# Metallic mineral resources of the Karpatho-Balkan metallogenic province: Eastern Serbian Sector (general review)

# Nahajališča kovinskih mineralov v Karpatsko-balkanski matalogeni provinci: območje vzhodne Srbije (splošni pregled)

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**Abstract:** At the territory of Eastern Serbia, that represents only one small part of the Karpatho-Balkanic metallogenic province (ESSCBMP-East Serbian sector of the Carpatho-Balkan metallogenic province), were located numerous mineral deposits (Cu, Au, U, Fe, Pb-Zn etc.), very important from the economic point of view. Their formation and spatial distribution are connected with complex processes of structural, geological and metallogenic reshaping of the territory of spatial deposition, primary during baikal, hercyian and alpine metallogenic epoch. Of special interest are deposits of alpine and hercyian age connected with hydrothermal solutions and magmatic complexes, formed during complex processes of subduction and intracontinental rifting. Generally, all deposits are classified in few metallogenic zones characterized with specific associations of elements and genesis: Ridanj-Krepoljina, Neresnica-Beljanica, Bor and Porec-Stara Planina metallogenic zone.

**Izvleček:** Na območju vzhodne Srbije, ki je le majhen del Karpatsko-balkanske metalogene province (ESSCMP - vzhodni srbski del Karpatsko-balkanske metalogene province) so številna ekonomsko pomembna nahajališča Cu, Au, Fe, Pb-Zn in drugih kovin. Njihov nastanek in prostorska porazdelitev je posledica kompleksnih geoloških, tektonskih in metalogenetskih procesov ter preoblikovanja prostora v času baikalske, hercinske in alpidske metalogene faze. Posebna zanimivost so rudišča alpidske in hercinske starosti, ki so zvezi s hidrotermalno dejavnostjo in magmatskimi kompleksi nastalimi pri subdukciji in intrakontinentalnem riftingu. Na splošno lahko ta rudišča razvrstimo glede na specifično združbo elementov in genezo v sledeče metalogene cone: Ridanj-Krepoljina, Neresnica-Beljanica, Bor in Porec-Stara Planina.

**Key words:** Karpatho-Balkan metallogenic province, metallogenic zone, subduction, copper, association of elements

**Ključne besede:** Karpatsko-balkanska metalogena provinca, metalogena cona, subdukcija, baker, elementna združba

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## INTRODUCTION

In the sector of Karpatho-Balkanic metallogenic province, at the territory of Eastern Serbia, are known numerous rock complexes formed as product of magmatic, sedimentary and metamorphic activities that took place during proterozoic and quaternary. In the formerly mentioned geologic units has been noticed presence of numerous metallic mineral deposits, characterized by different features (mineral composition, associations of elements and genesis). They were localized in different litho-stratigraphic complexes, primary in magmatic, sedimentary and partly in metamorphic rocks, where of specific economic importance are Cu and Au deposits, partly Fe, W, U etc.

From the general point of view, metallic mineral deposits are classified in few metallogenic zones with specific associations of elements and genesis: Ridanj-Krepoljina, Neresnica-Beljanica, Bor and Porec-Stara Planina metallogenic zone (Fig. 1). The formation of formerly mentioned deposits, have been connected to different geologic settings and processes, where of specific economic importance are Cu-Au±Pb-Zn deposits connected to the processes of intracontinental rifting and associated magmatic activity in the area of the Bor metallogenetic zone, and deep rift structures over the zone of subduction in the area of the Ridanj-Krepoljina metallogenic zone.

## GEOLOGIC SETTING

The problem of the structural-geological composition and metallogenic analysis of the Karpatho-Balkanian metallogenic province, in the part of Eastern Serbia, in the past was analyzed only by few scientists. Detailed information about geohistorical development of this zone can be found in: ANTONIJEVIĆ (1957), GRUBIĆ (1962), JANKOVIĆ ET. AL. (1980 a, b), MASLAREVIĆ AND KRSTIĆ (1986, 1987) etc. About the same problem but from northern part of the boundary, in the area of Romania detailed works are published by: RADULESCU ET. AL. (1973), RUSSO-SANDULESCU ET. AL.. (1979; 1984; 1986), STRUTINSKI ET. AL. (1986) etc., and at the territory of Bulgaria detailed information can be found in: STANISHEVA-VASSILEVA (1980, 1989), NACHEV (1993), POPOV (1981, 1987, 1989), DABOVSKI ET. AL. (1989) etc.

*Proterozoic-cambrian formation* are rare in the area of the ISSKBMP. Formations of *old-baikal* age are present with shale sediments with presence of volcano-sedimentary rocks formed in ocean crust without ore mineralizations. *Young-baikal* volcano-sedimentary formations were formed from Late Proterozoic up to the Cambrian. They are laying transgressivelly over the cratonized old-baikal formations. Of special importance are diabase, keratophyre and quartz-keratophyre complexes associated with large masses of volcano-sedimentary rocks. Their formation is connected with continental rifting and spreading of the old-baikal lithosphere, but it has been treated as development of the marginal eugeosynclinal zone on the edge of the old-baikal continent. With this products are connected hematite and magnetite volcano-sedimentary deposits, associated with chalcopyrite.

In the higher levels of the Omanis near Kucaj, in the chlorite schist, are known siderite deposits associated with disseminated magne-

