Rudarsko-geološko-naftni zbornik	Vol. 18	str. 43-61	Zagreb, 2006.

UDC 551.7:552.18
UDK 551.7:552.18

Original scientific paper
Originalni znanstveni rad

Language/Jezik: *English/Engleski*

GEOLOGY AND METALLOGENY OF THE DRINA-IVANJICA METAMORPHIC COMPLEX IN EASTERN BOSNIA – WESTERN SERBIA

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Key words: eastern Bosnia, western Serbia, Drina-Ivanjica Formation, Neo-Proterozoic, Paleozoic, iron ore deposits, age and genetic types

Abstract

This paper gives a critical review of all relevant, published works on the stratigraphy, tectonics, magmatism, metamorphism and metallogeny of the metamorphic complex of the Drina-Ivanjica Formation in eastern Bosnia-western Serbia. Special attention was paid to all unresolved or controversial issues in geology and metallogeny of this area. The basic controversial geological problem is the question whether the Drina-Ivanjica Formation ends with the Drina Phyllitoid Formation of Upper Cambrian-Lower Carboniferous age, or underneath it discordantly lies an older iron-bearing volcanogenic-sedimentary formation of Lower Cambrian-Vendian age. Detailed analysis of all studied Caledonian and Cadomian metallogenies in Bosnia and Herzegovina, western Macedonia and Serbia, and their comparison with iron deposits of the Drina Formation, considerably clarified the problem. As for controversial metallogenetic problems, a number of ore horizons, their age, genetic type and commercial value were considered. This led to the conclusion that only three ore horizons exist. The first horizon containing magnetite is also the oldest one and represents the liquid-magmatic segregation type of ore. The second horizon consists of Fe-quartzites and corresponds to SEDEX type of ore. It is characterized by hematitic and magnetitic subhorizons. The first and second horizons are bounded to the same volcanogenic-sedimentary formation. The third horizon containing hematite represents also SEDEX type of ore but is bounded to the younger, Carboniferous volcanogenic-sedimentary formation.

Ključne riječi: istočna Bosna, zapadna Srbija, Drina-Ivanjica formacija, neoproterozoik, paleozoik, ležišta željeza, starost i genetski tip

Sažetak

U radu je dat kritički osvrt na sve relevantne publicirane radove o stratigrafiji, tektonici, magmatizmu, metamorfizmu i metalogeniji metamorfnog kompleksa Drina-Ivanjica formacije u području istočne Bosne-zapadne Srbije. Posebna pažnja je usmjerena na sve neriješene ili dvojbene probleme u geologiji i metalogeniji tog područja. Osnovni dvojbeni geološki problem je pitanje da li Drina-Ivanjica formacija završava s filitoidnom Drina formacijom iz razdoblja gornjeg kambrija-donjeg karbona ili ispod nje diskordantno leži željezonosna vulkanogeno-sedimentna formacija iz donjeg kambrija-vendija. Detaljna analiza svih proučenih kaledonskih i kadomijskih metalogenija u Bosni i Hercegovini, zapadnoj Makedoniji i Srbiji, i njihova komparacija sa željeznim ležištima Drina formacija u znatnoj mjeri je rasvijetlila problem. U odnosu na dvojbene metalogenetske probleme, razmatran je broj rudnih horizonata, njihova starost, genetski tip i ekonomska vrijednost. To je dovelo do zaključka da postoje samo tri rudna horizonta. Prvi horizont koji sadrži magnetit je ujedno i najstariji i predstavlja likvidno-mgamatski segregacijski tip rude. Drugi horizont se sastoji od Fe-kvarcita i odgovara SEDEX tipu rude. Karakteriziran je hematitskim i magnetitskim subhorizontima. Prvi i drugi horizont su vezani za istu vulkanogenu-sedimentnu formaciju. Treći horizont koji sadrži hematit također predstavlja SEDEX tip rude ali je vezan na mlađu karbonsku vulkanogeno-sedimentnu formaciju.

Introduction

The Drina-Ivanjica Formation extends into the part of the Drina Basin from Vlasenica, Zvornik and Ljubovija in the north-east, across Bajina Bašta and Rogačica, Užice and Užička Požega in the central part, and in the south-east from the area of Arilje, Ivanjica, Novi Pazar to Mokra Gora (Fig. 1, Fig. 2, Fig. 3).

Its current name was first used by Dimitrijević (1974). The terrane boundary at the north-east and east toward the Vardar Zone (the Jadar Paleozoic) is the Zvornik suture, a system of westward oriented thrusts.

At the south-east, its boundary with the Ophiolite Belt is mostly covered by Triassic limestone olistoplaques. The north-west part of the terrane is covered by Eocene deposits according to Dimitrijević (in Karamata et al., 1994). The geologic synthesis of the Drina-Ivanjica Formation was made by Đoković (1985), the petrology of low-metamorphosed rocks by Milovanović (1984), and the metallogeny of iron ores by Popović (1984).

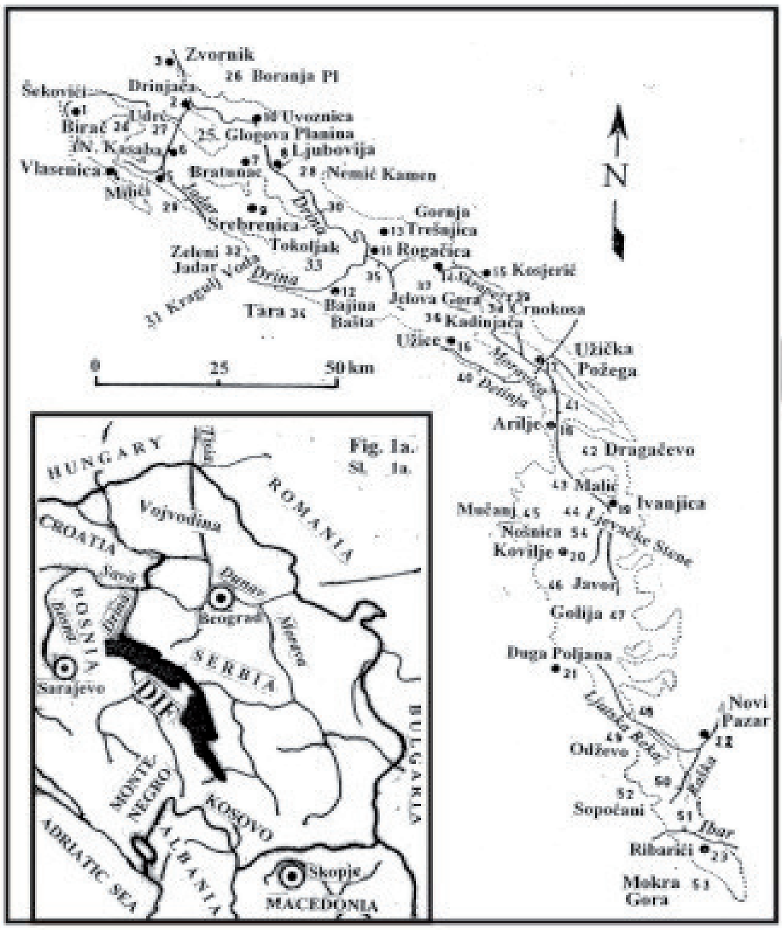

Fig. 1 Toponymic sketch of the Drina-Ivanjica Formation (modified after Đoković, 1985).

Sl. 1. Toponomska skica Drina-Ivanjica formacije (modificirano prema Đoković, 1985).

Figure 1a Geographic situation of the Drina-Ivanjica Formation (DIF).

Slika 1a. Geografski položaj Drina-Ivanjica formacije.

In Mojsisowics et al. (1880) E. Tietze provided the first account and classification of the Paleozoic of Eastern Bosnia. Žujović (1893) was the first to identify Paleozoic in the area of Dragačevo, western Serbia.

A significant contribution to the understanding of the Paleozoic of Eastern Bosnia was made by Katzer (1924). Katzer suggested Permian age for limestones and Carboniferous age for all other rocks. He claimed that there are not magmatic rocks of Paleozoic age in Eastern Bosnia.

Katzer's (1924) assumption about the Carboniferous-Permian age of the Paleozoic had also been accepted by Serbian geologists until Ercegovac (1975) discovered palynomorphs (acritarch) from Cambrian, Ordovician and Silurian in the deepest parts of the Drina Formation at Crvice, Okletac, Varda, and Kostojevići.

The more significant publications between Wold War I and II are those written by Simić (1933, 1934, 1934a, 1935, 1938). Studying the Drina-Ivanjica Formation and the Jadar Formation he identified very clear differences between those two Paleozoic complexes. Milovanović (1934) found Paleozoic rocks in the Vardište region and a large antiform in Mt. Jelova Gora.

After the Second World War, the exploration of the Drina-Ivanjica Formation was intensified. Podubsky (1979) established the following rock series: a) the oldest one, of presumed Lower Paleozoic age (no fossils), consists of metasandstones and phyllite shales (thickness is unknown); b) the Lower Carboniferous (C_1) one, being verified by conodonts, 200 m thick, composed of graphitic shales, phyllitic shales and phyllites with local layers of metasandstones and carbonate rocks; and c) the Middle Carboniferous (C_2) one, documented by macro- and micro-fauna, 400 m thick, composed of metasandstones of subgraywacke and graywacke type with subordinate layers of shales, limestone and dolomite, rarer ankerite. In the uppermost part, there are interstratified magmatic rocks, brecciated and conglomeratic sandstones. The fourth series belongs to Permian, consisting of quartz-sandstones and reddish shales (no findings of fossils).

The Paleozoic complex of Eastern Bosnia is regionally metamorphosed, mostly as greenschist facies, less frequently as semimetamorphic rocks, and as epidote-amphibolite facies.

In the post-war period basic geological maps (1: 100,000) were made covering the Drina-Ivanjica Formation on both banks of the Drina. Lithostratigraphic units of "green rocks" (volcanogenic-sedimentary formation), clastic and carbonate rocks unit and the Drina anticlinorium have been singled out from maps.

Dimitrijević (1974) examined geotectonic positions of the Drina-Ivanjica Element, Jadar Block, Bukulja Paleozoic and Studenica Series. He believed that the Bukulja Paleozoic Formation (BF) and the Jadar Block Formation (JF) belonged to the extreme Vardar Subzone, and that the Drina-Ivanjica Formation (DIF) belonged to a separate geotectonic unit. The Paleozoic of the Studenica Series (SS) is considered as a tectonic plate between DIF and the Kopaonik Block.

