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SOME QUANTITATIVE ASPECTS OF THE MAJOR TYPES OF ORES AT THE RŽANOVO FE-NI LATERITIC DEPOSIT, R. MACEDONIA

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A b s t r a c t: The results of detailed laboratory studies of ores from the laterite Fe-Ni deposit Ržanovo, Republic of Macedonia, enabled separation of 9 types of ore and definition of the chemical composition of these ore types and quantitative mineral presence in them. In all of ore types was defined nickel content in the range from 0.34 to 3.1% NiO. However, the most productive types are considered massive magnetite ore, schist magnetite ore, schist hematite and massive hematite ore. Economically the most important is the compact hematite ore with nickel content within the range of 0.93 to 1.49% Ni. The main mineral phases (nickel bearers) in the Ržanovo deposit are: magnetite, hematite, clinochlore, talc, sepiolite, magnesioribekite, lizardite, dolomite, phlogopite and stilpnomelane. Percentage of the most abundant mineral in the ore deposit Ržanovo is hematite with 40.61%, followed by talc with 20.90%, amphibole 13.60%, magnetite with 11, 16% and clinochlore with 10.65%. High iron content by 55% Fe_2O_3 is characteristic of magnetite and hematite ores, while the high silicon content over 50% SiO_2 is characteristic for magnesioribekite, talc, schists etc..

Key words: pedeposited laterites; nickeliferous ores; chemical compositions; quantitative mineral compositionsч mineral phases

INTRODUCTION

The importance of lateritic ore deposits is high, especially if we are bearing in mind that the first major nickel production in the world came from nickeliferous laterites (Evans, 1993). Residual nickel deposits are formed by the intense tropical weathering of rocks rich in trace amounts of nickel, such as peridotites and serpentinites, running about 0.25% Ni. During the lateritization of such rocks, nickel passes (temporarily) into solution but is generally quickly reprecipitated either on to iron oxide minerals in the laterite or as garnierite and other nickeliferous phyllosilicates in the weathered rock below the laterite (Golightly, 1981). Grades of potentially economic deposits range from 1 to 3% Ni and tonnages from 10 to 100 Mt of ore.

The Republic of Macedonia is one of the rare World countries with its own nickel production. For more than 30 years the nickel production comes from the Ržanovo, or more precisely, from the Ržanovo redeposited Fe-Ni laterites. The process of lateritization took place on Jurassic ultrabasics (mainly serpentinites), but however the formation of lateritic crust occurred during the Cretaceous. Redeposited laterites were formed during the Upper Cretaceous and with the Alpine tectonic movements (Upper Cretaceous-lower Eocene) the already formed Fe-Ni lateritic layer was tectonically altered and its present position is as an inverted and almost sub-vertically positioned while in its footwall are Creatceous limestones and in its hanging wall are positioned ultrabasics. The average thickness of the ore layer ranges from 30 to 35 m, and it can be followed up to 4 km. The Ržanovo's calculated total ore reserves are 40 Mt with an average content of about 1% Ni. Today the Ržanovo mine is in production, but with reduced capacity.

Geological, metallogenetic and chemical features of ore from the Fe-Ni lateritic deposit Ržanovo can be found in works of Ivanov (1962, 1965), Maksimović and Panto (1982), Boev (1982), Boev and Stojanov (1985), Boev and Lepitkova (1994), Boev and Serafimovski (1992, 1995,1996), Boev and Janković (1996) etc. All the authors in general found that the Ržanovo deposit represents a specific type of a redeposited Fe-Ni lateritic deposit, which have a very distinctive sedimentary character. One of the numerous specifics related to this deposit is the presence of oolithic-pizolitic ores, which allows its comparison with numerous deposits of lateritic type from the Balkan and wider.

THE POSITION OF THE RŽANOVO FE-NI DEPOSIT IN THE LATERITIC OCCURRENCES WITHIN THE VARDAR ZONE

Deposits and occurrences of nickeliferous iron are known in several places along the Vardar River, in the Republic of Macedonia, in the famous Vardar zone in general, but the degree of exploration varies for various deposits. Major Fe-Ni deposits and occurrences in the Vardar zone are located in the Serbia, Macedonia, Greece and continues and it is connected with the Anatolian zone in Turkey (Fig. 1).

The Serbian Fe-Ni lateritic deposits are related with Jurassic peridotites (ultramafics), where on them, during Lower Cretaceous, more or less voluminous weathering crust has been developed, which resulted in lateritic Fe-Ni ore deposits that have been partly redeposited in Upper Cretaceous. Genral metallogenetic features for these deposits have been reported by Maksimović, (1981), Maksimović and Panto (1982), Karamata (1974), Janković (1990, 1997), Janković et al. (1997), Boev and Janković (1996), Popović (2008), Robertson et al. (2009) etc.