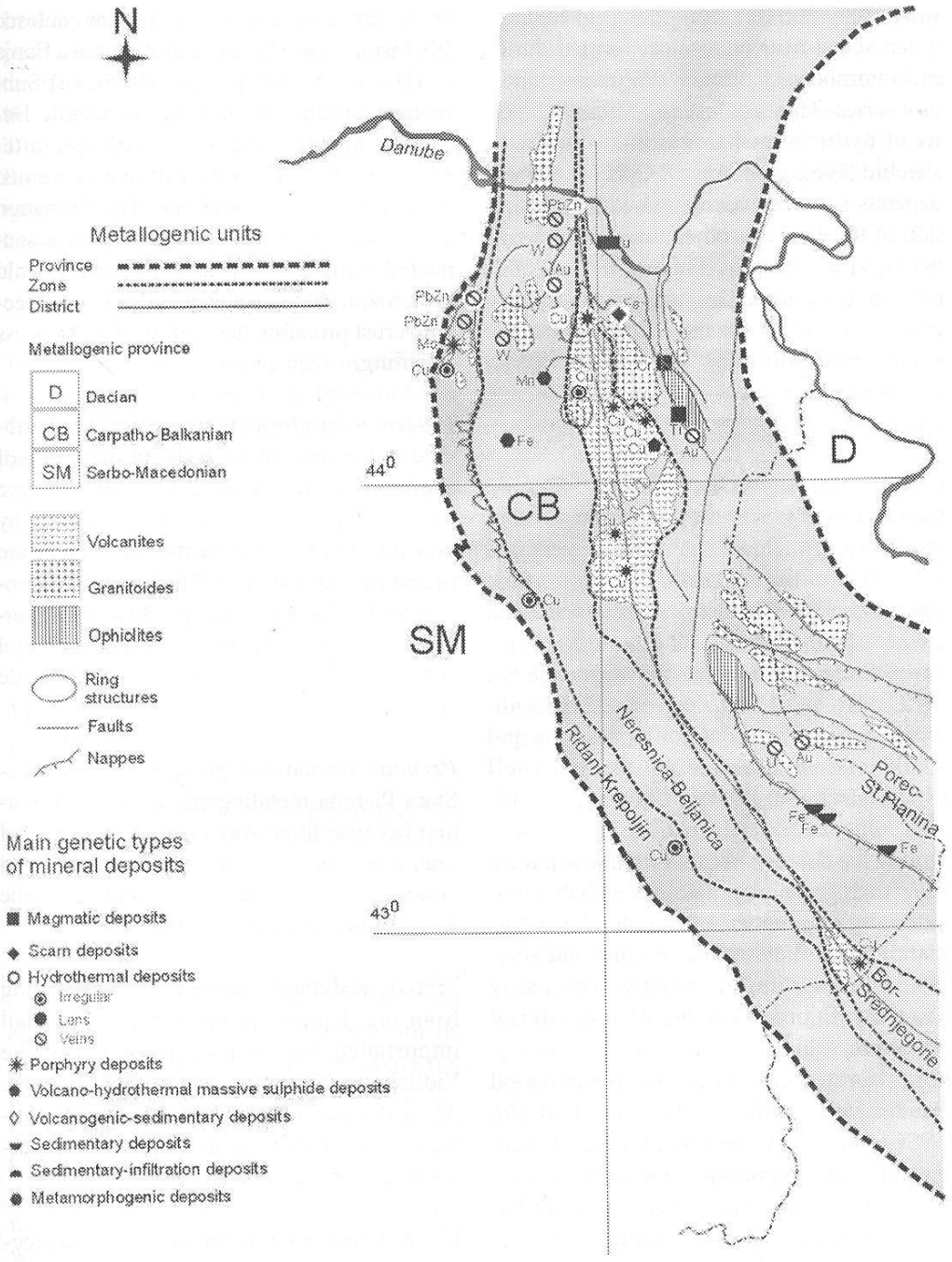


**Figure 1.** Karpato-Balkanic metallogenic province - Eastern Serbia sector
**Slika 1.** Karpatsko-balkanska metalogena provinca - območje vzhodne Srbije

tite and pyrite. Of metallogenic interest are green schist near Neresnica, formed during metamorphosis of primary volcano-sedimentary series. They enclose gold-quartz deposits of hydrothermal origin with or without sheelite (Blagoev Kamen). Genesis of these deposits has been connected with mobilization of the gold from the green rocks during the metamorphic processes and deposition in the fracture zones. One part of the thermal energy necessary for movement of the hydrothermal solutions was generated by granitoide intrusion additionally injected into green schist (JANKOVIĆ, 1990).

*Ordovician* products are laying transgressivelly over the consolidated metamorphosed proterozoic base and are very rare in the area of the ESSCBMP. In most of the cases they were formed in shallow sea and are not of some significant economic importance. Some interest was shown for the Sc, Cr, Cu, Zn and Cu in deep-seated sea sediments formed in reduction conditions and small lagoons near the continental shelf (MASLAREVIĆ AND KRSTIĆ, 1987).

During the *Silurian* period were formed warp (mud) and graphitic graptolites with disseminated organic matter and pyrite. Their formation was connected with quiet and shallow sedimentation in reductive and partly alkali conditions. They are of insignificant economic value.

Formations formed during Devonian period are located in the central parts of the ESSCBMP. They are not of some greater metallogenic importance. Of some significance are mainly: (i) Lower Devonian basins with muddy sediments formed in reductive conditions (black meta-alevrolites with anthracites, meta-clays, laminated cherts and small barite nodes). Some of them enclosed Pb, Mo, Cu etc. (locallity of Zvonacka Banja – MASLAREVIĆ AND KRSTIĆ, 1986); (ii) Submarine basaltic flows and (iii) Middle Devonian quartz sandstones with goethite-silicite oolites and shelf carbonates formed in shallow water conditions. The formation of the diabase-phillitoide formation was connected with continental rifting during old proterozoic. Horizontal spreading of the oceanic crust probably has followed the process of rifting.

*Carboniferous* formations are widely distributed in the zone of analysis. In the group of sedimentary rocks of smaller interest are those with occurences of products formed by volcanic actvities. Of greater importance are magmatic complexes of Delijovan gabbro-peridotite massive (Cr) type. Also, of importance are Neresnica and Gornjane granitoid (Fe, W, Au) and Stara Planina granitoide (U±Au).

*Permian* formations present in the Porec-Stara Planina metallogenic zone are important because there was noticed existence of uranium mineralizations. Some copper and uranium mineralizations, were noticed in the Ridanj-Krepoljina zone, also.

Triassic sediments are not very interesting from ore deposits point of view. Of small importance are Jurassic products in the Vidlicka and Visocka zone at Stara Planina. Also, of some economic importance are sedimentary formations and flysch formed during lower cretaceous.

Upper Cretaceous formations and geotectonic evolution during that period are of special metallogenic and economic importance.

In their frame were formed large Cu-Au deposits. In that period were formed some structural forms of greater importance: (a) regional lineaments such as Ridanj-Krepoljina and Timok-Dobropoljski that continues through Romania and Bulgaria, respectively and (b) igneous volcano-intrusive complexes genetically connected with formation of the Cu-Au deposits and locally with formation of the Pb-Zn.

Tertiary formations are located in the intramountain basins, formed on different basis. Tertiary products were formed in non-salt basins and composed of proluvial and lake-river sediments, locally intersected with coal.

Quaternary sediments are known for gold deposits and some other deposits (titanium, rare earth elements etc.).

## Mineral Potential of the Metallogenic Zones

The Alpine metallogenic unit in the East Serbian sector of the Karpatho-Balkan metallogenic province is represented by two metallogenic zones: the Ridanj-Krepoljin zone on the west, and the Bor zone in the central part. They were formed in the front of the Jurassic-Cretaceous oceanic slab, subducted from the Vardar zone beneath the Eurasian plate. Both metallogenic zones run, in some sectors, subparallel. The mineralization is associated mainly with late Upper Cretaceous calc-alkaline igneous activity. Although both metallogenic zones contains many common major elements, they differ with regard to the styles of mineralization, and environments of deposition (Janković et. al., 1974, 1980 b, 1990 b).