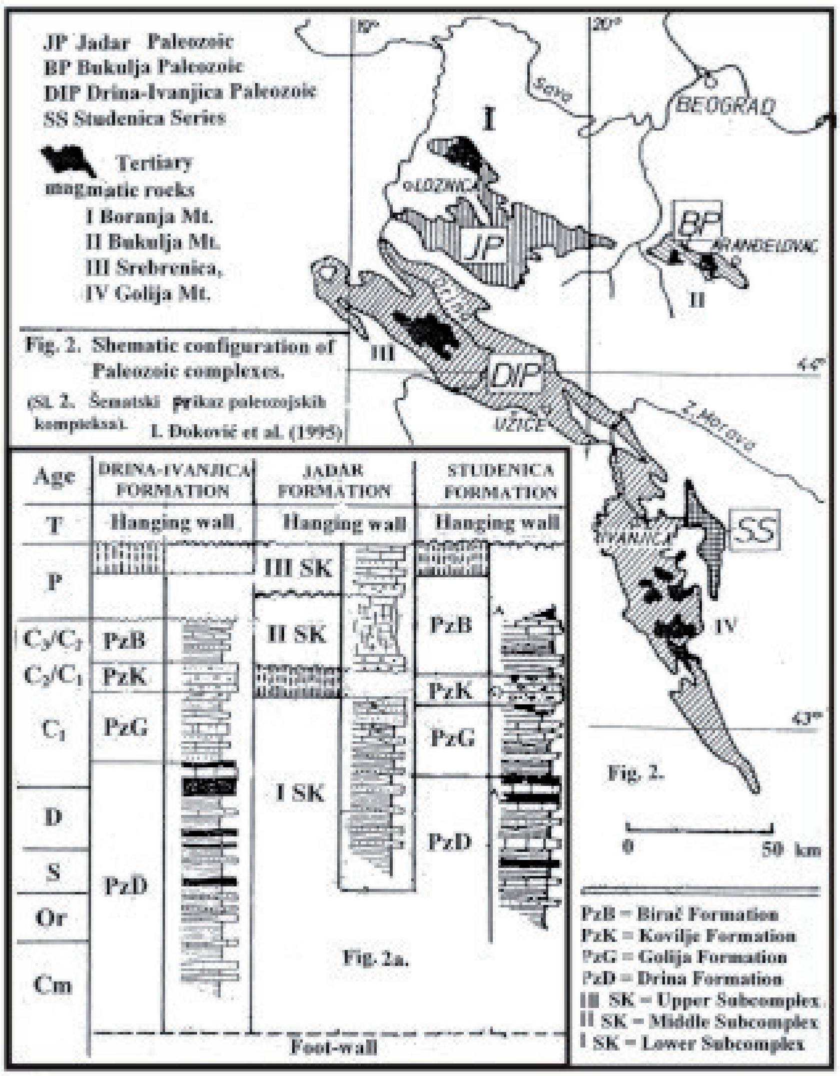

Figure 2 Shematic configuration of Paleozoic complexes (Đoković et al., 1995).

Slika 2. Shematski prikaz paleozojskih kompleksa (Đoković i dr., 1995).

Figure 2a Correlation shema of the Drina-Ivanjica, Jadar and Studenica series Paleozoic Formations (modified after Đoković & Pešić, 1985; Đoković, 1990).

Slika 2a. Korelacija između Drina-Ivanjica, Jadar i Studenica paleozojskih formacija (modificirano prema Đoković & Pešić, 1985; Đoković, 1990).

The best developed study of the geology and tectonics of the Drina-Ivanjica Formation in the territory of western Serbia was written by Đoković (1985). This formation, extending NW-SE, consists of a 3 km thick succession of low metamorphosed sedimentary and magmatic rocks, divided into four units formed from Upper Cambrian to Upper Carboniferous.

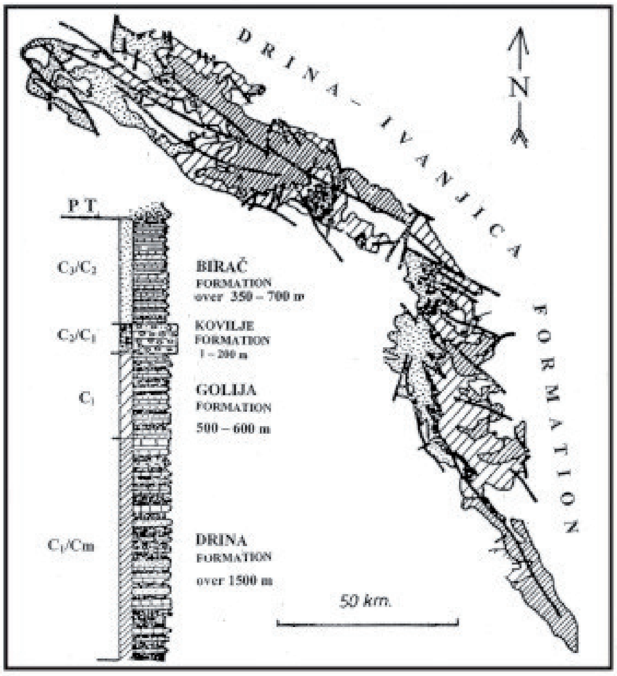

Figure 3 Geological shematic map of the Drina-Ivanjica Formation (Đoković, 1985).

Slika 3. Shematska geološka karta Drina-Ivanjica formacije (Đoković, 1985).

Geology of the Drina-Ivanjica Formation

According to Popović (1984) there are two large lithological formations in the Drina-Ivanjica Formation: an older volcanogenic-sedimentary formation of Upper Proterozoic age, and a younger, phyllitoid formation of Cambrian to Carboniferous age, both characterized by iron ore horizons. Popović established angle discordance between the metamorphic volcanogenic-sedimentary formation and the phyllitoid formation, as well as differences in the degree of metamorphism and differences in the position of folds between those two formations. Additionally he recognized two sterile formations: a formation of metaconglomerates which is Carboniferous, and a formation of metasandstones with traces of coal which is Permo-Carboniferous in age.

Drina Formation (DF) (more then 1 km). According to Đoković (1985) the Drina Formation is the lowermost and the oldest member in the Drina-Ivanjica Formation (Fig. 3). Its thickness is estimated at over 1 km. It is characterized by polyphase folding during the Variscan and Alpine orogenies. Several generations of folds are distinguished, with axes that are congruent or partly at the right angle. The Variscan orogeny produced anticlinal and synclinal features, while the Alpine orogeny produced a long antiform parallel with the Drina-Ivanjica Paleozoic belt.

The deepest part of the Drina Formation (600-700 m thick) is exposed in the Drina, Derventa and Rogačica valleys (Crvica, Okletac, Kostojevići). It consists of arenitic-silty and pelitic rocks, lenses or discontinuous m-dm sets of arenitic, silty-argillaceous or carbonate rocks. Less common are thin interbeds or lenses of conglomerates, tuffaceous arenites and diabases.

The upper part of the Drina Formation levels (300 m thick) appears in the Drina, Rogačica, and Seča Reka valleys, as well as in Mts. Crnokosa and Golija. It consists of arenitic-silty rocks but, unlike the lower levels, it includes sets of bedded limestones (10-30 m thick), diabase tuffs (30-60 m thick), several meters thick diabase and gabbro-diabase, and on the top, locally ferrugineous sediments.

The phytoplancton remains of the acritarch group and primitive spores, found in the dark-gray limestones (Crvica, the Drina valley) indicated Cambrian-Ordovician age. North of Varda, in the limestones of Veliko Brdo, the remains of poorly preserved spores and acritarchs are Ordovician-Silurian in age. Ercegovac (1975) found an association indicating Silurian-Devonian age in several localities of the Rogačica river valley and in the Derventa stream valley near Kostojevići in recrystallized limestones of intermediate Drina Formation levels.

Carboniferous conodont fauna (Visean-Namurian) is found in the dark-gray low marbleized limestones in the area of Tmuša, Skrapež, Tvrdići and Kalenić (Pajić, 1963) as shown in Fig. 1 and 5. Đoković (1985) suggested that the sediments (without fossils) between Devonian-Silurian are Devonian and Tournaisian in age. Other important paleontological papers were published by Spasov et al. (1967), Spasov et al. (1968) and Veselinović et al., (1990).

Golija Formation (500-600 m thick). The Golija Formation, being 500-600 m thick, lies conformably on the Drina Formation and is overlain with Kovilje Formation (Fig. 3). Two levels are clearly distinguished: the lower one, composed of arenites and siltstones with associated thin interbeds or lenses of dark-gray limestones, and the upper one, consisting of the same rocks and thin-bedded chert in Jelova Gora, Dragačevo and Levačke Stene.

Visean and Namurian conodont fauna was found at Pakošnica and Jeknići (Mt. Golija) and in Dragačevo (Stojanović & Pejić, 1966-1971). The Namurian stage is indicated by conodont fauna found in Tvrdići and Skrapež valleys, Pjesak and in Kopljača (eastern Bosnia).

Kovilje Formation (2-200 m). This formation is composed of conglomerates and sandstones forming a narrow zone (2-200 m thick) exposed west and southwest of the Drina-Ivanjica Formation. It exhibits a variety of lithology and thickness. Kovilje conglomerates in both, lower and upper parts, are identical in composition. These are polymictic rocks, composed of well-rounded pebbles (2-10 cm) of quartz, chert, quartzite and lydite.

Kovilje Conglomerates are covered with limestones containing conodont fauna of Lower Carboniferous. South of Tvrdići, conglomerates were formed in Late Lower and Early Middle Carboniferous, and in Eastern Bosnia (at Kopljača) in Middle Carboniferous.

Birač Formation (300 m – 700 m). The Birač Formation (300 m thick at Ivanjica and 700 m in the Drina blocks) lies over the Kovilje Formation and under transgressive Permian-Triassic and Jurassic rocks. It is composed of arenites, siltstones, shales, rare limestones and quartz-sandstones with preserved sedimentary flysch features. Conodont fauna confirmed Lower / Middle Carboniferous age (Stojanović & Pejić, 1967) in western Serbia (Klik, Beli Kamen, Bratljevo, Đokovići – Ivanjica region) and in eastern Bosnia (Kravica in the Rijeka valley, Drina region). Upper Baskhirian – Lower Moskovian age is proposed by Kubat (1974).

Metamorphism in the Drina-Ivanjica Formation (DIF)

Metamorphism and tectonization were studied by Dimitrijević (1974), Karamata (1976), Đoković (1985), Milovanović (1984), Đoković et al (1996). According to Đoković (1985), the south-eastern part of the Drina-Ivanjica Formation is older than its north-western part. This author singled out three metamorphosed zones in the DIF. The first zone, characterized by great amount of albite porphyroblasts, is exposed along the eastern margin of Ivanjica and in axial part of the Drina block. The second zone (without albite porphyroblasts) is situated west of the first zone in Ivanjica and southwest and northeast Drina blocks. The third zone is located in the western area of the Drina and Ivanjica blocks (the Birač Formation). The rocks of the DIF suffered a strong deformational phase between the Middle Carboniferous and the Middle Permian (Karamata and Krstić, 1996).

Regional metamorphism of diabase, gabbro-diabase and their tuffs produced greenschists. In median metamorphosed parts, these are chlorite-actinolite and epidote-actinolite schists, then metadiabase, and metaspillite. In the highest metamorphic zones, rocks have increased albite and grade into albite-chlorite-actinolite schists. Subduction of the Drina-Ivanjica Formation resulted in the metamorphism characterized by low temperatures and high pressure.

The oldest metamorphism is Variscan. It developed in Upper Carboniferous (C_3) and Lower Permian (P_1), and it is of regional character. During the Sudetic orogeny all formations were folded into a system of isoclinical folds (NW-SE) and refolded during the Alpine orogeny into NW-SE striking folds.

In Jurassic (J) and Lower Cretaceous (K_1), according to Milovanović (1984), the Paleozoic block docked on the SW borders of the Vardar Zone. Reforming semimetamorphita reactivated the Variscan axial planes, forming a zonal intensity pattern of schistosity which traced the route for thermal flux and development of zonal metamorphism.