In regards to Fe-Ni lateritic deposits many classifications and metallogenetic units has been distinguished within the Vardar zone at the territory of the Serbia. However, the major Fe-Ni lateritic deposits and occurrences in the Serbian part of the Vardar zone were distinguished into five major ore-bearing zones. In the first ore bearing zone belongs the deposit located in Lipovac (near Arandjelovac) as an integral part of the Stragari – Kutlovo zone; the second one is represented by the Šumadija oolithic iron ore deposits (unlike the previous zone, where Fe-Ni mineralizations belong to primary weatherig crust, in this case is redeposited weathering crust); the third one is represents again by the nickel bearing primary weathering crust while itself it is going to the southeast, to the West Morava and probably extended to Kosmet (Goleš); the fourth zone represent deposits belonging again to Upper Cretaceous as a redeposited weathering crust (starts from northeastern Bosnia, through Tara and Zlatibor mountains up to the southeast into the Grebnik bauxite ore deposit in Kosovo), and the fifth Fe-Ni ore bearing zone is presented by deposits in the Mokra Gora (Serbia) – Vardište (Republic of Srpska) basin.

In general, these Fe-Ni ore zones continued to southeast, throughout Macedonia, Greece and probably in southwestern Turkey and northwesterly to Bosnia.

At the territory of the Republic of Macedonia the redeposited nickeliferous iron deposits can be divided into two groups:

♦ *The Ržanovo type* includes the Ržanovo, Studena Voda, Roždeni, Kozarnik, Klinovo, Bojančište, Krivi Vir, Janovo Lozje, Šeskovo, Čalma, Skačinci, Kale, Omelo, Vrvovi, Govedarica, Zaečki Rid, Oraovec, Babuna, Raduša and Ivaja.

♦ *The Rakle type* includes Rakle, Nikodin, Carević, Dren, Vrpsko, Živovo, Crna Tumba, Urup, Pčinja and Kožle.

Based on the metallogenic classification all mentioned occurrences belong to the Serbo-Macedonian metallogenic province. Occurrences and deposits of silicate nickel and nickeliferous iron within this regional metallogenetic unit are grouped into three districts:

♦ the Veles–Klepa ore district,

♦ the Rakle–Nikodin ore district.

♦ the Kožuf ore district.

Deposits and occurrences of nickeliferous iron in the territory of the Republic of Macedonia are very common and some of them are of economic importance (the Ržanovo deposit).

Conditions for sedimentation were not identical resulting in a variety of deposits. However, based on their genesis they have many common features.

Lateritic weathering crusts formed on serpentinized ultrabasic rocks and were redeposited by running water into a marine environment. Thus, they all represent marine sediments of iron with high nickel, chromium and cobalt concentrations. All deposits possess oolitic, pisolitic structures.

Deposition of eroded material from the lateritic crust took place in the surrounding sedimentary basins and transportation of eroded material did not have a great influence. This is also supported by the fact that some redeposited occurrences and deposits of nickeliferous iron overlie relicts of fossil lateritic crust (the Gradište, Babuna, Vrvovi, Ržanovo). In some cases there is a pronounced mixing of material from the lateritic crust and material which does not originate from it, but from surrounding members. In such cases there is a greater dilution of lateritic materials and lower nickel and iron contents result, such as the Studena Voda, Rakle, Crna Tumba deposits.

