit of hornblende andesite at a depth of about 270 metres.

## Concept and definition of an olistostrome

An olistostrome is a sedimentary chaotic formation lacking bedding, composed of $cm^3$-clasts or $m^3$-olistoliths in a matrix. It is formed by mechanical accumulation of clasts and gravity sliding of semi-fluid rock material down land and submarine slopes (Extraolistostrome/Intraolistostrome).

[1] Vjekoslava Kovača 14, Belgrade, Serbia.

An olistostrome body has distinct and uneven lower and comparatively even and regular upper boundaries. The bodies vary in size from 0.5 to 100 km or more in length (DIMITRIJEVIĆ 1975; NACHEV 1977).

Olistoliths are rock masses (blocks) or elements of an olistostrome, which vary in size and shape, being mainly oval, ellipsoid to irregular. Classified by dimensions, there are: macro- (over 1000 $m^{3)}$, meso- (under 1000 $m^3$) and micro-olistoliths (tens of $m^3$) (RIGO DE RIGHI 1956). Note that olistostrome is a generic concept (NACHEV 1977).

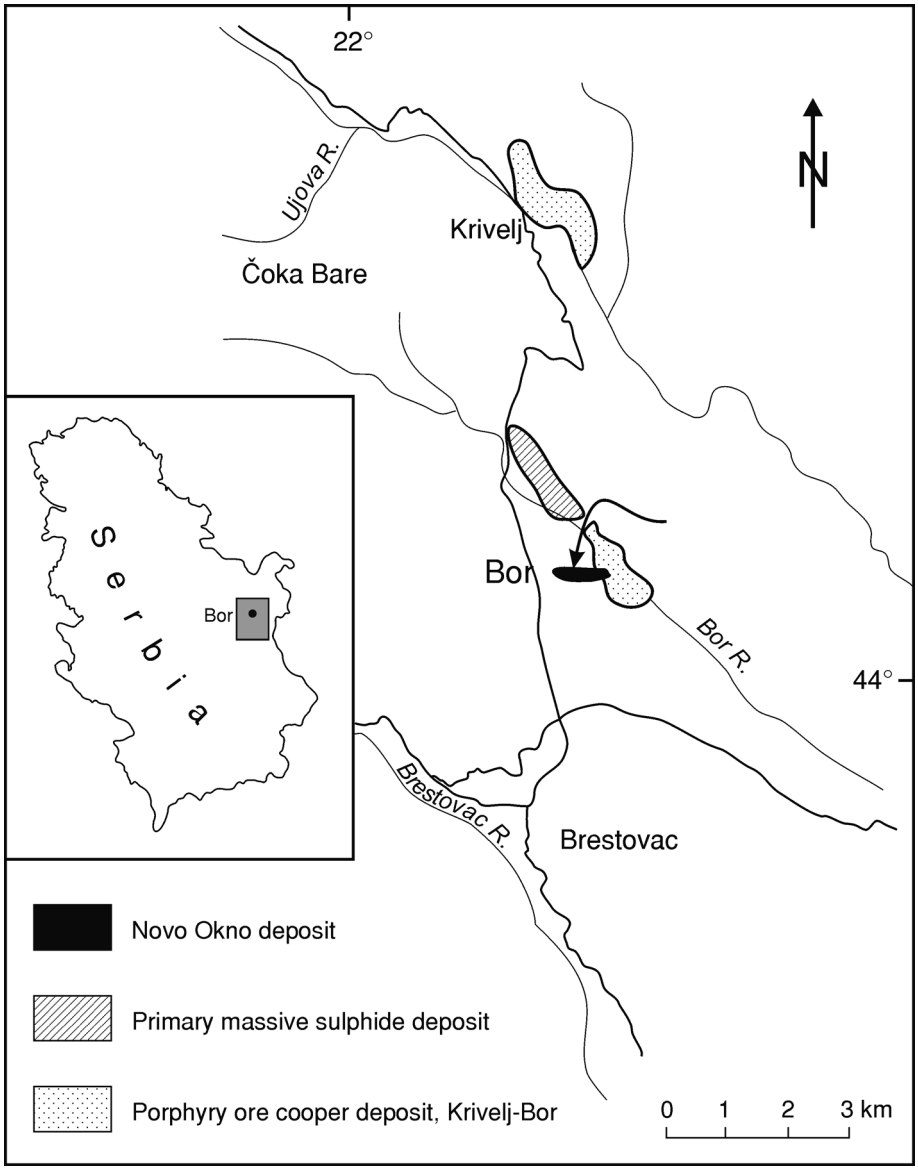


Fig. 1. Geographical location of the Novo Okno copper deposit of olistostrome origin.

Olistostromes in Serbia were mentioned mainly in flysch sequences of different ages, and were recognized and described by GRUBIĆ (1975, 1976), DIMITRIJEVIĆ & DIMITRIJEVIĆ (1973), BOGDANOVIĆ (1975), *etc*.

Mineral olistostrome deposits and occurrences of only non-metals?, building materials and ornamental stone, such as Ropočevo decorative breccias, are known in Serbia (GRUBIĆ 1975).