The Oligocene-Miocene intrusions of granodiorites and dacito-andesites in Mt. Golija formed a contact aureole in which regional metamorphosed rocks of the DIF were converted into skarns and schists of amphibole-hornfels facies. Green rocks graded into amphibolite, and marble into skarn, and Paleozoic rocks near acid magmatic rocks were subject of hydrothermal alteration.

Other interesting works regarding palinspastic feature of the sedimentary area of the Drina-Ivanjica Formation were written by Đoković (1989, 1989a) and Đoković et al. (1995). Relations between tectonization and metamorphism in the Paleozoic of western Serbia were studied by Đoković et al. (1996). All this authors believed that relative to the spatial distribution of the Drina-Ivanjica formations and their sedimentologic characteristics, the formations must have developed in an NW-SE elongated basin.

Basic characteristics of other Paleozoic complexes

The Paleozoic of western Serbia and Šumadija is dispersed into several separate blocks. They have the form of large domes or the antiforms formed during the Alpine orogeny (Fig. 2).

Considering the palinspastic features of low-grade metamorphic rocks Đoković et al. (1995) concluded that the Drina-Ivanjica Formation, the Bukulja Paleozoic and the Studenica Series had very similar lithostratigraphic features, which is an evidence of identical basin space. On the other side the Jadar Formation shows significant differences pointing to a different basin space or at least to the margins of the DIF basin.

Đoković (1989) determined that the Paleozoic of the Drina-Ivanjica Formation had a trough-like shape of NE-SW elongation. By backward rotation of the Ivanjica Block, the basin width of 1000 km and length of 1500 km were determinated.

Bukulja Paleozoic (BP) is situated in Šumadija, around 100 km north-east of the Drina-Ivanjica Formation (Fig. 2). It consists of low-grade metamorphic clastic rocks that correspond to middle and upper levels of the Drina-Ivanjica Formation, partly equivalent to the middle and upper levels of the Golija Formation.

Studenica Series Paleozoic (SS) is located in the Studenica river basin, east of the town of Ivanjica. The

Paleozoic of this series without fossils consists of meta-arenites, siltstones, carbonate rocks and basic volcanics, regionally metamorphosed into greenschists. The crystallinity of these rocks is relatively high (Đoković, 1990). The Series is composed of 4 large lithostratigraphic units that correspond by composition and superposition to the Drina-Ivanjica Formation in the area of Mt. Jelova Gora (Fig. 2a). According to Janković (1990) the Studenica Series metamorphic complex is of Upper Jurassic age and this opinion is supported also in this paper.

Jadar Paleozoic (JP) and Ub Paleozoic complexes are located west of the Bukulja Paleozoic and north of the Drina Block (Fig. 2). The Jadar Block was first mentioned by Dimitrijević (1974; 1992), who considered it as a part of the Vardar Zone. Karamata et al. (1994) singled it out as a terrane pushed into the Vardar Zone composite terrane in Upper Cretaceous.

The stratigraphy and paleontology of Jadar and Ub Blocks were studied by Simić (1938), Spasov and Stevanović (1962), Filipović (1974), Filipović et al. (1993); Đoković and Pešić (1985) and many others.

According to Đoković & Pešić (1985), the Jadar Formation consists of three large transgressive subcomplexes. The oldest one is made of arenite and alevrolite with some carbonate rocks that are formed in the range from Middle Devonian (D_2) to and including Middle Carboniferous (C_2). The second subcomplex lying transgressively and is olistrome unit containing sandstones-alevrolites formed between Middle Carboniferous (C_2) and Middle Permian (P_2). The highest subcomplex consists of transgressive arenito-alevrolites with carbonates from Middle Permian (P_2) to Upper Permian (P_3).

In the Jadar Formation Filipović et al. (1993) differentiate between four structural-facial units with different lithostratigraphic development: (1) the Krupanj Unit, (2) the Likodra Unit, (3) the Vlašić Unit, and (4) the Slovec Unit.

Ore deposits in the Drina-Ivanjica Formation

Introduction

All iron (± manganese) ore occurrences and deposits of the Drina-Ivanjica Formation are located exclusively in the middle part of the Drina Block and, moreover, only in the Drina Formation. The Golija Formation, Kovilje Formation and the Birač Formation are sterile. Mineralization is largely limited to the rocks of the central axis of the Mt. Jelova Gora antiform, and to an irrelevant degree (Karan and Duboko occurrences) to the NE and SW wings of this antiform (Fig. 5). The zone of mineralization is 25-30 km long, 1-2 km wide (30 km^2), striking WNW-ESE. It extends from Srebrenica, Močevići, Brezovica, Krnjići, Tokoljak and Gradina in eastern Bosnia, continuing across the Drina river, to Bajina Bašta, the village of Višesava, Kik, Mt. Višesava, Lazića Potok Brook, the village of Lazići, Kamenjača and Blagojevići in western Serbia (Fig. 4; Fig. 4a, Fig. 5 and Fig. 6).

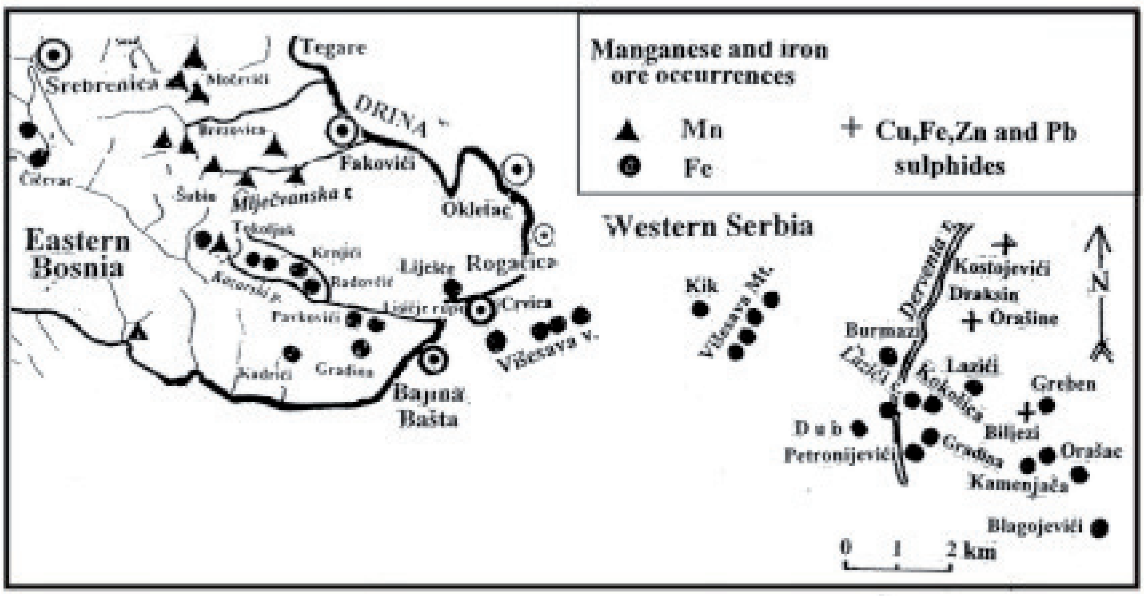

Figure 4 Manganese and iron ore occurrences in the Drina-Ivanjica Formation (Estern Bosnia – Western Bosnia)

Slika 4. Manganske i željezne rudne pojave u Drina-Ivanjica formaciji (Istočna Bosna – Zapadna Srbija).

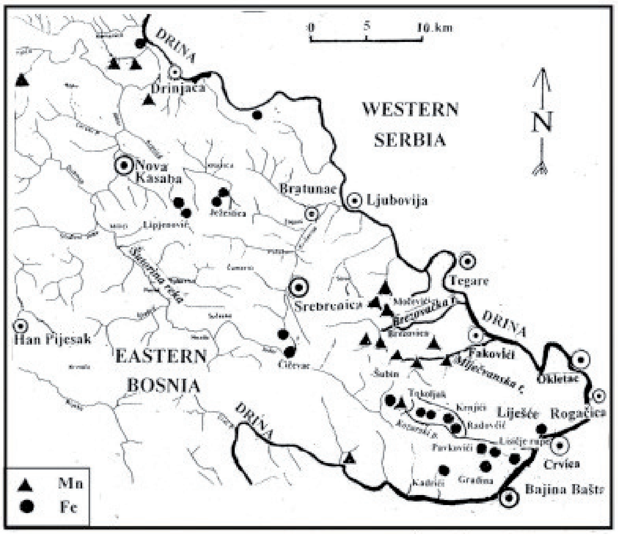

Figure 4a Manganese and iron ore occurrences in the Paleozoic metamorphic complex, Eastern Bosnia (Kubat, 1969, 1974, 1979; Popović & Tomičević, 1990).

Slika 4a. Magmatske i željezne rudne pojave u paleozojskom metamorfnom kompleksu, Istočna Bosna (Kubat, 1969, 1974, 1979; Popović & Tomičević, 1990).

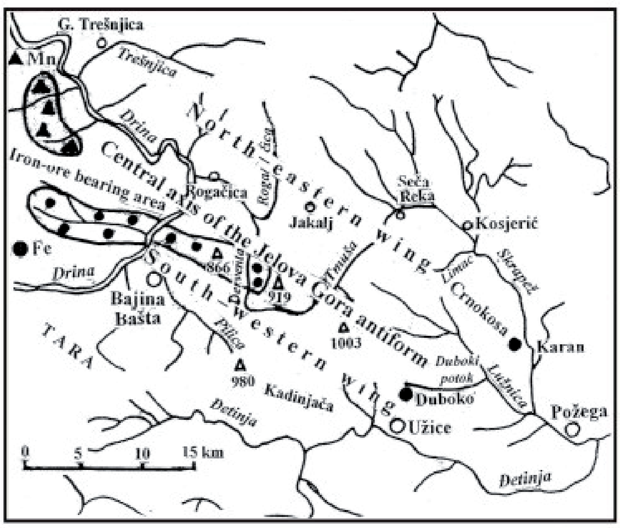

Figure 5 Position of the Jelova Gora antiform (supplemented after Đoković, 1975)

Slika 5. Položaj antiforme Jelove Gore.

In the mineralized belt, erosion and tectonic disturbances revealed the deepest layers of the Drina Formation. According to Đoković (1985), these are Upper Cambrian-Ordovician deposits, and according to Popović (1984), it is a Vendian-Lower Cambrian volcanogenic-sedimentary formation lying in a discordant position to the Drina Formation. These two authors also differ in their interpretation of intensity of mineralization in certain lithostratigraphic units. Đoković favours Carboniferous deposits (localities Karan, Ćatića Vis), and Popović Neo-Proterozoic hematite deposits (Horizon II) and the iron-quartzites with magnetite (Horizons III and IV). The claims of Popović, who had for years planned and managed iron ore explorations, first in western Serbia and later in eastern Bosnia (Popović, 1984; Popović and Tomičević, 1990), are more credible.

Popović (1984) was the first to make a classification of iron deposits in the Drina-Ivanjica Formation. His classification was accepted also by Janković (1990) in his monograph "Ore Deposits of Serbia."

All iron ore horizons, according to Popović, are 5 m thick, containing cca 75 million tons of iron metal. In his monograph Janković (1990) estimates that iron deposits of the Drina-Ivanjica Formation have no commercial value. The author of this paper is of the same opinion.