### The Ridanj-Krepoljin metallogenic zone

This metallogenic unit has been located along the contact of the Karpatho-Balkanic province and Serbo-Macedonian metallogenic province (Fig. 2). At the ESSCBMP it is developed from Danube at the north, via Krepoljin, Josanica-Ozred fault and Svrljig Mts. to Yugoslavian-Bulgarian border at south, along a regional, almost vertical dislocation zone, from the width of which is mostly up to 1 km, but at local intervals - up to 10-15 km (Lanovici et. al., 1977; Janković, 1990 b).

A major fracture is, at intervals, accompanied by second-order fractures. Regional fracture penetrates deep into continental crust, close to its contact with upper mantle (the occurrences the basaltic alkaline rocks of south of the Danube). It is not proved whether this deep fracturing was followed by horizontal movements (precursor of rifting).

The ore mineralization is associated with high plutonic intrusions of predominantly calc-alkaline magma(s), emplaced as narrow dyke-like bodies, discontinuously distributed along dislocation, or dislocation zone; the intrusions are accompanied by intense contact and hydrothermal metamorphism of wallrocks (hornfels and skarn). South-southeastward from Krepoljin, this regional dislocation and accompanied igneous rocks are partly covered by the nappe (near Senj), partly they are indicated, at intervals, by geomagnetic data and/or ore mineralization of telethermal type.

In the sector south of the Danube, two groups of igneous rocks are distinguished: (a) calc-alkaline, and (b) alkaline basaltic rocks.

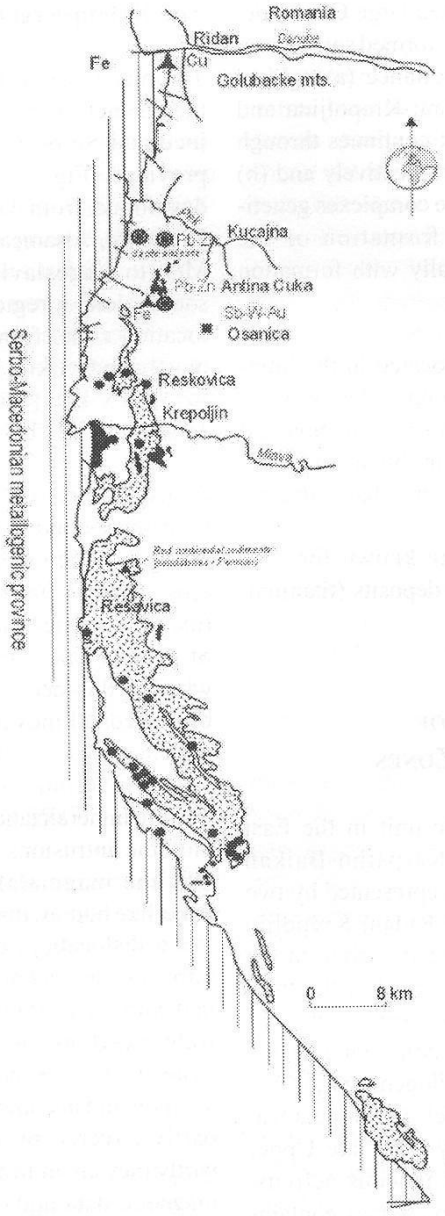


**Figure 2.** Location of the most important metallic mineral deposits in the frame of the Ridanj-Krepoljina metallogenic zone.
**Slika 2.** Položaj najpomembnejših nahajališč kovinskih mineralnih surovin na območju Ridanj-krepoljinske metalogene cone.

The calc-alkaline rocks are represented by subvolcanic dacite intrusions of dacite and andesite, locally developed as pyroclastics, and minor quartz diorite porphyry. The absolute age of dacites and andesite in the area of Krepoljin (K-Ar determination) ranges from 72.6 my to 60.6 my, but mostly between 72.6 and 67.1 my (Only one age determination of hornblende andesite did show 60.6 my, but its plagioclase - 56.4 my, and hornblende 76.9 my.)

The alkaline rocks occur sporadically as dykes of olivine-nephelite, limburgite, nephelinite, teschenite. Genesis of these rocks is still uncertain (they derive from a basaltic magma from upper mantle intruding along deep fracture?). The age of these alkaline rocks is not yet established, except that their dykes cut Jurassic and Lower Cretaceous sediments.

Deposits and occurrences in Ridanj-Krepoljina zone, southern from Danube, more detailed have been explained by JANKOVIĆ (1990 b). Between, up to date, identified mineral deposits most important are:

- Skarn and partly skarn-hydrothermal magnetit deposits in zone of Golubac Mountains on the north to the Mlava River on the south. They are with small dimensions (500 t to 20.000 t), with ore bodies with node and irregular shapes. In these deposits magnetite is associated with sulphides (pyrite, chalcopyrite, rarely sphalerite). Copper content is mostly under 1%.
- Skarn-hydrothermal metasomatic Pb-Zn deposits are known in Reskovica (+Bi-minerals, molybdenite, chalcopyrite and sheelite), Kucajna (Kucajna deposit comprises small lenses and nests of massive ore (Pb-Zn, Ag-Au association) in limestone and skarn-type mineralization of galena and sphalerite, along the contact between dacite-andesite and Jurrassic limestone) and Antina Cuka. They are with small dimensions.
- Occurrences of the lead-zinc mineralizations can be noticed locally, southern from Krepoljina.
- Antimony deposits are rare in this metallogenic zone. Of economic importance is the Osanica deposit and occurrences of antimony-jasperoidal type in carbonates near Breznica northern of Mlava River. Epithermal Sb-W deposit Osanica is of vein type(stibnite-wolframite accompanied by gold).
- Low temperature hydrothermal copper mineralization in the Permian red sandstones.- Numerous but very small deposits of this type are known south of the Dunav through to Suva Mts, near the Yugoslav-Bulgarien border. The mineralization occurs along faults in the Permian red sandstone, accompanied by hydrothermally altered wallrocks. These small deposits, consisting mostly of small lenses, are located along zone of faulting.

The associations of elements concentrated in the ore deposits is a specific metallogenic feature of the Ridanj-Krepoljin zone are classified as: (i) Major elements: Fe (oxide, Py), Pb/Zn, Cu, ± Au/Ag. (ii) Significant elements: W, Sb.

The principal associations of elements identified in the ore deposits are classified as follows: (1) Skarn deposits: (a) Fe (Mgt,He,Py)-Pb/Zn-Cu ± Au/Ag; (b) Fe (O,S); (c) Pb/Zn-

Cu, Mo ± Bi, W. (2) Skarn / hydrothermal deposit and hydrothermal deposits: (a) Pb/Zn-Au/Ag ± Cu /replacement deposit/; (2b) Cu-S /epithermal deposit/; (c) Sb-W / epithermal deposit/; (d) Cu-S, U /epithermal deposit/.