## Olistostrome characteristics of the Novo Okno copper deposit

Contrary to previous interpretations in the mentioned references, this work presents the geology of the Novo Okno copper deposit, mechanism and formational processes of ore and non-ore clasts, volcanism, and so forth in terms of the olistostrome origin of the deposit, based on available geological publications (MIŠKOVIĆ 1989, 1995; JANKOVIĆ 1990; DROVENIK 1982, 2005, *etc.*), drilling and mining records and own investigations.

The deposit Novo Okno is characterized by a chaotic structure of rocks and concentration of ore and non-ore clasts in a volcaniclastic matrix. Some clasts (from 0.5 to 50 $m^3$ in size) shape extraordinary examples of olistoliths.

This deposit includes two classes of ore-clasts (olistoliths A and B). Olistoliths A and B (in MIŠKOVIĆ 1989, 1995) correspond to ore-clasts of mineral associations A and B, respectively.

Mixed olistolith classes A and B are local occurrences, because the lighter and smaller Class B are mixed in almost every interval of the olistostrome ore body.

The deposit is elongated east to west, 335 m long, up to 140 m wide and about 25 m thick, embedded in a heterogeneous unstratified mass of rocks. This morphogenetic characteristic indicates a typical development of a mineralized olistostrome in epiclastics of the parent Metovnica Formation.

A basic feature of the Novo Okno olistostrome body is the lower irregular, deformed surface over the source rocks. It was observed many years ago by Mišković in the northern incline drift (el. 45). “A large

ore-clast (olistolith Class A) fell and deformed the underlying grey pelite" (MIŠKOVIĆ 1989).

## Mechanism and processes of the olistostrome formation

The relation in time and space of the Novo Okno olistostrome deposit, the environment and formational processes indicate two different geochronologic phases:

– Turonian preolistostrome (volcanogenic) and
– Senonian olistostrome (submarine) phases.

### Preolistostrome volcanogenic phase

This was a phase of subaerial eruption and explosion of the central Bor edifice; destruction of primary massive sulphide ore bodies into fragments and blocks (ore and non-ore clasts), their ejection and deposition on land.

Volcaniclastics and ore-clasts, while being ejected on the land surface, formed the initial contour of the subsequent slide or the Novo Okno ore body with its mineral distribution.

Heterogeneous rock mass of ore and non-ore clasts in a matrix cooled and consolidated epigene in the subaerial phase. While still semi-fluid, however, fragments of similar size or gravity separated and sorted:

– Heavy and large blocks (olistoliths) Class A, 1.0–50 $m^3$, on the lower, and
– Light blocks Class B, 0.3–0.5 $m^3$, on the upper part of the slopes.

This distribution and vertical (gravitational) zonation of the ore-bearing materials on land, in the preolistostrome phase, persisted through the subsequent submarine olistostrome phase of the formation of the deposit.

In a similar consideration of this issue, JANKOVIĆ (2002) writes as follows: "Formation of the Novo Okno ore body through mechanical accumulation of massive sulphide fragments, produced by destruction of the already formed ore bodies, indicates a polyphase activity that affected the environment of the already formed sulphide ore bodies and impregnated stockwork before Bor pelite had been deposited." He continues: "It would be difficult, however, to be more precise about the origin of ore-clasts in the epiclastics and the copper deposit of Novo Okno." (JANKOVIĆ 2002).

Drovenik studied the genetic aspect of the Bor mineral deposits, ore-clasts and the newly found copper deposit Novo Okno, and as early as in 1966 invented bonanzas, rich bodies of copper ore, somewhere in the Upper Cretaceous?, far from the Bor deposits, the likely primary material of the massive sulphide ore-clasts and the Novo Okno copper deposit. In order to maintain the untenable but prevailing concept of the Laramian (post-Senonian) formation of the Bor copper deposit, in association with structural geology, he repeated the same in 1982 and 2005 (DROVENIK 2005, p. 34).

MIŠKOVIĆ (1989, 1995) interpreted the Novo Okno ore-clasts as material of the primary deposits destroyed by Senonian volcanic explosion and projected into Senonian marine environment.

ĐORĐEVIĆ (1977), however, mentions the lack of evidence of Senonian volcanic activity in the Novo Okno deposit, or in the Bor area proper. All ore-clasts are indeed angular to subangular pebbles and likely blocks moved by gravity, and the rocks bearing them are epiclastics of the Senonian Metovnica Formation.

It follows from the above that these are sedimentary copper ore occurrences in pebbles (or olistolithic or bodies in a sedimentary, olistostrome environment).

### The olistostrome submarine phase

Invasion of the Senonian Sea over the volcanic landscape created conditions for the onset of the submarine olistostrome phase. Erosion and deposition of the reworked Turonian volcaniclastics formed new, Senonian epiclastic deposits on land and in the sea, including olistostrome sequences and ore-clasts.

Gravity sliding of the mineralized material down the volcanic relief and accumulation of fragments in the marine environment produced the authentic olistostrome copper deposit of Novo Okno (Table 1), although in the group of primary copper deposits Jugoistok (ore bodies H, J, *etc*.), after which it was given the attribute "distal" (MIŠKOVIĆ 1995), Novo Okno differs in being a particular copper deposit of olistostrome origin.