According to Popović, all non-commercial younger small Fe, Cu, Pb, Zn hydrothermal occurrences, such as Orašine, Biljezi, and Orašac, as well as the occurrences of the mineral skarn, are genetically bounded to the Tertiary hidden acid pluton.

I Ore deposits in eastern Bosnia

I/1 Manganese ore occurrences

A dozen smaller and larger *manganese occurrences* were discovered in 1966 in a location 11 km SE of Bratunac, and explored in 1967-68 (Kubat and Reljić, 1964; Kubat, 1969; 1974, 1977, 1979; Kubat et al., 1968). The most important localities are **Močevići** and **Brezovica**, while **Šubin** and **Pismulići** are of lesser importance (Fig. 4, 4a). These deposits are situated in the Carboniferous phyllitic schists, schistose metasandstones with rare lenses of schistose iron-quartzites (Kubat, 1969). In the footwall, these are clays, graphitic and sericitic schists with intercalations of platy limestones with calcitic veinlets ($^{1}C_{1-2}$). In the hanging wall, there are coarsegrained metasandstones and conglomerates ($^{2}C_{1-2}$). Genetically they are linked to diabase-gabbroid magma (diabases, spillites, tuffs, locally lydites). Magmatites (10-30 m thick packages) are interstratified into the Paleozoic sediments of rivers Mlječanska Reka, Šutorinska Reka and Zapoljska Reka, as well as in the hills of Karan and Kamenica near Drinjača. **Manganese ore bodies** are situated: 1) **on the outskirts of the village of Brezovica,** with ore outcrops that are 250 m long and 0.6-2 m thick; 2) **near the spring in the village of Brezovica,** with an ore outcrop being 10 m long and 0.8m thick and containing *30 % Mn, 70 %* SiO_2; 3) **in the brook above the village of Brezovica** with an ore outcrop that is 6 m long and 0.4-0.6 m thick; 4) **in the village of Močevići**, approximately 1.5 km SE of Brezovica, with ore outcrops of 1-2 m thickness being investigated in the length of 200 m and having reserves of 50.000 t of C-category. On the surface, the ore is brecciated but in the depths, it is schistose, and compact. It contains 5-18% of *Mn* (locally up to 35%) with less than 3% of *Fe*.

The manganese ore bodies are elongated and irregular, concordant with the schistosity of the surrounding rocks (metasandstones). The syngenetic mineralization takes the form of jets, bands and incrustations parallel to the schistosity, whereas the postore generation occurs in younger fissures. Paragenesis consists of *pyrolusite, psilomelane, romaneshite, hausmannite, manganite,* and *limonite.*

I/2 Iron ore occurrences

Iron ore occurrences were discovered in 1967 in the area of the villages **Krnjići** – **Tokoljak** – **Lipjenovići** (Kubat et al., 1968, Kubat 1969, Kubat, 1974, 1977, 1979) in the same geological environment as the Mn occurrences. The ore occurrences have the thickness ranging from 0.1 to 0.6 m (Fig. 5a).

The ore outcrops are the most numerous around Krnjići village. The most important is the outcrop being situated **200m east of the church** in metasandstones and phyllites with a footwall of greenschists and marbles. The ore beds and lenses (a few cm to 0.8m) are concordant with the schistosity of the rocks. They occur in a 20m thick package. Paragenesis includes *magnetite*, *martite*, *hematite*, *specularite*, *siderite*, and in the younger phase veinlets and stockworks of *quartz* with *chalcopyrite* and *marcasite*. The gangue consists of *quartz*, *calcite*, *ankerite* and *chlorite*. As far as secondary minerals are concerned, *maghemite*, *goethite*, *hydrogoethite*, *neodigenite*, *chalcocite*, *elemental copper*, *malachite*, *chrysocola*, *pyrolusite*, *manganite* and *romanechite* were identified. There are two structural ore types: (a) densely packed *magnetite idioblasts* in SiO_2-Fe_2O_3 schists, in SiO_2-carbonate schists and in SiO_2-mica-chloritic schists and (b) yonger *SiO_2-$CuFeS_2$ veinlets*, in recrystallized quartz-carbonate rocks. Type a) contains 25-35 % *Fe* (rarely 40%), 25-55 % *SiO_2* and <1 % *Mn*.

SW of Krnjići village, near the villages of **Podrid** and **Tokoljak**, the ore outcrops are scarcer and predominantly *Mn-sandstones* and *Fe_2O_3 schists*. Six outcrops were discovered.

Further mining and geological investigations were carried out in 1988 (Popović & Tomičević, 1990) on the basis of aeromagnetic investigations and geophysical measurements in the NW extension of the western Serbia ore zone (Vukašinović, 1977, Popović & Vukašinović, 1978). Two stratigraphic horizons were identified, the older one with *specularite* and *magnetite*, and the younger one with *magnetite* (**Gradina**). The ore consists of 10-40% *Fe*, 60-90% *SiO_2* and less then 5% of all other constituents.

The following localities were explored: 1) **Tokoljak village**; 2) **Kamenjača**, **0.5 km east of Tokoljak**; 3) **Krnjići village**; 4) **Radovčići**; 5) **Pavkovići**; 6) **Lisičje rupe**; 7) **Liješće**; 8) **Gradina ridge**; 9) **Podševar**; 10) **Kadrići** (Popović and Tomičević, 1990) (Fig. 4a).

Tokoljak-Krnjići-Radovčići are the northernmost iron ore occurrences (Fig. 5a). Mineralization occurs in the greenschists at the contact with the calcschists of hanging wall. The ore is 0.1 to 2 m thick. The main gangue mineral is *quartz*, the most important ore mineral is *specularite*, while *magnetite* is subordinate. Other constituents are *martite, ilmenite*, *calcite, chlorite* as secondary minerals.

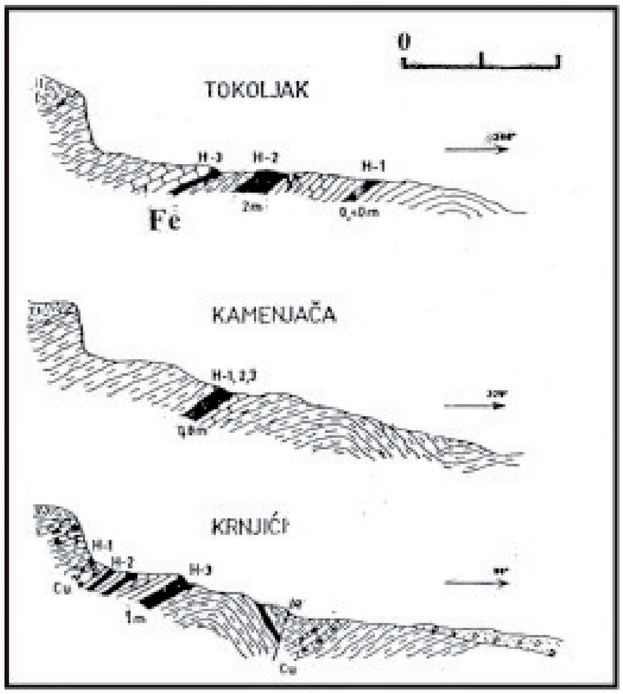

Figure 5a Profiles of the iron ore deposits Tokoljak, Kamenjača and Krnjići in East Bosnia (Kubat, 1969).

Slika 5a. Profili željeznih ležišta u Tokoljaku, Kamenjači i Krnjićima u Istočnoj Bosni (Kubat, 1969).

Pavkovići – Lisičje rupe – Liješće, occurrences are 0.5 to 1 m thick.

Paragenesis: *quartz* and *specularite* with subordinate *magnetite*. The mass of finegrained *quartz* was formed from the cherts displaying the relicts of oval forms. The grains of specularite have diameters of 70-200 μm; larger grains are rare. Also visible are younger *quartz* veinlets with *specularite* of >0.5 cm^2 surfaces (Fig. 5b, 5c).

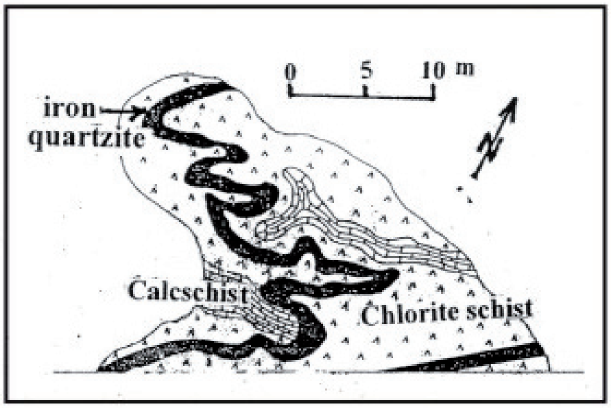

Figure 5b Geological profile of the iron quartzite in the Liješće locality, Eastern Bosnia (Popović & Tomičević, 1990).

Slika 5b. Geološki profil željeznog kvarcita u Liješću, Istočna Bosna (Popović i Tomičević, 1990).

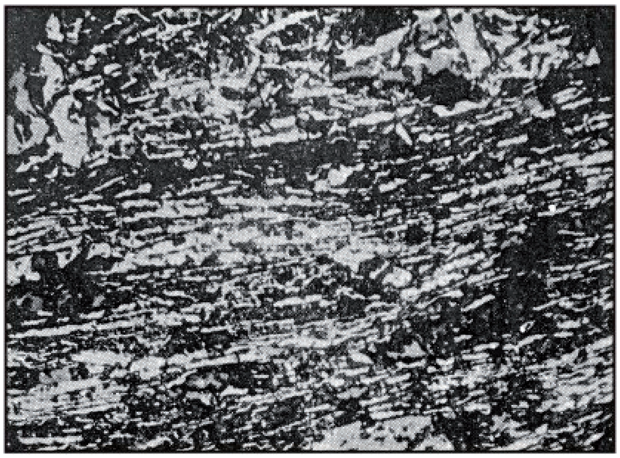

Figure 5c Specularite bands (light) and larger magnetite grains (grey) replace rock (black), Petronijevići village (Popović, 1984).

Slika 5c. Igličasti spekularit i krupnije zrnati magnetit (sivo) potiskuju stijenu (crno), selo Petronijevići (Popović, 1984).

Kadrići. This locality is situated west of Gradina, lying on the multiple aeromagnetic anomaly (Vukašinović, 1977). Old mining works have been found, they were discovered in 1988. The ore is banded, 0.6 m thick. The most abundant mineral is *quartz*. *Specularite* is more abundant ore mineral than *magnetite*.

Gradina. Gradina iron quartzites, near **the village of Dvizovići.** Outcrops occur along 1 km from the slopes on the left bank of the Drina river, across Malta to Gradina.

It is the most important iron ore occurrence in eastern Bosnia. The aeromagnetic anomaly has a surface of 2 km^2, extending further in east and southeast directions. The ore deposit is more than 2 m thick. The main minerals are *quartz* and *magnetite* (with a grain diameter of 25-100 μm), *hematite* is very scarce. *Magnetite* is very unevenly distributed in *Fe-quartzite* ranging from dispersions up to 50% volume. The ore is either massive or banded (*jaspilites*?) with bands of 1-5 mm (5d). In the immediate vicinity, there are *metajaspilites* with *magnetite* and marbleized limestones. In cherts, there are *dusty magnetite* and *hematite* (<20 μm). *Magnetite* and *hematite* in the *Fe-quartzite* have grains >100 μm. Younger hematite with grains >200 μm occur across the surfaces of schistosity or as veinlets of 0.3-1 mm. *Martitization* is uneven. Accessories are *biotite*, *hydromica*, *calcite*, *chlorite*, *muscovite*, *sericite*, *coisite*, *actinolite* ± *garnet* and *albite*. Subsequent hydrothermal activity is locally identified.