The distribution of associations of elements is characterized by a regional zoning (from the north to the south): (i) Reskovica: Cu, Pb-Zn, +/- Mo, Bi (skarn); (ii) Krepoljin/ Osanica: Sb, W +/- Au (epithermal); (iii) Bancarevo: Cu-S (epithermal).

**The Bor metallogenic zone**

The Bor metallogenic zone is one of the most important metallogenic units in the Karpatho-Balkanic province. In the sector of Eastern Serbia, this zone takes place from Dunav through Majdanpeka and Bor up to the Donji Nevlji on the south. On the south it continues to the Romania (IANOVICI ET. AL., 1982) and to Southeast and east to the Srednogorie zone in Bulgaria and Turkey.

The Bor metallogenic zone was formed in different magmato-tectonic environment than the Ridanj-Krepoljin zone (JANKOVIĆ AND JELENKOVIĆ, 1998). The ore deposits associated with the Upper Cretaceous ± Paleocene multistage igneous complexes are located within a narrow basin of rift-graben structure filled by sedimentary and volcano-sedimentary rocks, mainly of the Upper Cretaceous age (JANKOVIĆ, 1977). At ESSCBMP this basin is, at present, 0.5-20 km wide and over 80 km long (Fig. 1). The nature and the models of its development have been subject of discussion and disagreement among geologists. It was defined by various terms such as "subduction zone between Moesia and the Rhodope" (DEWEY ET. AL., 1973; BONCEV, 1978; BOGDANOV, 1977), "Upper Cretaceous paleorift" (ANTONIJEVIĆ ET. AL., 1974), "Banat-Srednogorie rift" (POPOV, 1981), "back-arc through" (BOCCALETTI ET. AL., 1974; HSU ET. AL., 1977), "inter-arc through" (NACHEV, 1993), "rift with spreading" (DABOVSKI, 1980) etc.

Regardless of the term, this basin and its evolution, characterized by the structures found with rift-graben environments. It was developed in multistage process mainly during Late Cretaceous. The rift stage begins, in the Timok sector, in the Upper Aptian and lasted through to the Paleogen (ANTONIJEVIC ET AL., 1974). The rift regime, involved intensive fracturing and opening of the rift, followed by further subsidence, particularly during the Senonian, sedimentation and intensive magmatic activity, lasted during the entire Upper Cretaceous and the lowest part of the Paleocene, when the final consolidation took place (JANKOVIĆ AND JELENKOVIĆ, 1998).

The volcano-plutonic and volcano-sedimentary complexes of whole metallogenic zone are characterized by the followings:

(i) They are predominantly of Upper Cretaceous age (105-65 my). The occurrences of igneous activity during Paleocene are recorded only in the northernmost sector of the metallogenic zone; they are of subordinate volume and of small metallogenic significance. The magmatic activity did not start and not terminate simultaneously in this zone, and with the same intensity.

(ii) They are mainly of kalc-alkaline composition but in some sectors alkaline rocks prevail. The changes of petrochemical features of volcano-plutonic

rocks are in close connection with the changes of tectonic development of the rift-graben environment.

(iii) Plutonic complexes are of composite nature. The plutonic bodies are represented by single or clustered hypoabyssal intrusions.

(iv) The prevalence of volcanic rocks over plutonic rocks. The volcanic activity takes place usually within volcano-tectonic depression or grabens. The structural features of volcanic environment indicate central type, and related ring-radial fractures. Numerous submarine volcanoes are identified, mainly with linear character of distribution.

(v) Variable thickness of tuffaceous and volcano-clastic sediments. Pillow lavas are found sporadically only.

At the ESSCBMP (the Bor zone) the volcano-intrusive complexes are represented by the volcanic, volcano-sedimentary and plutonic rocks. They derived from subcrustal, contaminated magma(s) - KARAMATA AND DJORDJEVIĆ (1980). The $^{87}Sr/^{86}Sr$ ratios range from 0.707 to 0.712 ‰. The calc-alkaline series is prevalent with respect to tholeitic rocks.

Igneous activity began in Turonian time and lasted intermittently until Paleogene time, mainly between 90 and 60 m.y. There were two main breaks in igneous activity, and three principal phases are recognised, each of them characterized by multiple lava flows, explosive eruptions with pyroclastic rocks and subvolcanic intrusions as well as volcano-sedimentary series. Namely, volcanic rocks are represented by andesites and their pyroclastics, and by minor amounts of dacites as well. Latite and trachyandesite occur locally, particularly in the third volcanic phase. The volcano-sedimentary suite includes interbedded shales and tuffaceous pelites. Besides, submarine flows are mostly deposited in shallow water environment. Hypabyssal rocks occur as multistage composite complex ranging in composition from syenite, monzonite, granodiorite to quartzdiorite, diorite and gabbro; monzonites prevail. The petrochemical composition of intrusions is variable, ranging from saturated to oversaturated with respect to silica, and from calc-alkaline to potassic (KARAMATA ET AL., 1981, 1983).

The copper and gold are the dominant metals in the ores from the Bor; the base metal ores are sporadically of the economic significance (JANKOVIĆ ET. AL., 1980 b; 1992; JELENKOVIĆ, 1998) (Fig. 3). The copper deposits contain often high grade ore and significant tonnage. (The mineral potential of the Bor ore field exceeds 12 million tons of copper and 300 tons of gold). With respect to morpho-structural types and mineral paragenesis, the following principal groups of copper deposits are recognised in the Bor metallogenic zone (JANKOVIĆ, 1990 b; JANKOVIĆ ET. AL., 1996).

- *Porphyry copper deposits:* According to the reserves and dimensions Cu-Au deposits are most important deposits in the Bor metallogenic zone. Copper content is usually 0.3-1.0% Cu, while gold contents about 0.25% Cu. In most of the porphyry copper deposits gold content decreases by the deepness (in the higher levels of the Majdanpek deposit gold content is about 1 g/t Au while at deep of 600 m, decreases to 0.25% Au). Copper mineralization is mostly confined to subvolcanic intrusions and/or

shallow emplacement of porphyritic dykes (quartz diorite, granodiorite and/or monzonite porphyritic) in and above the zone of a calc-alkaline comagmatic stock. The spatial relation of the plutonic intrusion and porphyry copper mineralization is evident (Crni Vrh) or it is assumed on the ground of the development of porphyry dyke suites (Majdanpek, Veliki Krivelj).