Unlike nearly all more or less rounded olistolith ore-clasts, andesite clasts, fresh or hydrothermally altered, are mostly angular (JANKOVIĆ 1990).

Mineralized olistostrome was found underlain by laminated pelitomorph and some other rocks, often over homogeneous Turonian andesite. The underlying pelite or the parent epiclastic association is dated the uppermost Turonian and the lowermost Senonian using a microfossil assemblage of *Marginotruncana coronata*, *Globotruncana linneinana*, *G.* sp. *arca*, *Hedbergela* sp., *etc*. (SLADIĆ-TRIFUNOVIĆ & GAKOVIĆ 1988).

Some thirty metres above "the main ore layer" in the olistostrome sequence of Novo Okno, JANKOVIĆ (1990) reports "a second layer" of epiclastics and small ore and non-ore clasts as a likely unit of a new olistostrome sequence. This layer consists of pelite and sandy tuffite embedding fragments of hornblende andesite, hydrothermally altered, and pyrite and chalcopyrite ore-clasts. JANKOVIĆ assigns it to the mineral association C.

Larger ore-clasts overlying epiclastics are scarce or not mentioned.

The mentioned olistostrome character of the Novo Okno copper deposit, the processes and mechanism of development, indicate that it was a sedimentary reworked deposit.

phase of the Timok eruption area. The formation is built of well-stratified clastic, epiclastic beds, dominantly of hornblende andesite (breccia, conglomerate), fresh and altered angular fragments of psammite, subordinately pelite, ore-clasts, matrix, hydrothermally altered epiclastics, *etc*.

Table 1. Metallogenetic model of the Novo Okno olistostrome copper deposit.

| Model Phase | | | Geology | Genetic process | | Metallogeny | | Epoch |
|---|---|---|---|---|---|---|---|---|
| Submarine | Olistostrome (Sec. II) | Epiclastic | Epiclastics, ore and non-ore clasts<br>(0.5-10 m$^3$) Cl.B<br>OLISTOLITHS<br>(1-50 m$^3$) Cl.A | Gravity downslope sliding in volcanic relief<br>OLISTOSTROME | | **Min. ass. C** pyrite, chalcopyrite<br>**Min. ass. B** chalcopyrite, bornite, Au, Ag, etc.<br>OLISTOLITHS | Massive copper sulphide mineralization | Senonian |
| | Olistostrome (Sec. I) | | Chaotic heterogeneous epiclastic rocks in pelite matrix | Sliding into sea basin; accumulation | | **Min. ass. A** pyrite, covellite, chalcocite, Au, Ag | | |
| Volcanigenic subaerial | Preolistostrome | Pyroclastic | Volcaniclastics, v. bombs in ore-clast matrix, tuff, v. agglomerate, v. Breccia | Mechanical subaerial accumulation on land | | **Min. ass. B**<br>ORE-CLASTS<br>**Min. ass. A** | | Turonian |
| | Volcanigenic explosive<br>Volcanigenic | Edifice | Volcanic breccia, hornblende, biotite andesite<br>Homogeneous andesite flows | Explosive polyphase volcanism<br>Volcanics | Hydrothermal alteration | Massive copper sulphide paragenese (Bor)<br>Stockwork impregnation | | |
| | Subvolcanigenic intrusive | | Amphibole andesite, diorite, quartz diorite | Hypabysal consolidation | | Porphyry mineralization (Bor River, Krivelj) | | |

## The olistostrome parent rocks

Large amounts of Senonian epiclastic rocks under, over and around the Novo Okno olistostrome deposit are the source-formational unit of the olistostrome and ore-clasts of massive copper sulphides. The unit is similar to Turonian pyroclastic rocks of the first volcanic phase, the Timok Association, from which it derives. It was not treated in previous research.

The unit, classified as formation, was recognized and investigated in detail south of Bor and Novo Okno as an epiclastic rock mass that deposited in the sea (ĐORĐEVIĆ 1994, 1997, 2005). It formed over the volcanic Turonian, precisely over the first volcanic

The major parent rocks of the epiclastics include the Novo Okno olistostrome copper deposit and many individual ore-clasts in the greater Bor area.

The source rocks have a variable thickness from a few to hundreds of metres and include fragments of all pre-existing Turonian rocks, mainly pyroclastics, ore and non-ore clasts (olistoliths) and some erosional remnants of destroyed olistostromes (Čoka Bare, Metovnica).

This body of rocks formed in the late Upper Turonian and the Lower Senonian (Coniacian–Santonian) by filling depressions in the rugged Turonian volcanic relief. The formation is not recognized in Bor, although, like in Novo Okno, a large part of the Timok

Formation volcaniclastics (timocite) corresponds to epiclastics of the Metovnica Formation. A recent reference (Antonijević 2010) to the formation reads: "for further copper investigation and targeting of the exploration works in Bor, the potentially different epiclastic Senonian and volcaniclastic, or volcanigenic, Turonian lithogenetic units must be separated".