In *Gradina*, chlorite schists contain *glaucophane* and *ilmenite* (>3 % TiO_2) in the form of *neoilmenite* (veinlets of 1-2mm thickness).

I/3 Other mineral occurrences in the metamorphic complex of the Drina-Ivanjica Formation, eastern Bosnia

1) ***Roofing schists.*** In the Drina valley, outcrops of *roofing schists* (Middle Carboniferous (C_2) finebedded, platy alevrolites and alevrolitic sandstones) were found near the villages of **Voljevica**, **Brezak**, **Vranješevići**, **Abdulići**, **Fakovići** and **Skelani** (Kubat, 1969, 1974, 1979; and Kubat et al., 1968). They have been technologically tested and they are suitable for lining, insulation, and for correction or roofing works.

2) ***Quartzites and quartz-sandstones***. SW of the town of **Srebrenica**, there are *riffs* of *quartzite* and *quartz sandstones* on **Škorac** and **Rid hills** above **Podrid**.

3) ***Phosphorite occurrences.*** Janković (1990) mentions *phosphorite* occurrences in the area of **Ljubovija.**

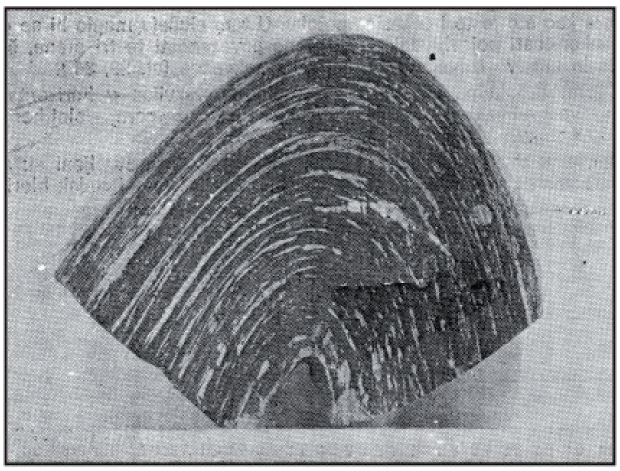

Figure 5d Folded, banded quartz (white)-magnetite (dark-gray) ore on the road Kokošica-Lazići village. Size 1:1. (Popović, 1984).

Slika 5d. Uborana trakasta kvarc (bijelo)-magnetitna (tamnosivo) ruda na putu Kokošica-Lazići. Veličina 1:1. (Popović, 1984).

II. Iron ore occurrences in the metamorphic complex of Drina-Ivanjica, western Serbia

Old mining works from the pre-1940 period, aimed at exploration of iron quartzites, were found on **Kamenjača** and on **Mt. Gradina**. Exploration of *copper ores* in **Orašine**, the village of Draksin, started in 1940 by mining works (an adit 50 m long), which were terminated due to poor results. The ore consisted of *pyrite*, *chalcopyrite* and *galena* (Popović, 1984).

Marković & Protić (1954) report on *hematite occurrences* between **Madžarevac** brook and **Ćatića vis**, the hamlet of Lelići, near **Karan**. Those are the first written records on iron ores in the Drina metamorphic region. Nikolić (1968) investigated *copper ores* in the location of **Duboko**, 4 km north of Užice. Spasov & Miličić (1970) present the results of the prospecting for *copper occurrence* in **Orašine**. In 1967, aeromagnetic explorations were carried out on **Kamenjača** and **Mt. Višesava**, and in 1973, aeromagnetic anomalies were again registered on **Mt. Višesava**, in the anomalous zone Bajina Bašta – Užice – Požega (Vukašinović, 1975).

In 1975 and 1976, during the exploration of the area **Jelova Gora – Tara**, financed by the copper rolling mill from Sevojno, *iron quartzites* were discovered on **Kamenjača, Greben**, between **Kokošica** and **Lazići village**, in **Lazića potok brook**, as well as in **Petronijevići brook**. On **Mt. Višesava**, the observed aureole of dissipation of *iron quartzites* accounted for the aeromagnetic anomalies that were found (Vukašinović, 1975).

In the course of the five-year investigation of iron ores in Serbia (1976-1981), *new iron occurrences* were discovered in **Gradina** (eastern Bosnia), the villages of **Višesava, Kik, Burmazi, Petronijevići, Greben**, east of the village of Lazići, **Orašac,** and **Blagojevići** (Popović, 1984). Popović & Vukašinović (1978) are of the opinion that the iron quartzites and metaspilites from Mt. Gradina were the cause of aeromagnetic anomalies. Popović (1979) presented to the Serbian Geological Society (SGD) the data on *iron ores* between **Jelova Gora** and the **Drina river**. Đoković (1985) mentions the *iron ores* on **Ćatića vis** near **Karan** (Fig. 4; 6; 7).

Iron ore deposits were later written about by Popović (1978, 1981), Antonijević (1983), Popović (1984a, 1984b), Đoković (1985), Popović & Cvetić (1984), Milovanović (1984a), Popović (1986), Popović (1989), Popović (1990) Popović & Tomičević (1990), Janković (1990), Popović (1991), and Janković (1996).

The most detailed account of the iron ore occurrences in western Serbia was given by R. Popović (1984). He identified six mineralized stratigraphic horizons: four in the Neo-Proterozoic volcanogenic-sedimentary sequence, the fifth horizon in the Cambrian-Ordovician Caledonian epoch, and the sixth horizon in Carboniferous which was formed in the Variscan metallogenic epoch (Fig 7). In Post-Variscan, genetically linked to the Alpine metallogenic cycle, the occurrences of *Cu, Pb, Zn, Fe sulphides* were locally formed, as well as the occurrences of the *contact-metamorphic mineralizations*.

II/1 Main characteristics of iron ore horizons presented by Popović (1984)

Horizon I. The horizon contains the oldest discovered iron ore occurrences of western Serbia, formed, according to Popović, in the Baikalian metallogenic epoch. This horizon is most pronounced on the NE slopes of **Mt. Višesava**, less pronounced on the SW slopes of the same mountain, and even more poorly pronounced in the **village of Višesava** and in **Lazića potok brook**.

In the series of *chlorite schists* with accessory finegrained *magnetite*, locally enriched till some percents, packages of *Fe-chlorite schists with magnetite*, from 0.2 to >1 m thick, were observed. They are more compact, heavier and of even darker shade of green than the normal chlorite schists. The TiO_2 (*sphen*, *neoilmenite*) content is increased. In later stages (regional metamorphism, hydrothermal activity), *garnet*, *epidote*, *apatite*, *actinolite*, *alkalic amphibole* were formed. The other forms of iron ore occurrences are weaker or stronger (up to 14% *Fe*) *impregnations of magnetite*, with the size of grain from 5 to 70 μm. They are unevenly martitized. In addition to the impregnations, there are bands of *magnetite* and *quartzite*.

Horizon II with hematite (specularite). This horizon was discovered in **Lazića potok brook**, also on the northern slopes of **Mt. Gradina NE of the village of Petronijevići**, and as aureole of dissipation (ore blocks) in the **Ignjatovići,** on the southern slopes of the **Malić peak** (+780 m), 2 km east of Lazića potok brook. Mineralization occurs in *chlorite schists*, *Fe-chlorite schists*, *chlorite quartzites*, *Fe-quartzites* (most abundant) and in the *skarnized occurrences*.

In **Lazića potok brook**, in a 40 m thick package of chlorite schists (metamorphosed volcanogenic-sedimentary formation) there are 4 mineralised beds. The lower two thin beds (0.3 m and 0.2 m) consist of *Fe-chlorite*, the medium deposit (0.6 m) and the upper deposit (1.0 m) are made of *hematite* (*specularite*). The medium and the lowest ore beds are accompanied by white marble (0.5 and 0.3 m) in the hanging wall, and by chlorite schists in the footwall.

Mineralization is syngenetic, stratiform, while the ore and the gangue occur in alternating bands. The mineralization is the most abundant in *Fe-quartzites with hematite* and *some magnetite* (31.3-38.4% *Fe*, out of which 25% soluble). In the *Fe-chlorite schists*, the main ore mineral is *Fe-chlorite*, and in *chlorite quartzites*, the main mineral is *finegrained magnetite*.

Horizon III – Dark-gray quartzites with magnetite. This horizon was discovered in chlorite-actinolite schists on **Mt. Višesava** and in the villages of **Lazići, Višesava, Petronijevići** and **Dvizovići** (Fig. 6, Fig. 7). The occurrences consist of two beds. The older one is 0.60 m thick, consists of massive *dark-gray quartzite with magnetite*, in the footwall in which there is 0.30 m thick marble bed. The younger bed, which is situated at a distance of 15 m, consists of *banded iron-quartzite*, often strongly „boudiné.

Magnetite is the dominant ore mineral (fine-grained or even powdery), although chiefly recrystallized, coarse-grained (200 μm) and cataclased. Popović (1984) claims that the recrystallization was caused by a Tertiary thermal flux. The needle-shaped *specularite* is very subordinate constituent. Magnetite is partially martitized.

In the village of **Petronijevići**, then on the left bank of the **Derventa river**, near Lazića potok brook and in the outermost SE part of the village of **Burmazi**, a considerable number of dissipated ore blocks and fragments of iron ores have been found. On **Mt. Višesava**, and on the peak called **Kik**, only ore fragments (1 cm^3 – 0.25 m^3) have been found on the locations covered by high aeromagnetic anomalies (Popović & Vukašinović, 1978). This indicates the presence of an iron ore outcrop bellow the ore fragments.

The older ore horizon in the **village of Višesava** is represented by an *Fe-chlorite* bed (*chamosite* with 18-36% *Fe*) being 1 m thick. Krstanović identified *Fe-chlorite* (Popović, 1984) using RTG method. The Fe-chlorite is of the transitional type between *thuringite* and *bavalite*. It contains 26-30% Fe^{2+}. In the post-ore phase, thermal and hydrothermal activity caused an intensive recrystallization of Fe-chlorite into larger leafy crystals and the formation of neominerals including *tourmaline*, *rutile*, *epidote*, *ilmenite*, *sphen*, some *pyrite* (*marcasite*), *quartz*, and *calcite*.

Horizon IV – light-gray Fe-quartzites. According to Popović (1984) this is the youngest ore horizon of the volcanogenic-sedimentary Pre-Cambrian formation. It has been found on Mt. Kamenjača, on the Kamenjača-Orašac route and in the village of Blagojevići. Popović (1984) singled out this horizon as special because of its clearly expressed stratification and mineral content *quartz* (40-90%) and *magnetite* (10-60%). Beds are 1-3 m thick. They consist mainly of *Fe-quartzites*; only on Kamenjača an older *Fe-chlorite* bed has been found. Ore samples have been found only in the old mining works (shallow shafts, dumps, spoil heaps) on Mt. Kamenjača or as ore fragments on the Kamenjača-Orašac route and in Blagojevići village.