- *Hydrothermal-volcanic–massive sulphide deposits* are often located over the copper porphyry deposits and that is specific feature only of the Bor metallogenic zone. To this type of mineralization belongs Bor, Lipa etc. Gold content in this type of deposits is high. This type of mineralization is hosted by andesitic volcanics, and it is of replacement type. The ore often contains an increased content of gold. In some of these deposits, the enargite ore is abundant.
- *Volcano-hydrothermal vein deposits* are of small economic importance. Represent of this type of deposits is the deposit Kraku Bugaresku.
- *Mechanically redeposited deposits.* This is very rare type of copper ore deposits, composed of mechanically con-

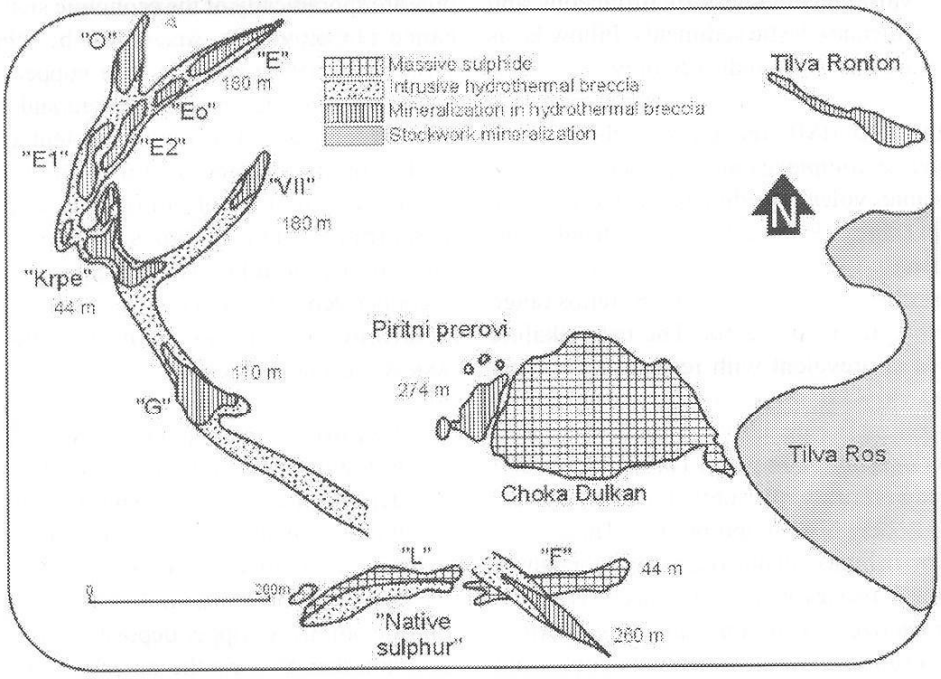


**Figure 3.** Schematic view of spatial distribution of the porphyry copper deposits and ore bodies with massive sulphides in ore field Bor (JANKOVIĆ AND JELENKOVIĆ, 1998).

**Slika 3.** Shematski prikaz prostorske porazdelitve porfirskekga bakrovega orudenja in rudnih teles z masivno sulfidno rudo na območju Borskega rudišča (JANKOVIĆ AND JELENKOVIĆ, 1998).

centrated pieces of masive-sulphide ore. By the fact that these massive-sulphide ore pieces (rich with pyrite and copper minerals) are numerous and disseminated in the Bor metallogenic zone volcanics, there are locations where came to their deposition and formation of smaller deposits (Novo Okno). These deposits are with small dimensions but of great economic importance because of high content of copper and gold.

- *Skarn deposits* are very rare. Mostly that are small lead-zinc (Valja Saka) and/or copper deposits (Potoj Cuka). Economically these deposits are not interesting. It must be mentioned genetical possibility for formation of important skarn copper deposits in carbonate rocks at the eastern margin of the Bor metallogenic zone.

Generally, features of the mineralizations are:

- The principal associations of elements are classified as follows: (a) Cu, Au, Mo ± Ag, PGE (porphyry copper); (b) Cu, Pb/Zn, Fe (Py), Au/Ag ± Se, Bi, Sb (massive sulphide); (c) Cu, Au, Fe (Py), As ± W, Sn, Se, Sb (cupriferous massive sulphide/replacement); (d) Fe-S (massive pyrite); (e) Cu, Fe(Py) ± Mo, Bi, W (skarn). The longitudinal zoning of the distribution of associations of elements can be displayed as follows: (a) Majdanpek: Cu, Mo, Au/Ag, Fe (Py) ± PGE, Pb/Zn (porphyry); (b) Choka Marin: Cu, Pb-Zn, Fe (Py), Au/Ag (massive sulphide); (c) Bor: Cu-Fe (Py), Au, As ± Se, Sb, W,Ag (massive sulphide); (d) Donje Nevlje: Cu ± Mo (porphyry copper).
- By the economic importance they can be grouped: (i) Major elements: Cu, Au i S; (ii) Minor elements: Fe, Se, Ag, As, locally PGE, Ge, Mo, Te, Ga, Sb, Mn; (iii) Local concentrations: Pb, Zn, Cd, Pb, Ba.
- Mineral associations are made of: (i) Copper deposits of massive-sulphide type: pyrite, rarely markasite, pyrhotine, covelline, halkozine, chalcopyrite, enargite, bornite, associated with neodigenite, djurleite, silvanite, lazarevicite, luzinite, domejkite, tethraedrite; locally are noticed magnetite, arsenopyrite, tenantite, frajbergite and native gold. In frame of the pyrite deposits of massive-sulphide type, pyrite is almost single ore mineral sometimes followed by native gold and magnetite. (ii) Copper porphyry deposits: chalcopyrite, pyrite followed by magnetite, molibdenite, and locally by lead-zinc sulphides (galena and sphalerite). By the presence of gold there can be distinguished deposits with important gold contents in copper porphyry mineralization (Veliki Krivelj). (iii) In frame of the polymetallic deposits (Choka Marin) mineral association is represented by: pyrite, sphalerite, sometimes with galena, copper minerals (enargite, luzonite, chalcopyrite, bornite, stibioluzonite, djurleite, chalcozine, covelline), markasite, Pb/Sb sulphosalts; especially important component is gold- native or interstitial in chalcopyrite, pyrite, enargite and thenantite.

## The Neresnica-Beljanica metallogenic zone

This zone is located between Ridanj-Krepoljina zone on the west and Bor metalogenic

zone on the east (Fig. 1). It contains numerous occurrences of ore mineralization, but they are mainly of small economic importance. Among association of metals, Au, W, Fe and Mn prevail; uranium occurs only occasionally. By the mineral composition, morphogenetic types and age, mineral deposits in this zone are distinguished in: (i) Early Paleozoic epoch (Fe, Mn, Au ± W); (ii) Hercynian mineralization (Au), (iii) Quaternary deposits (Au, monazite) (JANKOVIĆ, 1990 b).