Pelitomorphic rocks in the lower part of the primary epiclastic formation have a microfaunal content identical to that in pelite under the Novo Okno olistostrome. These are Coniacian-Santonian foraminifera from the Lower Senonian and the uppermost Turonian (Đorđević *et al.* 1997).

A section of the Novo Okno deposit (Mišković 1989) shows the underlying hornblende andesite as the oldest Turonian rocks (±90 m.y., K/Ar method). Epiclastics of the source formation and laminated pelite of the lower Senonian and the uppermost Turonian are transgressive and unconformable over the deposit.

The deductions based on the deposit section are the following:

– Turonian amphibole andesite basement is underlying the Novo Okno olistostrome parent rocks, and

– Laminated pelite of the olistostrome parent rocks, immediately over them, is part of the epiclastic Lower Senonian–Upper Turonian formation.

## Massive sulphide ore-clasts

Many ore-clasts of massive copper sulphide are notable in the epiclastics of the Metovnica Formation, excluding the Novo Okno deposit. Drovenik (1966) studied some forty of the more than hundred mentioned ore-clasts on the margin of the primary ore bodies from which they derive.

The exposure of ore-clasts of about 25 km$^2$ surface area extends north to south from Kriveljski Kamen to Metovnica, with the largest olistostrome copper body of Novo Okno between them. The ore-clasts are isolated blocks, 15×25 cm in size, mostly in Senonian epiclastics of amphibole andesite, the products of destroyed ore bodies from the older Turonian copper deposits in the central mineral zone of Bor.

Agglomerations of ore fragments in a nearly defined set of epiclastic hornblende andesite deposits are also known on the slopes of Čoka Bare and at Metovnica south of Bor (Drovenik 1966; Đorđević 1977; Mišković 1989).

This does not rule out the possibility that the occurrences of Čoka Bare and Metovnica ore-clast were erosional remnants of the destroyed olistostromes, like the economic ore-clast bodies in the Novo Okno olistostrome copper deposit. Physically, they are identical with the mineral parageneses of the primary deposits and, naturally, with ore-clasts of the massive copper sulphide deposit of Novo Okno, formed on land during explosions of the volcanic structure (from plugs in channels), probably in the preolistostrome Turonian phase.

The ore-clasts are coated with iron oxides or copper carbonates (azurite, malachite, *etc*.). Mišković (1989) studied only partly the ore-clasts near Novo Okno and Metovnica, mainly citing the results and conclusions of Drovenik (1966).

Drovenik is still the most informative about ore-clasts in the Bor area, and far less Đorđević (1977) *etc*. Ore-clasts of the epiclastic deposits will be presented for several major locations, based on the available sources (Drovenik 1966, 1982; Đorđević 1977; *etc.*) and some own observations.

## Čoka Bare ore-clasts

Remnants of the chaotic, destroyed olistostrome? A high proportion of massive sulphide ore-clasts are preserved on Čoka Bare and Ujova some 4–5 km NW of Bor. These are probably the next largest exposures of massive sulphide ore-clasts after Novo Okno, explored before Drovenik but the exploration results were not available to this author.

Ore-clasts of Čoka Bare are useful for correlation with those of the Novo Okno olistostrome mineral deposit. Whether outcrops *in situ* or erosional remnants of the olistostrome, the ore-clasts should be verified by evidence of their structural elements and strike and dip, in view of the olistostrome zone length of about 400 metres (Drovenik 1966).

The ore-clasts are subrounded or rounded, 1–30 cm in size, mostly 3–8 cm. Olistoliths of 0.3 m$^3$ are rare. They are emplaced in hornblende-biotite andesite epiclastics [Drovenik (1966, 1992), takes them for volcanic breccia of amphibole-biotite andesite from the first volcanic phase, *i.e*., the Timocite association.] that form an east to west zone about 400 metres long, like the Novo Okno deposit, and less than 100 metres wide. The thickness of the ore zone is not known, because it is wholly covered, but the given morphogenetic parameters are sufficient for a comparison with the Novo Okno ore body.

Ore-clasts of massive sulphides are located in the Ujova Valley and on the Krivelj Kamen Hills, "on the other side" of the Bor volcanic structure, some 8 km north of Novo Okno.

According to Drovenik (1966), the Čoka Bare and other ore-clasts consist of pyrite, chalcopyrite, bornite, digenite and chalcocite, similar to the Novo Okno mineral parageneses of associations A and B.

The ore-clasts rich in massive sulphides have appreciable amounts of gold and silver. Fragments with 42.61 % Cu contain Au 105.6 g/t and Ag 544 g/t (Drovenik 1992).

For the genetic and other aspects of the Čoka Bare ore-clasts in the Novo Okno deposit, the opinion of Drovenik is cited previously.

### Ore-clasts of Metovnica–Nikoličevo

Massive copper sulphide ore-clasts of Metovnica, south of Bor and Novo Okno, were recognized and investigated before the Novo Okno deposit was uncovered. These ore-clasts were found in association with fresh epiclastic breccia of hornblende-biotite andesite and Timok andesite and subvolcanic rocks of the Borska River.