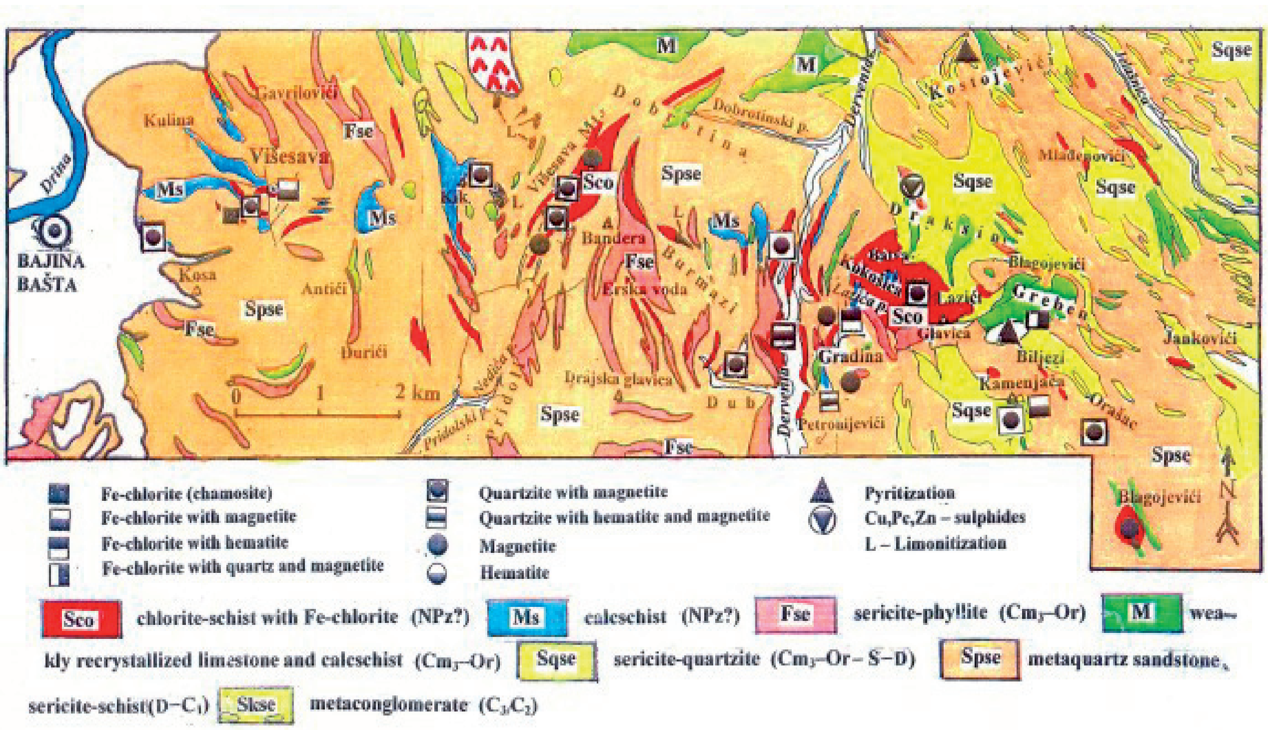

Figure 6 Iron ore occurrences in the Drina-Ivanjica Formation, Western Serbia (modified after Popović, 1984).

Slika 6. Željezne rudne pojave u Drina-Ivanjica formaciji, Zapadna Srbija (modificirano prema Popović, 1984).

The older ore horizon of *Fe-chlorite* with some *magnetite* and *pyrite* on **Mt. Kamenjača** contained 33.50% *Fe*, 33.65% SiO_2 and 0.06% *P*. The younger horizon of *Fe-quartzite* from the old mining works, which has a banded structure, contains primary *magnetite I*, *recrystallized* coarsegrained (up to 1 mm) *magnetite II* and *primary quartz I*, veinlets of *quartz II*, some *pyrite I* in the form of *mineralized bacteria*, *pyrite II*, *Fe-carbonate* and secondary *Mn-oxides*.

On the **Kamenjača-Orašac** route, only a secondary block of banded *Fe-quartzite* (20 x 20 x 2 m) has been found with 20.03% *Fe*, 69.22% SiO_2, 0.25% Al_2O_3, 0.16% *S*, 0.04% P_2O_5. Secondary *Mn-oxides* are also visible.

In the village of **Blagojevići**, *blocks of Fe-quartzite* interbedded by calcschists and intersected by veinlets of *quartz II* have been found. The ore has a banded structure.

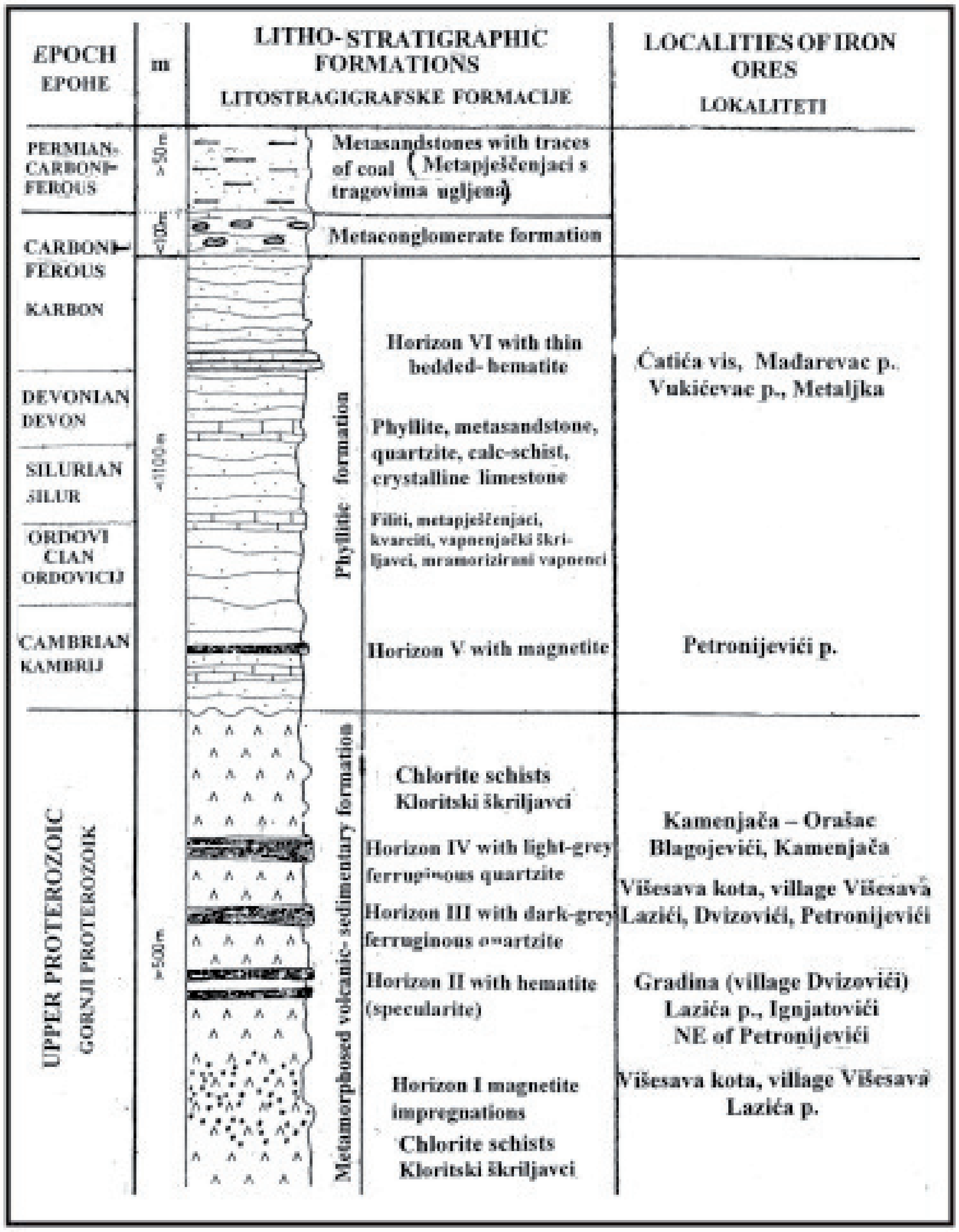

Figure 7 Geological column of the metamorphic complex of the Drina-Ivanjica Formation with iron ore horizons (modified after Popović, 1984).

Slika 7. Geološki stup metamorfnog kompleksa Drina-Ivanjica formacije s horizontima željeznih rudnih pojava (modificirano prema Popović, 1984).

II/2 Sulphidic ore occurrences in the Paleozoic metamorphic complex of western Serbia, genetically bounded to the Alpine Cycle

The post-Paleozoic ore occurrences bounded to the Alpine metallogenic epoch have been registered in **Orašine**, **Biljezi**, **Kostojevići** (the hamlet of **Porčići**), all in the Jelova Gora area, and in **Duboko**, 4 km NE of Užice (Popović, 1984) as shown in Fig. 5. and 6.

In 1940, *pyrite*, *chalcopyrite* and *galena copper ores* were investigated in **Orašine**, the village of **Draksin**. The mining works were nevertheless terminated due to poor results. Nikolić (1968) investigated copper ores at the location of **Duboko**, 4 km **NE of Užice**. Prospecting works were conducted at the same location by T. Spasov & M. Miličić (1970).

Orašine. In the *quartzites* of an old land-slide, three ore outcrops have been found at vertical intervals of 50 m. The uppermost main quartzite bed is 0.2 m thick and contains mostly the impregnations of *chalcopyrite* (2.8%, 1.7%, 1.6% *Cu*), very little *sphalerite* (0.012%, 0.400%, 0.082% *Zn*), *galena* (0.008%, 0.48%, 0.34% *Pb*) and traces of *gold* (0.02, 0.03, 0.02 g/t *Au*). As far as microelements are concerned, there is 7-31 ppm *Sn*, 130 *Bi*, a trace of *Ba*, 5-32 *Ni*, 2-22 *Co*, 12-14 *Cr*.

Kostojević (the village of Porčići). This occurrence is characterized by a strong silicification and weaker pyritization. The composition of microelements in ppm is: 60 *Pb*, 110 *Cu*, 7-19 *Mo*, 28 *Be*, 3.5 *Ag*, 210 *Ba*, 70 *Ni*, 65 *Co*, 23 *Cr*.

Biljezi. At this location, *quartz* and *pyrite* form nests and impregnations in the ratio of 1:1. An analysis of *pyrite* ore gave the following results: 480 ppm *Cu*, 90 *Zn*, 53 *Pb*, 0.02 *Au*.

Duboko. It is situated 4 km NE of the town of Užice. The ore occurrence consists of *Fe-oxides* and *pyrite*, *chalcopyrite*, *bornite*, and *tetrahedrite*. Popović (1984) is convinced that this ore occurrence is very similar to *skarns*.

I/3 Other ore occurrences in the metamorphic complex of the Drina-Ivanjica Formation

Published works have registered the following occurrences: 1) *graphitite* in the metasandstones of Orašine; 2) *mineralized marbles* in Orašine; 3) *glaucophane* and *neoilmenite* in the chalorite schists of the village of Višesava and in the vicinity of the village of Dvizovići; 4) *Mg-riebeckite* in the Tmuša – Kostojevići – Bajina Bašta area (formed at 350°C and under pressure of 2.5 to 4 kilobars, Milovanović, 1984); 5) *quartz-pyrite veins* near Ivanjica (Popović, 1991) with 0.11 g/t Au and 1.5 g/t Ag; 6) *calcitic marble* at the village of Kalenić and Bakionica (Fig. 5).