Volcano-sedimentary Fe deposits of Beljanica i Kucaj (Jelja, Kucaj, Omanis etc.) are the oldest of all of them. That are magnetite-hematite deposits localized in ordovician volcano-sedimentary series of Beljanica and Kucaj. That complex in lower parts is composed of diabase and gabbro-diabase. In higher levels there are keratophires and tuffs, while the highest levels of the complex are composed of "green-schist". Orebearing volcano-sedimentary complex, with compact and impregnated Fe-oxides, occupies territory of 50 km$^2$.

Manganese deposits are located in the ordovician metamorphic volcano-sedimentary complex represented by keratophyres with sedimentary parts composed of chert, siliceous and clay schist with hematite intercalations ("violet schist") and sandstones with Mn-oxides. At Laznica near Zagubica has been confirmed existence of few Mn-bearing packages with width of few meters. Manganese content in primary mineralization (braunite followed by psilomelane, locally hematite) is very low.

Gold ± sheelite deposits near Blagoev Kamen are of economic importance. Numerous quartz-gold veins with sheelite are known in early Paleozoic mafic volcano-sedimentary complex ("green schist"). Ore veins are enclosed in the foliation of the schist (Fig. 4a,

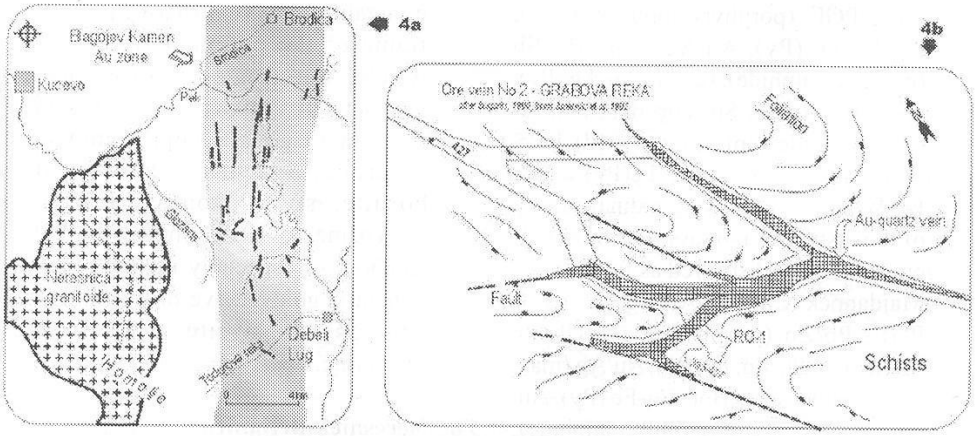


**Figure 4.** Position of Blagoev Kamen ore bearing structure with marked locations of separate ore veins (a); Specific Au bearing vein in frame of Blagoev Kamen ore bearing zone (b).
**Slika 4.** Rudonosna struktura Blagojevega Kamna z vrisanimi posameznimi rudnimi žilami (a); značilna zlatonosna rudna žila v v rudonosni coni Blagojevega Kamna (b).

4b). Native gold and sheelite are the main ore minerals accompanied by minor pyrite, and subordinate sphalerite, galena and rare pyrargirite; pyrite occurs occasionally in green schist. Primary gold is, most probably, of volcano-sedimentary origin. In the processes of later metamorphism, gold was mobilized from ultimate source(s), and concentrated in veins.

Quarternary deposits: Significant alluvial gold deposits are known in Pek, and occurrence of monacite in the placer formed on the Neresnica granitoid.

## The Porec-Stara Planina metallogenic zone

This metallogenic zone took place between Dunav on the north, up to the Stara Planina and Yugoslavian-Bulgarian state border on the southeast (Fig. 1). In this metallogenic zone has been located numerous deposits of different morphogenetic types with common features, small dimensions and limited economic importance. They are grouped in few areas:

(a) *Ore deposits of Gornjane granitoide complex.*- At the contact margins of the Gornjane granitoide, of hercyan age, were identified few mineral deposits and occurrences. In most of the cases they are of skarn and hydrothermal origin.

*Skarn magnetite deposits* with some chalcopyrite are known at Rudna Glava, while in the area of Crnajka were noticed small hydrothermal magnetite lenses. Also, are known smaller sheelite mineralizations (as thin quartz veinlets) near by Luka locality. Their genesis has been connected to hydrothermal solutions genetically connected with the Gornjane granitoide. Sheelite veins and veinlets, with variable concentrations of molibdenite, in the localities of the Perin Potok and Gabar are of limited economic importance.

(b) *Deli Jovan ore deposits.* Gold deposits in the gabbro-peridotite complex Deli Jovan (Fig.5) are represented by numerous quartz veins with native gold. From the genetic point of view, they probably were connected to the Gornjane granitoide. Confirmed reserves of gold in the hydrothermal veins are already exploited. At the Rusmen-Gindus mine, quartz veins with gold were about 1 m in width, spread in zone long about 6 km. Gold content was about 10-14 g/t Au.

(c) *Chrome deposits in the Deli Jovana gabbro-peridotite complex.*- In the frame of this magmatic complex up to date are known only chromite deposits with high contents of alumna in the chrom-spinels.

(d) *Stara Planina.*- In the region of the Stara Planina predominant are mineral deposits of Hercyian age, and deposits of Mesozoic age in the southeastern parts. In the metal associations of major economic importance are concentrations of: U, Au, partly Bi and Ag, while concentrations of other metals (Cu, Pb-Zn, Mo) are of minor importance (Fig. 6).

*Uranium deposits.*- In the ore district of Stara Planina, as a constituent part of Karpatho-Balkan metallogenic province, can be found numerous uranium ore deposits or occurrences of different genetic and morphostructural types, mineral paragenesis and associations of elements (Getrik, 1978; 1988; Janković, 1990b; Jelenković and Grzetić, 1995; Grzetić and Jelenković, 1995; Kovačević et. al., 1995). The most