Large chaotic accumulations of ore-clastic rocks near Metovnica were identified as hydrothermal ore occurrences on the banks of the Brestovačka and Suva Rivers. The presence of hydrothermally altered rock fragments and matrix was notable. The rock fragments varied in size from a few to 25 cm and were angular, coated by malachite or azurite, but including no olistolith habit.

Pyritized rocks with chalcopyrite and chalcocite were most abundant in the examined fragments (DROVENIK 1966; ĐORĐEVIĆ 1977); there were also fragments of the primary massive sulphides (bornite, chalcopyrite).

MIŠKOVIĆ (1989, p. 167) explored the area of the Novo Okno copper deposit and reported ore-clasts from "several" intervals, the lowest of which had a somewhat higher concentration, in the Jasenovo Brdo and the Suva Reka locations, similar to that of Novo Okno [sic.].

Pyrite fragments were more abundant than fragments containing chalcopyrite, bornite, and especially low chalcocite. The occurrences of ore fragments in the epiclastics of the Grlište–Lenovac eruption area are the least known.

The potential mineral resource of Metovnica ore-clasts has not been ascertained even though the occurrences were explored by trial adits and test wells before the First World War.

A general metallogenic map of Serbia on the scale 1:200,000 (JANKOVIĆ & JELENKOVIĆ 1994) shows ore-clasts as the occurrences of copper ore. ĐORĐEVIĆ (1997), however, takes Metovnica occurrences (Jovanovo Brdo, Kameni Potok, *etc*.) to be pebbles or ore-clasts in epiclastic rocks of the Metovnica Formation, like other similar occurrences, only without an economic concentration of ore as in Novo Okno.

## Metallogeny of the deposit

This section, including isotopic analysis of sulphur, is an integral interpretation of the exploration data from the mentioned published sources, in the measure necessary for a better understanding of this concept of the genesis the Novo Okno olistostrome mineral deposit.

All mineralization processes in the Novo Okno copper deposit virtually ended in the pre-olistostrome phase on land, subaerially, through long gradual cooling of the volcaniclastic and mineral ore materials extruded from the primary copper deposits of the central Bor Zone.

It probably was the time when the structure of chalcopyrite and other sulphides changed ("internal concentric structure") to which DROVENIK (1992) referred.

Slides of consolidated rocks with massive sulphide ore-clasts into the sea basin finally shaped the lens-like ore body, or the Novo Okno olistostrome. Vertical disposition of ore-clasts, while still on land, was completed in the submarine phase of the deposit development; coarse olistoliths Class A concentrated in the lower and finer olistoliths Class B in the upper parts of the deposit (Table 1).

Material in the olistostrome is sorted to a variable degree, chaotic, but there is no break in the arrangement of the olistoliths and matrix.

Based on detailed laboratory examinations, the mineral parageneses of the massive sulphide deposits in the olistoliths and accessories in particular, MIŠKOVIĆ (1989), CVETKOVIĆ (1989), JANKOVIĆ *et al*. (1990) distinguished three mineral associations of ore-clasts:

A. Pyrite-covellite-chalcocite,
B. Chalcopyrite-bornite and
C. Pyrite-chalcopyrite.

### A. The pyrite-covellite association

Blocks (olistoliths) of the pyrite-covellite association prevail in the lower-central part of the olistostrome. The association in ore-clasts (olistoliths Class A) was also denoted A by MIŠKOVIĆ (1989).

Class A olistoliths (pyrite-covellite-chalcocite association), commonly large, even 30–50 $m^3$, and with high concentrations of Cu, Au, Ag, *etc*. were probably ejected on land in the preolistostrome phase and deposited in the basin as the lower part of the deposit.

The mineral constituents in the Class A olistoliths, low-lying in the deposit, are copper from 1.9 % to 13.7 %, gold from 0.6 g/t to 30.5 g/t, locally much higher, and silver from 0.4 g/t to 40 g/t (JANKOVIĆ 1990, p. 308).

### B. The chalcopyrite-bornite association

MIŠKOVIĆ (1989) takes that the mineral association B is largely related to ore-clasts, or to Class B olistoliths. The association is located in the upper part of the olistostrome body without breaks in the development of either association. The boundary between ore-clasts of Class A and Class B is gradual.

Ore-clasts of the chalcopyrite-bornite association differ from those of association A not only in their mineral composition, but also in the size of the fragments. Fragments prevailing in the higher part of olistostrome, or in the ore body intervals, are smaller,

0.3–10 $m^3$, according to MIŠKOVIĆ (1989) than the ore-clasts (olistoliths) of the pyrite-covellite-chalcocite association.

Some sulphides in the deposit show internal structure (CVETKOVIĆ 1989) of alternating thin zones of chalcopyrite and pyrite, a likely consequence of epigenetic consolidation and cooling on land, during the preolistostrome phase, not in a marine environment.

The mean amounts of the main constituents: copper, gold, silver and other minerals in olistoliths depend on the ore body (olistostrome) thickness and varies, according to JANKOVIĆ (1990, p. 312), from 1.9 % to 8.48 % Cu, 2.5 to 24.5 g/t Au and from 2 to 40 g/t Ag.