Laterite iron ores on Radočelo in the Studenica Series

In the lateritic crust in the **Perišinov potok brook**, the magnetite band is 4 m thick (Simić ,1954; and Popović & Kleut (1979). It consists of *magnetite* (48-50% *Fe*; 0.7-3.0% *Mn*), *martite*, *chromite* (2.5-3.6% Cr_2O_3), *pyrite* (0.1-0.45% *S*), 8-17% SiO_2, 0.7-0.9% *Ni*, 15-50 ppm *P*. The ore is of oolitic structure, oolits are predominantly made of petrogenic minerals, while the ore minerals are in their interspace.

Resedimented laterite ore has been found in the village of **Božići** on the left bank of the **river Reka** (Popović & Kleut, 1979; Janković, 1990). An ore band is located in the quartzchlorite schists and talcschists. The main mineral is *hematite* (10-15% of the total mass), then *magnetite* and very little *chromite* with 10-15% *Fe*, 44-65% SiO_2), 0.6-0.7% Cr_2O_3, 0.45-0.70% *Ni* and 33-60 ppm *P*.

Janković (1990) claimed that these ore deposits are of Jurasic or Paleozoic age, whereas author of this paper is of the opinion that they are formed in Upper Jurassic-Lower Cretaceous period.

Discussion and retrospection

The metamorphic complex of the Drina-Ivanjica Formation was studied by many authors. Nevertheless, a number of problems still remain unresolved. Some of the most important ones, as well as possible solutions are presented below.

1) The age of the deepest stratigraphic horizons in the Drina Block of the Drina-Ivanjica Formation

Micropaleontological results in the deepest discovered sedimentary rocks of the Drina Block carried out by Ercegovac (1975) led Đoković (1985) to conclusion of a continuous sedimentation ranging from Upper Cambrian to and including Lower Carboniferous. Popović (1984) presented his very bold hypothesis on the lowest horizons of the Drina Formation. In his view, underneath the layers of Upper Cambrian, in a discordant position caused by the Lower Cambrian orogenic phase, there is a Neo-Proterozoic volcanogenic-sedimentary formation. Popović's hypothesis is based on a) angle discordance between the Upper Cambrian sediments and the volcanogenic-sedimentary formation formed due to the orogenesis and lifting in Lower Cambrian. The B-axis of the oldest folds found in the Fe-quartzites of the iron ore horizons II and III strike E-W with the inclination of 45° towards west. The younger folds found in the phyllitoid formation strike NE-SW and N-S; b) in different metamorphic grade between both formations; c) on existence of numerous similar little iron ore beds in the Baikalian volcanogenic-sedimentary formation in Zagrebačka gora (Mt. Medvednica, Croatia), in Beljanica (Kučaj, eastern Serbia), Vlasina area (south-eastern Serbia) and in the Čar Sedlar-Žitni Potok area (Serbo-Macedonian Mass).

2) Difference in interpretation of the stratigraphic position of ore horizons between eastern Bosnia and western Serbia

Kubat (1969, 1974, 1979) considered the Mn-ores of Brezovica and Močevići and the Fe-ores of Krnjići and Tokoljak in eastern Bosnia to be stratified between Lower and Middle Carboniferous. At the time, the discovery of Lower Paleozoic in western Bosnia had not been known. Kubat linked the Fe-Mn occurrences to the Sudetic orogenic phase.

After the discovery and examination of a series of new Fe-occurrences SE of Krnjić-Tokoljak (Fig. 4), and particularly the Fe-quartzites at Gradina, Popović and Tomičević (1990) concluded that these were the deposits of Horizon II (mostly) and Horizon III or IV (Gradina), i.e. the deposits of the Baikalian Upper-Proterozoic metallogenic epoch.

In the opinion of the author of this paper, the Gradina deposit and the neighboring deposits are not of Carboniferous age but older. They are Ordovician-Cambrian-Upper Rhiphean in age, because they lie along the central axis of the Jelova Gora antiform (Fig. 5).

3) The problem of genetic type of the iron ore at Horizon I

In Popović's (1984a) opinion, the ore Horizon I is the oldest one among the six ore deposits he had singled out. Outcrops were found in the Lazića potok brook and in the area of Viševsava (Fig. 4, Fig. 6). They are relatively poor (10-20 % Fe at most) impregnations and thin beds of magnetite (grains are 5-70 µm in diameter) within several meters thick packages in compact dark-green chlorite schists enriched by TiO_2 (over 3%). Only in this ore horizon, the isotopic composition of oxygen in magnetite ($\delta^{18}O_{SMOW}$ = +5.3 ‰) and in quartz ($\delta^{18}O_{SMOW}$ = 11.1 ‰) has magmatogenic character (Fig. 8). Based on a coeval pair magnetite-quartz, Pezdič (1980) determined the formative temperature of +706ºC so he interpretated this as the contact metamorphism of undiscovered Tertiary acid pluton (skarnization) which also caused the occurrence of garnet, epidote, actinolite, and alkali-amphibole. The author of this paper is of the opinion that the occurrence of magnetite in Horizon I is a magmatic syngenetic segregation in the protoliths of ortho-greenschists.

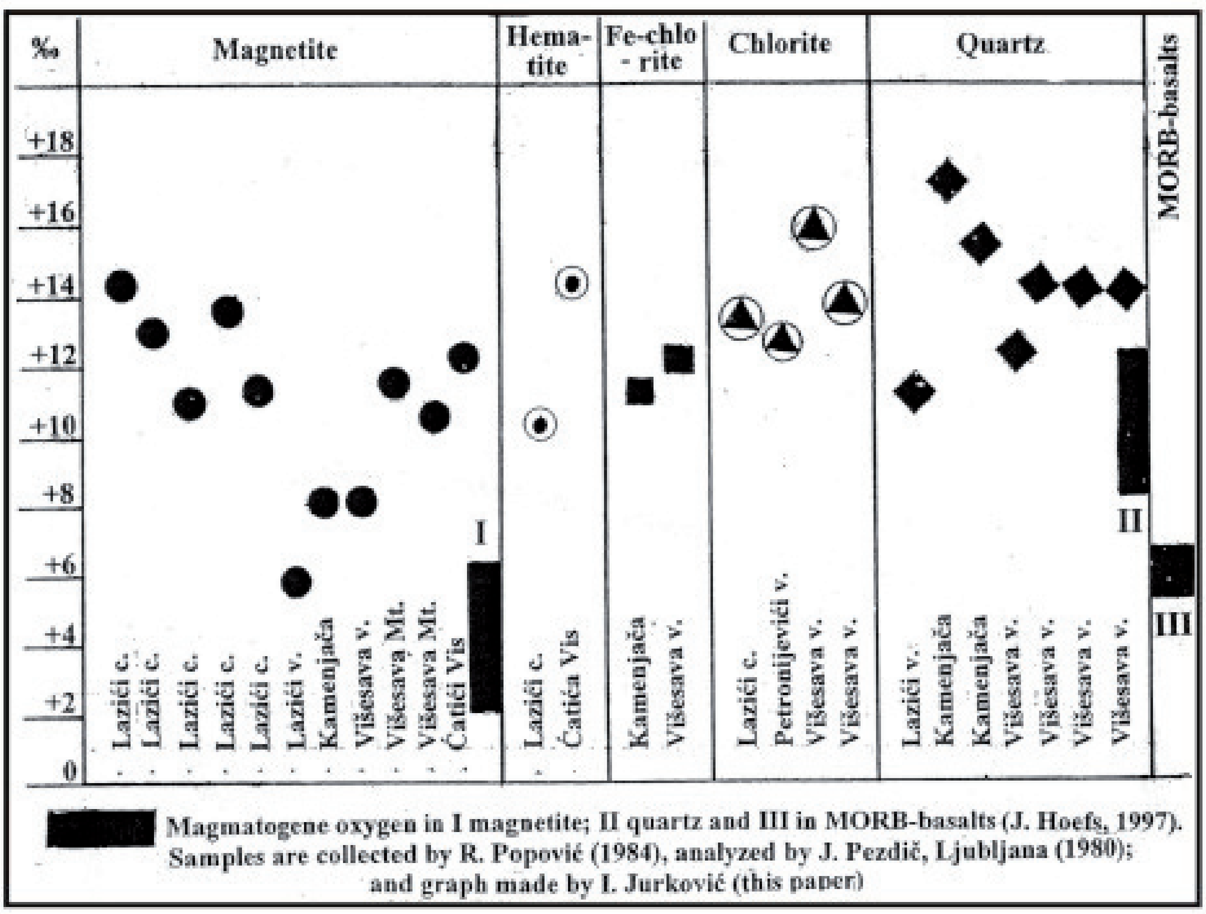

Figure 8 Isotopic compositions of oxygen ($\delta^{18}O_{SMOW}$ in ‰) in magnetite, hematite, Fe-chlorite, chlorite and quartz of the iron-ore deposits in the Drina-Ivanjica Formation.

Slika 8. Izotopski sastav kisika u magnetitu, hematitu, Fe-kloritu, kloritu i kvarcu željeznih ležišta Drina-Ivanjica formacije.

4) The problem of the number of ore horizons

Kubat (1969) suggests that the Mn-occurrences of Brezovica-Močevići and the Fe-occurrences of Krnjići-Tokoljak (Fig. 4a) are found in an ore horizon as superpositioned beds situated in the volcanogenic-sedimentary formation between Lower and Middle Carboniferous.

In his dissertation, Popović (1984) proposed an outline with six ore horizons of iron beds in western Serbia. The oldest are Horizons I-IV, which belong to the Neo-Proterozoic Baikalian metallogenic epoch; Horizon V is younger, being the product of the Caledonian metallogenic epoch, formed in the Cambrian-Ordovician period, and the youngest is Horizon VI, which formed in Lower Carboniferous (Variscan metallogenic epoch). It should also be emphasized that in Popović's opinion the Cambrian-Ordovician Horizon V formed from the lateritic weathering-crust so it could not be classified into the genetic sequence linked to the volcanogenic-sedimentary processes of other horizons, and its stratigraphic position has yet to be resolved.

In the opinion of the author of this paper, the classification into six horizons is excessive and the four oldest horizons should be reduced to two horizons of different genetic type. Horizon I should remain Horizon I, representing very poor magmatic segregation magnetite deposit formed from parent silicate liquid (protoliths of ortho-greenschists). Horizons II, III, and IV should become Horizon II with multiple superpositioned ore beds with hematite, chamosite (Fe-chlorite) and magnetite-bearing Fe-quartzite in different mutual quantitative relations. Horizon II should be the horizon with SEDEX type of Fe-deposits bounded to the volcanogenic-sedimentary formation. Horizon III should represent Fe-occurrences from Horizon VI in the Carboniferous volcanogenic-sedimentary formation, also SEDEX type deposit, linked to the Variscan metallogenic epoch. Horizon V was never found as outcrop and its precise stratigraphic position is unknown.

Conclusion

The smaller part of the Drina-Ivanjica Formation (DIF) lies in eastern Bosnia, on the left bank of the river Drina, between Vlasenica and Bajina Bašta. The larger part of the DIF lies in western Serbia, occupying a narrow belt on the right bank of the river Drina between Zvornik and Rogačica, as well as the Bajina Bašta and Novi Pazar areas (Fig. 1).