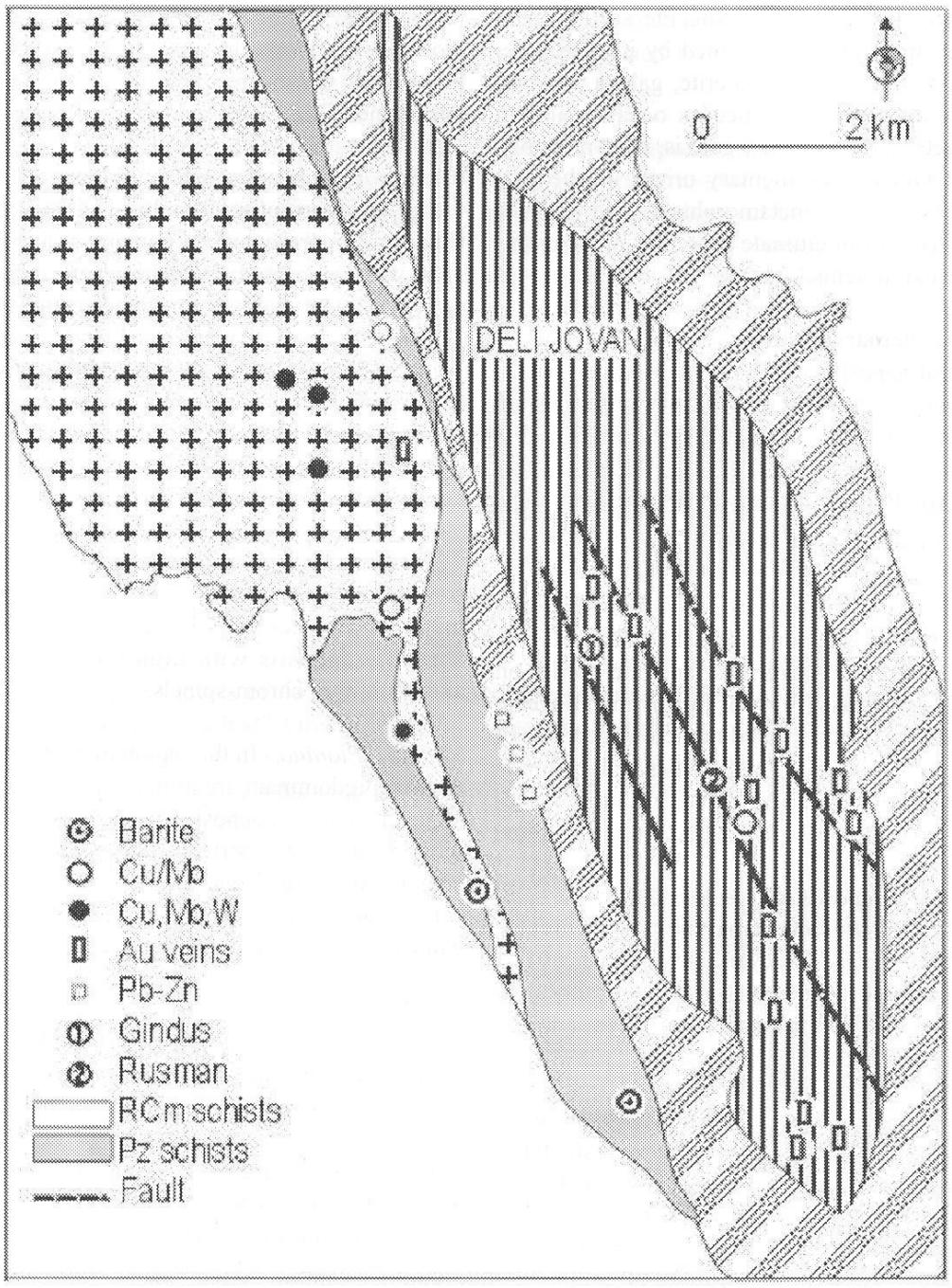


**Figure 5.** Locations of Deli Jovan ore deposits.
**Slika 5.** Položaj rudišč na območju Deli Jovana.

dominating are: a) uranium vein type hydrothermal ore bodies in the ore field of qranitoide complex of Janja (Mezdreja, Gabrovnica and Srneci Do ore deposits), which are most important; b) diagenetic and epigenetic mineralization of uranium in sandstones of the Permian Triassic sediments of Stara Plarnina; and c) ore appearances in the part of the "Crnovrska"' series where the mineralization is bound to granite-porphyry intrusive (U-Mo-W ore formation) (JELENKOVIĆ ET. AL., 1996). From the geological and economical point of view the most important are ore deposits in the Janja ore field, between Trgoviski Timok River and Yugoslavian-Bulgarian border.

Granitoide complex of Janja consists mainly of medium size grained and less porphyroide kalc-alkaline biotitic granite of the monconite type with the tendency to change into Na-plagiogranite. In the lateral and endomorphic parts of the massive one, can be recognized granodioritic and granosienitic facies. On the basis of QLM and kP diagrams it was concluded that during magmatic differentiation Ca was enriched in endomorphic differentiates followed by K depletion in feldspars. Solidification of the granitic complex occurred most likely at the medium depths of 5 to 10 km. Tectonic movements during al-

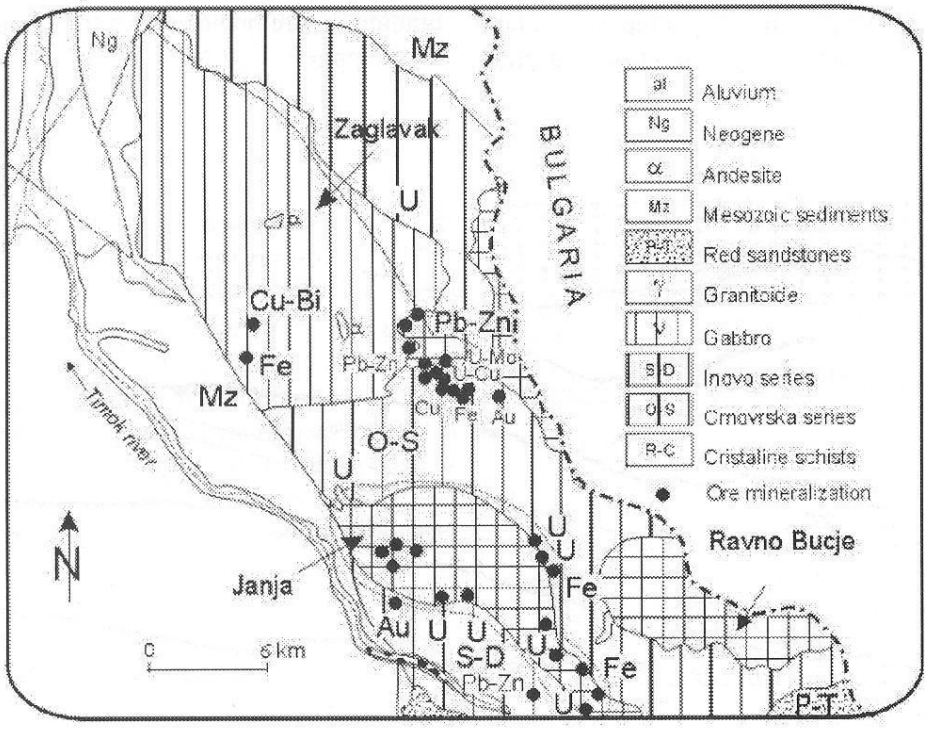


**Figure 6.** Position of some most important mineral deposits in the area of the Stara Planina (JANKOVIĆ, 1990).
**Slika 6.** Položaj nekaterih najpomembnejših rudišč na območju Stare Planine (JANKOVIĆ, 1990).

pine orogenesis intensively deformed granitoide complex of Janja. High degree of tectonization represented by numerous fractures and cracks define the main structural characteristics of the granitoide complex.