### C. The pyrite-chalcopyrite association

The association was recognized by JANKOVIĆ (1990, p. 312). It is aligned with fragments of hydrothermally altered andesite with chalcopyrite and pyrite over the chalcopyrite-bornite association some 30 m above "the main orebody" that includes Class B olistoliths.

The assemblage is widespread on the Novo Okno periphery, being undoubtedly marginal on a younger olistostrome sequence. The rock fragments are smaller and the copper content in them ranges from 0.05 % to 0.22 %, rarely higher (JANKOVIĆ 1990). It formed probably in the closing phase of the sedimentation basin filling.

The ore body Novo Okno was wholly uncovered in 1988/89. It was a small deposit of massive copper sulphides of high economic value, up to two million tons?, with the mean copper content of about 3% and Au+Ag more than 5 g/t (MIŠKOVIĆ 1995).

## Sulphur isotopes in the Novo Okno deposit

Isotopic analysis of the $S^{34}$ content of the massive copper sulphide in pyrite, covellite, chalcocite, chalcopyrite and bornite was performed for MIŠKOVIĆ (1989) in order to establish the source of sulphur and minerals in the Novo Okno copper deposit. The analysis of a total of 22 samples indicated a uniform $S^{34}$ content (from 1.8 to 3.8 parts per thousand) in the pyrites of the mineral association B (Table 2).

The sulphur isotope composition in covellite and chalcocite (Mineral Association. A) suggests some depletion of the light isotope, but $S^{34}$ is uniform as in pyrite, and indicates magmatic origin of the ore minerals (MIŠKOVIĆ 1989; JANKOVIĆ 1990).

The amounts of $S^{34}$ in the chalcopyrite and bornite of Association B are similar to those in other copper sulphides. Differences in some sulphides may be explained by fractional crystallization as a function of the precipitation temperature (JANKOVIĆ 1990).

## Geophysical information

The ore body or mineral deposit of Novo Okno was indicated by a local, positive gravimetric anomaly in the first exploratory borehole B 128, in 1979/80 (BILIBAJKIĆ 1985, personal communication; Partly confirmed by MIŠKOVIĆ (1989) who wrote: "I discovered by drilling the copper deposit Novo Okno in late 1978).

Certain disagreement or discrepancy in the gravimetric anomalies between the Novo Okno and the primary massive sulphide copper (ore bodies H, Jugoistok, Kraku Bugaresku and Severozapad) is a consequence, according to BILIBAJKIĆ (1985), of the shape and heterogeneous structural pattern of the mineral ores in the Novo Okno deposit.

An explanation of "the cause" of the anomaly, BILIBAJKIĆ (1985, personal communication) continues, should be looked for deeper in the Novo Okno ore body, in the particular configuration of the ore mass and the chaotic structural pattern of the deposit and the surrounding rocks.

The gravimetric (geophysical) interpretation of Bilibajkić was not controversial at the time with the current geological interpretation of the deposit's olistostrome origin. On the contrary, the chaotic heterogeneous structure, including olistoliths mineralized to various degrees, the size and shape, and other characteristics express faithfully the geophysical description of the cause of gravimetric anomaly that indicated the presence of the Novo Okno olistostrome copper deposit.

Table 2. Sulphur isotope $S^{34}$ in the massive sulphide of the Novo Okno copper deposit (amounts from JANKOVIĆ 1990).

| Sulphide | Amount (‰) | Mineral Assoc. | Olistoliths |
|---|---|---|---|
| Pyrite | from 1.8 to 3.8 | A | Class A |
| Covellite | from 4.1 to 4.3 | | |
| Chalcocite | from 2.6 to 5.2 | A | Class B |
| Chalcopyrite | from 3.5 to 4.8 | B | |
| Bornite | | | |

## Conclusions

The copper ore deposit Novo Okno, uncovered at present, consists of massive copper sulphide ore and non-ore clasts (olistoliths from 0.5 to 50 $m^3$ in size) and has many distinctive features characteristic of chaotic sedimentary products of the olistostrome origin.

The mineral deposit is heterogeneous in structure without bedding and has a lower surface unconformable on the basin bedrock. It is a lens-like, "trough-shaped" body elongated on the olistostrome axis in the east and west direction, variable in thickness from 15 m to 28 m, about 335 m long and less

than 140 m wide. These and other attributes of the body indicate a unified, reworked, and essentially extraolistostrome deposit of copper minerals.

The ore body was discovered in 1978 at a depth of about 270 m on the basis of a local positive gravimetric anomaly in Senonian epiclastic rocks of amphibole andesite.

The genetic and spatial relationships of the mineralized olistostrome indicate two synchronous (genetic) phases of the deposit formation, *viz*.:

– Turonian (volcanigenic) preolistostrome and
– Senonian submarine olistostrome phase.

The former phase includes volcanic explosion of the central Bor edifice and the breaking of the primary ore bodies and volcanic rocks into blocks and fragments, their emergence and deposition on land.

The latter phase, much later, embraced downslope sliding of consolidated rocks in the volcanic relief and chaotic accumulation of ore and non-ore clasts (olistoliths) in the sea basin.