The entire belt is 240 km long, with a varying width of 5-30 km and a surface of >3500 km^2. It consists of two parts; the north-western ore-bearing Drina Block and the south-eastern Ivanjica Block.

According to Đoković (1985), the Drina-Ivanjica Formation (DIF) consists of four subformations: Drina Formation (Cm_3)/C_1), Golija Formation (C_1), Kovilje Formation (C_2/C_1) and Birač Formation (C_3/C_2). Unlike Đoković, Popović (1984) believes that the oldest formation is the Neo-Proterozoic volcanogenic-sedimentary formation (VSF), which is in angle discordance with Phyllitoid Formation (Cm_3/C_1). The next is the Phyllitoid Formation (Cm_3/C_1), followed by the Metaconglomerate Formation (C) and, as the last, Metasandstone Formation (C_3 or P/C).

The Jelova Gora antiform is the main structural form of the DIF (Milovanović, 1934; Grubić, 1959; Dimitrijević et al., 1972; Đoković, 1975). Its internal structure is very complicated due to multiple folding. The first generation of folding is represented by isoclinal folds of Hercynian age. The original orientation of axes of these folds was SW-NE with a NW overturn. During the Alpine orogenic phase, the complex was refolded four times (Đoković, 1975). In the iron-quartzites of the VSF, Popović (1984) identified folds of Cadomian age. B-axes of these oldest folds strike E-W with the inclination towards west at an angle of 45°.

The main axis of the Jelova Gora antiform is situated in the Rogačica-Jelova Gora-Duboki potok zone. It is an area of the deepest stratigraphic level with Upper Cambrian-Ordovician fossils found at Crvica, Okletec, Kostojevići (Ercegovac, 1975, 1977; Đoković, 1985) and the majority of iron occurrences and deposits. The oldest ore horizons are characterized by the rocks of the VSF (albite-actinolite, albite-chlorite, actinolite-epidote schists interbedded with thin beds or lenses of marble, calcschist and iron or chlorite quartzites (Popović, 1984).

The north-eastern wing of the Jelova Gora antiform is in the Donja Trešnjica-Jakalji-Crnokosa zone, which is folded in the system of decameter and hectometer isoclinal folds whose axes are sinking in the direction of SE. In this zone, numerous Carboniferous conodonts were found at locations Tmuša, Zaseljska Reka, Crnokosa, and Zdravčići (Mojsilović et al., 1975; 1977), as well as at Skrapež, Šaramtovo and Kalenić (Đoković, 1985).

The south-western wing of the Jelova Gora antiform is in the zone Bajina Bašta-Pilica-Kadinjača, and it is characterized by hectometer and kilometer folds with axes sinking in the direction of SE. Carboniferous conodonts were also found in several locations in this wing, particularly near Tvrdići (Popović, 1984; Đoković, 1985). (Fig. 5)

All this leads to a conclusion that the youngest, Carboniferous deposits of the Jelova Gora antiform are found in its wings, while the oldest deposits of Upper Cambrian-Ordovician age have been discovered in the central, eroded, destroyed part. Those are the deposits of the lowest levels of the Drina Formation (Đoković, 1989). In Popović's opinion (1984), the lowest iron-ore bearing deposits are situated in the discordantly underlying VSF of uppermost Neo-Proterozoic (Vendian)-Lower Cambrian (Cm_1) age.

Popović (1984) and Đoković (1985) agree, that five of six ore horizons with a dominant number of outcrops and ore beds of iron ores in the Drina-Ivanjica Formation are located within a very narrow, 1-2 km wide and 20-25 km long strip, the surface of which is 25-30 km^2, extending E-W with a mild bend to WNW (Fig. 4, 5, 6). The entire belt is tied to the Drina Block.

Only the sixth horizon, which is spatially bounded to the Carboniferous deposits in the vicinity of Karan, with occurrences of very thin hematitic beds in Ćatića Vis, Madžarevac potok brook and Metaljka, is situated NW of Užička Požega in the NE wing of the Jelova Gora antiform. According to my opinion, manganese-oxides occurrence Močevići and Brezovica belong also to the NE wing of the Jelova gora antiform. The gold-bearing quartz-pyrite veins, south of the town of Ivanjica, are the only ore occurrences in the Ivanjica Block. They are genetically bounded to the Alpine metallogenic epoch.

In Đoković's opinion (1985), the oldest deposits in the Drina-Ivanjica Formation are Upper Cambrian-Ordovician in age, whereas their background is of unknown age. Đoković thinks that the most important iron ore zones are thin-bedded hematitic occurrences and iron sandstones in the Carboniferous sediments of the Karan area, bounded to the relatively thick outflows of the gabbro-diabase magma. The ore occurrences in the Upper Cambrian-Ordovician deposits, in his opinion, are of lesser significance, but they are also connected to the gabbro-diabase magma.

Popović (1984) is of the opinion that underneath the Upper Cambrian-Ordovician deposits, there is a discordantly positioned VSF, formed in Upper Neo-Proterozoic (Vendian) and metamorphosed in Lower Cambrian (C_1), in the Late Baikalian orogeny.

In order to determine the age of iron deposits in the Drina-Ivanjica Formation, the author of this article studied all key research papers on iron ore deposits that are genetically bounded to the VSF and formed in the Late Neo-Proterozoic and Caledonian cycles.

I Carpatho-Balkanide terranes (NE and SE Serbia)

In this region VSFs were identified, bounded to the island arc or back arc basin and formed during the Vendian-Lower Cambrian period. They were metamorphosed during the Late Baikalian (Cadomian) orogeny in greenschist facies. They include Vrška Čuka-Miroč (sterile in iron ores), Stara Planina-Poreč (sterile), Kučaj with the Beljanica iron ore deposit (Pre-Cambrian-Lower Cambrian) and siderite-chamosite ores in the Caledonian epoch (Cm_3-C_1), Homolje (sterile) and finally the Ranovac-Vlasina-Osogovo (SE Serbia), the so-called, Vlasina Complex“ or Upper Complex of the Serbo-Macedonian Mass, mineralized with numerous iron deposits in the region of Vlasina. In the same area iron ores formed during Early Paleozoic (Caledonian) epoch. All these regions were studied by Kalenić (1965), Kalenić and Aleksić (1976), Janković (1990, 1996), Krstić and Karamata (1992), Karamata et al. (1994), and Karamata and Krstić (1996).

II Serbo-Macedonian Mass (SMM) (central Serbia)

The SMM contains only Upper Mesoproterozoic VSFs, metamorphosed during the Baikalian orogeny in the medium-grade metamorphism (T = 600ºC, P = 6-7 kbars), locally with eclogitic, granulitic and greenschist facies relics. The Pre-Cambrian hematite-magnetite ores were found at Žitni Potok and Čar Sedlar (Milovanović, 1989; Janković 1990, 1996; Janković et al. 1997; Balogh et al., 1994; Karamata and Krstić, 1996; Jurković, 2005). Based on a rock sample from Mt. Plačkovica Deleon (1968) determined the age of 1130 Ma.

III Dinarides

1) Mt. Medvednica (Croatia) contains magnetite-hematite-quartz deposits, genetically tied to the VSF, on whose age many significantly differing views have been expressed. Miholić (1958) studied the greenschists of VSF and determined their age at 700 and 750 Ma (Sinian) using Pb-method. According Popović (1984) they are formed in the Baikalian epoch. Belak's opinion (2005) is that hey are of Triassic age, whereas Jurković (2005) and Pamić and Jurković (2005) claim that they formed in the Caledonian epoch.

2) Mid-Bosnian Schist Mountains (MBSM) comprise the oldest fossiliferous rocks of Upper Silurian age (verified by conodonts). Older rocks, found in the region of Busovača, belong most probably to the Vendian-Cambrian-Ordovician sequences (Karamata & Krstić, 1996). They are metamorphosed in the greenschist facies, locally in the epidote-amphibolite facies. Mineralization is very scarce and represented by thin magnetite-pyrite-quartz beds and an uncommon Zn-Mn-chrome spinel deposit (metamorphosed mostly in chrome-bearing magnetite) at Busovača (Jurković and Jakšić, 1994; Hrvatović, 1996).

3) Western Macedonia's oldest formation is known as the «gneiss complex» (Grenvillian cycle). Deleon (1968) determined the age of 800-1140 Ma in Mt. Selečka and 1090 Ma in Mt. Babuna. As for ore occurrences, well known are Mn-Fe quartzites (Makedonski Brod) and poor impregnations of magnetite in sericitic schists at Dolno Divjaci. The next is a discordant „greenschist complex,“ made of VSFs, situated in an antiform of submeridional strike in central part of western Macedonia and mineralized with two types of iron occurrences: a) magnetite and ilmenomagnetite impregnations in chlorite

schists and metagabbro and b) hematite in Fe-quartzites (north of Kičevo). According to Popović (1989) this complex is placed into the Baikalian tectonic-magmatic cycle. However, author of this article believe it is about a Vendian-Lower Cambrian (Cadomian) cycle. The following phyllitoid complex ($Cm-D_1$) is developed over most western Macedonia and composed of the VSF rocks. In the Cambrian-Ordovician of Mounts Stogovo, Karaorman and Slavej, there are numerous small chamosite-magnetite deposits and larger rodochrosite deposits of Kara Deva (Stogovo). The younger, large chamosite deposits (partially metamorphosed in siderite, magnetite, hematite and pyrite), type Tajmište and Demir-Hisar, are linked to Devonian.

From all of the above the following conclusion can be made: 1) the greatest resemblance in development is detectable between the Drina-Ivanjica Formation (DIF) and the Western Macedonia Formation (WMF). A comparative overview of the DIF and WMF features shows that: 1) the main structural form in the DIF is the Jelova Gora antiform, striking E-W and in the central part of the WSF this is the green complex antiform, striking N-S; 2) the axes of both antiforms are composed of volcanogenic-sedimentary complexes (VSFs), underlying Cambrian sediments; 3) there is incongruity between the B-axes of the folds in the VSF rocks in the DIF, and the WSF, and the B-axes of the folds in younger phyllitoidal formations in the DIF and the WMF indicating a discordance between of these formations, what is established by Popović (1984, 1989); 4) in both formations, iron quartzites occur in VSF of both formations, being hematite- and magnetite bearing in the DIF (Fig. 7) and hematite bearing in the WMF.

Although the aforementioned comparative similarities between the Drina-Ivanjica Formation and the Western Macedonia Formation seem to favor Popović's view (1984) who believe that the four oldest iron ore horizons in the Drina-Ivanjica Formation have been formed in Late Neo-Proterozoic (Vendian-Lower Cambrian, Cadomian orogeny), the autor of this article is of the opinion, that there is still no sufficient evidence to unequivocally support such a claim.

The most appropriate method of determining the age of the oldest ore-bearing horizons in the Drina-Ivanjica Formation, in its deepest volcanogenic-sedimentary formation, consists of paleontological study of calcschist, marbles and marbleized limestones being located in the immediate hanging wall or foot wall of ore beds. The other option is to attempt to determine the absolute age of any of the rocks in the oldest ore-bearing horizons, in which case there is a very real possibility that only the age of its later overprint is obtained, and not the age of protolith formation.

Received: 15.10.2006.
Accepted: 10.11.2006.

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