Average content of U in Janja complex is 1 to 5 ppm and locally up to 20 ppm. Dissolvable fraction uranium minerals reach 60%. In the domain of the wide epigenetic aureoles (wide up to several hundreds meters) the concentration of U reaches 25 to 90 ppm.

Economically most important mineralizations of uranium were found in Mezdreja (Fig. 7), Gabrovnica and Srneci Do ore deposits. These ore deposits are situated in the lateral parts of granitoide complexes in fault zones characterized by fracture and crack systems oriented along E-W and NW-SE lines. Thickness of the fracture zones is variable. They can be even 10 m thick and they stretch up to 1 km. With increase of the tectonic deformations increase the degree of rock alteration. Altered granitic complex contain kaolinite-sericite-hydromuskovite- illite-montmorillonite mineral associations. Thickness of ore veins and lenses is about 0.5 m, several hundreds meters long. The important minerals are: pitchblende as the most important mineral followed by variable concentrations of magnetite, hematite, pyrhotite, pyrite, marcasite, arsenopyrite, galena, sphalerite, chalcopyrite, bazite, strontianite, dolomite, calcedone, chlorite, kaolinite, and secondary pitchblende. The average content of uranium in ore bodies varies from 266 ppm to 566 ppm.

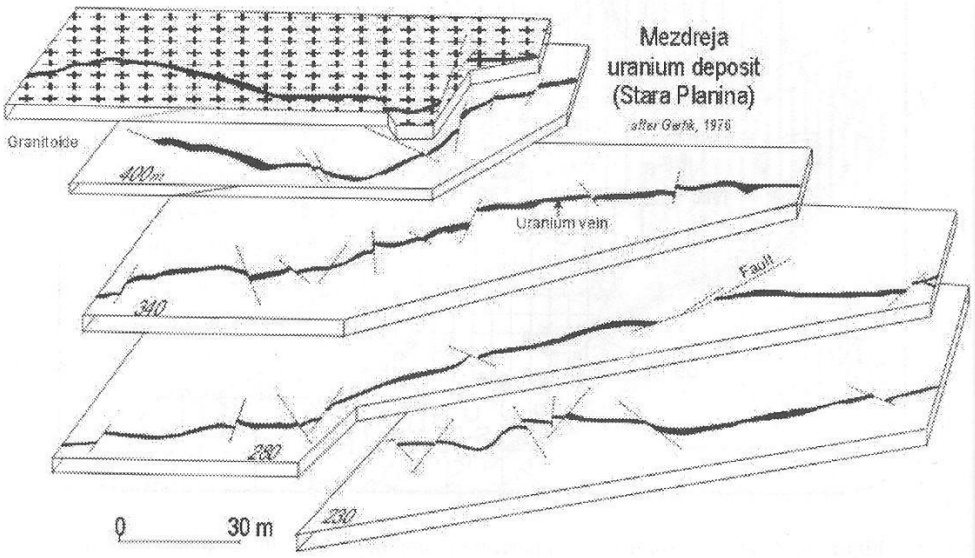


**Figure 7.** Mezdreja uranium deposit (GERTIK, 1976).
**Slika 7.** Uranovo rudišče Mezdreja (GERTIK, 1976).

The mineralization process of Janja granitoide complex with uranium is determined by geological factors such as the presence of granitoide intrusion enriched with uranium accompanied with sediment carbonates. Morphostructural characteristics of the complex made possible the percolation of hydrothermal solutions from deeper to upper parts of the granitoide where the process of uranium deposition occurred. The main factors of uranium deposition and rising of the ore bodies are physic-chemical. These are the changes of the hydrothermal solutions during the alteration of the parent rocks, changes of the oxygen fugacity and partial pressure of the $CO_2$ and the change of the pH value from acidic to neutral values followed with constant drop of the temperature and pressure from deeper to shallower parts of the granitoide complex. These factors actually influenced the process of oxidation and complexing-mobilization, and reduction and decomplexing-fixation and precipitation of uranium.

*Gold deposits* are located in the zone parallel to the Bulgarian state border and can be followed up to the Zaecar on the north and Pirot on the south. In almost of all of them up to date are noticed occurrences, gold is in association with some other metals, such as Cu-sulphides, locally Bi, Pb-Zn and Mo. Genesis of the gold deposits has been connected with granitoide complexes of Hercyian age and partly with volcano-sedimentary series of mafic composition. Gold is located in short quartz veins, mostly 0.2-0.4 m in width, which deposition was controlled by zones of faulting. By the presence of gold in the quartz veins, there are sulphide impregnations associated with gold, formed in frame of the bigger faulting zones. Economically most important gold mineralizations are located near ore field Vratarnica, where gold is associated with Pb-Zn sulphides, then, in the frame of ore field Trgoviste where the gold mineralizations are represented by thin quartz-pyritic veins in the serpentines and finally in the ore field Gradiste-Aldinac where quartz veins with gold are localized in gabbro and ore field Kalna (gold is concentrated in quartz-pyritic veins).

Except in the primary deposits, minor gold mineralizations are known in the alluvium of the Trgoviski Timok and zone of the Balt Berilovac (40 x $10^6$ $m^3$ of sand with 0.255 $g/m^3$ Au).

*Deposits and occurences of Fe* are known in the area of Vidlicka zone, Velika Lukanja and Temska. Spatially they are connected to the middle Jurassic sandstones; partly carbonate facies of Upper Jurassic (Early Alpine metallogenic epoch). They are presented as two subparalel layers long few kilometers. From the mineralogical point of view there can be distinguished two basic types of mineralizations:

- Oolitic deposits in form of layers, almost 1.0-7.0 m in width with 15-50% Fe, often 25-30% Fe. Mineral composition is: hematite, limonite and goethite with variable contents of carbonates.
- Hematitic type of mineralization, mostly compact ore (village Odorovci and Gulenovac) formed in products of Middle Lias. Width of the layer is about 1-5 m, and length is few hundreds of meters. Mineral composition is: hematite, siderite, limonite, followed by quartz. Content of the Fe is about 32-57% Fe.

The hydrothermal *bismuth-copper* mineralization at Aljin Dol lies in gabbro. The ore veins and nests contain numerous minerals such as arsenopyrite, pyrhotite, chalcopyrite, wolframite, sheelite, pyrite, siderite, Bi-minerals, even stibnite, molybdenite a.a.

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