Not all ore-clasts reached the sea basin, but were reworked and scattered in epiclastic rocks on the margin of the orebody, north and south of Bor. Major concentrations of ore-clasts in Čoka Bara and Metovnica may indicate remnants of destroyed olistostromes that resembled the Novo Okno orebody.

Vertical zonation of ore-clasts and other materials in the mineral deposit (matrix, cm-clasts) arranged on land remained unchanged in the aquatic environment. Coarser and heavier olistoliths Class A are always concentrated in the lower and lighter olistoliths Class B in the upper and middle parts of the olistostrome body.

The olistolithic ore-clasts of the deposit are characterized by complex mineral parageneses of massive copper sulphides:

A. The Pyrite-Covellite-Chalcocite Association of olistolith dimensions;

B. The Chalcopyrite-Bornite Association of olistolith dimensions; and

C. The Pyrite-Chalcopyrite Association (clasts, ore-clasts).

The mineral association of the Novo Okno is very similar to the primary massive sulphide minerals in individual bodies (Tilva Mika, Čoka Dulkan) of the central Bor ore deposit from which they originate, and to the Jugoistok (J and H) ore bodies.

Isotopic analysis of the $S^{34}$ content confirmed the magmatic derivation of sulphur and the ore minerals.

The geophysical interpretation of the Novo Okno geology expresses a true olistostrome structure and the cause of the gravimetric anomaly.

Genetic aspects of the primary copper deposits of Bor, the mineral parageneses, absolute age, and so forth confirm a pre-Senonian age of the deposits, their formation in the preolistostrome Turonian phase. The Novo Okno mineral deposit, formed in the olistostrome Senonian phase, is accommodated in epiclastics and pelites of the Upper Turonian and the Lower Senonian as determined from palaeontological evidence.

The olistostrome interpretation of the Novo Okno copper deposit therefore indirectly proves that the age of the ore bodies, the massive copper sulphides in the Bor ore deposit, is virtually determined as the Turonian.

## Acknowledgement

I wish to acknowledge gratitude to ALEKSANDAR GRUBIĆ (Faculty of Mining and Geology, University of Belgrade) and RADE JELENKOVIĆ (Faculty of Mining and Geology, University of Belgrade) for critical reading of the manuscript and useful suggestions.

## References

ANTONIJEVIĆ, I. 2010. Formational base of the Bor copper deposit. Proceedings of the 15th Congress of Geologists of Serbia, 177–180, Belgrade (in Serbian).

BOGDANOVIĆ, P. 1977. Upper Cretaceous (Senonian) Olistostrome Mélange in the Kozarčevo-Grđevci Zone of Kosovo, *Glasnik Prirodnjačkog muzeja*, Serija A, 32: 119–127 (in Serbian).

CVETKOVIĆ, Lj. 1989. Minerals of $Cu_3$ (As, Sa, V, Sn, Ge, W)$S_4$ System in copper deposits of eastern Serbia. Unpublished PhD dissertation. 161 pp., Faculty of Mining and Geology, University of Belgrade (in Serbian).

DIMITRIJEVIĆ, M.D. & DIMITRIJEVIĆ, M.N. 1973. Olistostrome mélange in the Yugoslavian Dinarides and Late Mesozoic plate tectonics. *Journal of Geology*, 81 (3): 328–340.

DIMITRIJEVIĆ, M. 1975. Olistolith. Olistostrome. *In*: PETKOVIĆ, K. (ed.), *Geological Terminology and Nomenclature, Petrology*. 4. 109 pp.. Zavod za regionalnu geologiju i paleontologiju Rudarsko-geološkog fakulteta (in Serbian).

DROVENIK, M. 1993. Contribution to the knowledge of the ore clasts from the Novo Okno orebody in the Bor copper deposit. *Geologija,* 35: 287–318.

DROVENIK, M. 2005. Origin of the Bor and Other Copper Deposits in the Surroundings, Eastern Serbia. *Razprave IV razreda SAZU*, 46: 5–81.

ĐORĐEVIĆ, M. 1994. Pyroclastic and epiclastic in "the first volcanic phase" of the Timok eruptive area. *Geološki Vesnik*, Serija A, B, Geology, 46: 291–311 (in Serbian).

ĐORĐEVIĆ, M. & BANJEŠEVIĆ, M. 1997. *Geology of the Timok Eruptive Region South*. 171 pp. Savezno Ministarstvo za privredu, Beograd (in Serbian).

ĐORĐEVIĆ, M. 2005. Volcanigenic Turonian and epiclastic Senonian in the Timok Magmatic Complex between Bor and Tupižnica Mountain, eastern Serbia. *Geološki anali Balkanskoga poluostrva,* 66: 63–71.

GRUBIĆ, A. 1975. *Sedimentologija*. 67 pp. University of Belgrade, Građevinska knjiga, Beograd (in Serbian).

GRUBIĆ, A. & ANTONIJEVIĆ, I. 1976. Olistolith near Mokranje and Rajac (Timočka Krajina). II Skup sedimentologa

Jugoslavije, Rudarsko-geološki fakultet, 51–57, Beograd (in Serbian).

Janković, S. 1990. *Ore deposits of Serbia. Ore field Bor "Novo Okno"*. 307 pp. Republički društveni fond za geološka istraživanja, Rudarsko-geološki fakultet, Beograd, Ekonomska geologija (in Serbian).

Janković, S. & Jelenković, R. 1994. Metalogenetic map of Serbia, 1:200 000. Unpublished, Republički društveni fond za geološka istraživanja, Beograd.

Janković, S., Jelenković, R. & Koželj, D. 2002. *The Bor Copper and Gold Deposit*. 298 pp., Mining and Smelting Basen Bor (RTB Bor), Copper Institute Bor (CIB), Bor.

Mišković, V. 1989. Genesis of the copper deposits "Novo Okno" and metalogenetic correlation with the oreclast in the Bor area, eastern Serbia. Unpublished PhD dissertation, 189 pp., Faculty of Mining and Geology, University of Belgrade. (in Serbian).

Mišković, V. 1995. Distal Copper Deposit „Novo Okno": A Special Type of the Massive Sulfide Deposit in the Carpatho-Balkan Metallogenic Belt. XV Congress of the Carpatho-Balkan Geological Association, 4 (2): 789–793, Athens.

Nachev, I. 1977. Olistostromes in the Tithonian Flysch of Bulgaria. *Review of the Bulgarian Geological Society*, 37 (1): 43–52 (in Bulgarian, English summary).

Rigo, De righi, 1956. Olistostromi neogenici in Sicilia. *Bolletino della Societa Geologica Italia*, 75/3: 185–215.

## Резиме

## Лежиште бакра „Ново окно" (Бор) олистостромске генезе

Данас већ откопано лежиште бакра „Ново окно" састоји се од нерудних и рудних класта масивних сулфида бакра (олистолити величине 0,5–50 $m^3$) и одликује се низом особености карактеристичних за хаотичне седиментне творевине олистостромске генезе.

Лежиште је хетерогене геолошке грађе и без слојевитости са доњим неравним контактом према подинским матичним стенама морског басена. Има сочиваст „коритасти" облик и издужено је по оси олистостроме исток–запад. Променљиве је дебљине од 15–28 m, дужине око 335 m и ширине до 140 m. По тим и другим особинама представља јединствено, редепоновано и у суштини екстраолистостромско лежиште бакра.

Откривено је 1978. године на дубини око 270 m на основу локалне позитивне гравиметријске аномалије у матичним сенонским епикластичним стенама амфибол-андезита.

Генетски и просторни односи рудоносне олистостроме указују на две синхроне хронолошке (генетске) фазе настанка лежишта. То су:

– туронска (вулканогена) преолистостромска фаза и

– сенонска субмаринска олистостромска фаза.

Прва фаза обухвата експлозију вулканског апарата централне борске структуре и разарање туронских примарних рудних тела и вулканита у блокове и комаде, затим њихово изношење на површину и синхроно депоновање на копну.

У другој фази, временски знатно касније, извршено је клижење консолидоване стенске масе у виду одрона и клизишта низ падине вулканског рељефа и хаотична акумулација рудних и нерудних класта (олистолита) у морском басену.

Сви рудокласти, међутим, нису доспели у морски басен. Значајан део њих је преталожаван и расејан у епикластитима по ободу примарних рудних тела северно и јужно од Бора. Веће концентрације рудокласта у Чока бари и Метовници указују, можда, на остатке разорених олистострома које су биле сличне лежишту „Ново окно".

Вертикална зоналност рудокласта и другог материјала у лежишту (матрикс, сантиметарски класти), остварена још на копну, задржала се и касније у воденој средини. Крупнији и специфично тежи олистолити класе А, по правилу су концентрисани у нижим, а ситнији, лакши, класе Б, у вишем и средњем делу олистостромског тела.

Олистолитски рудокласти лежишта се одликују сложеним минералним парагенезама масивних сулфида бакра:

А. Пиритско-вовелинско-халкозинска асоцијација олистолитских димензија;

Б. Халкопиритско-борнитска асоцијација олистолитских димензија;

В. Пиритско-халкопиритска асоцијација (класти, рудокласти).

Минералне асоцијације лежишта „Ново окно" показују веома велику сличност са примарним рудама масивних сулфида појединих рудних тела централног борског рудишта (Тилва мика, Чока дулкан) од којих воде порекло и са рудним телима лежишта „Југоисток" („J" и „H").

Изотопска испитивања садржаја сумпора $S^{34}$ потврдила су магматско порекло сумпора и рудне минерализације.

Гравиметријска геофизичка интерпретација геолошке грађе лежишта „Ново окно" верно одражава грађу олистостроме и узроке аномалије.

Генетски аспекти примарних борских лежишта бакра, менералне парагенезе, апсолутна старост и др. потврђују да су та лежишта старија, стварана пре сенона у преолистостромској туронској фази. Новообразовано лежиште „Ново окно", настало у олистостромској сенонској фази, смештено је у епикластитима и пелитима горњег турона и доњег сенона, чија је старост палеонтолошки доказана.

Олистостромска интерпретација лежишта бакра „Ново окно", према томе, посредно доказује да је старост рудних тела масивних сулфида бакра у борским рудиштима практично решена, односно да је туронска.