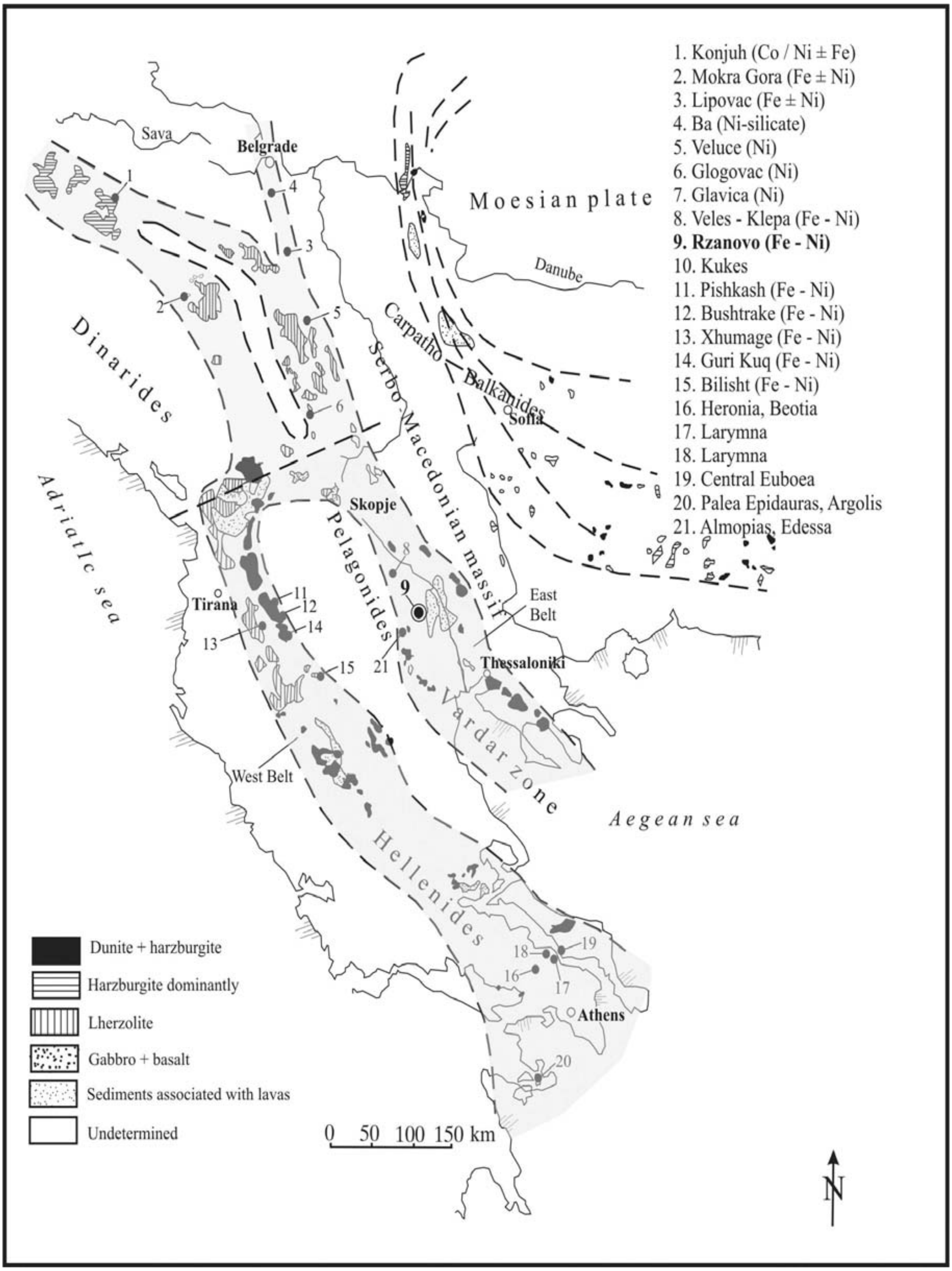


Fig. 1. Location of the principal deposits and occurrences of nickel silicate and nickelferous iron ore mineralization in the west and east ophiolite belts of the SE Europe (Boev and Janković, 1996; modified)

The ophiolite belt within the Vardar zone continues at the territory of the Republic of Greece where have been determined few important deposits, such in Northern Greece as well as in the Southern Greece and Atika. It should be emphasized that in this part of the Vardar zone all together with lateritic Fe-Ni deposits were determined latertitic bauxite deposits as well.

Lateritic crust formed on the ophiolites in these areas was the ultimate source of metals not only for the nickeliferous iron deposits but also for the bauxite deposits. Katsikatsos et al. (1980) assume that bauxite deposits formed from material which was the product of lateritic weathering crust, itself formed on the ophiolites and/or material which originated from the Cenomanian Fe-Ni deposits. This conclusion is based on the presence of hematite pisoliths and their fragments in the bauxite deposits (the Mandra area in Atika and Kimi area in Euboea). Namely, pisoliths associated with other nickel laterites within the region are generaly related with reworking and deposition of older Cretaceous deposits and are not part of the original lateritization process (Valeton et al., 1987; Molla et 1994). The profile is mineralogically and texturally similar to the in situ portions of other buried deposits within the region, e.g. Kastoria, Northern Greece (Eliopoulos and Economou-Eliopoulos, 2000), Bitincke Fe-Ni laterite deposit in Albania (Thorne et al., 2012), Ržanovo Fe-Ni deposit in the Republic of Macedonia (Boev and Janković, 1996), Čikatovo-2 in Kosovo (Jovanovski, 2011) etc.

Some of the well-known Fe-Ni lateritic deposits in the Republic of Greece are located around the Lokris (Petrascheck, 1954; Augustithitis, 1961; Albandakis, 1974). An average nickel contents is from 1.1 t 1.4% Ni, and Lokris mine is in exploitation for a longer period of time. Similar features are related for the Euboea where ore reserves of laterite Fe-Ni mineralization have been estimated well above 300 Mt (Albandakis, 1980). More data on the Greek lateritic deposits and occurrences can be found in Maksimović et al., (1993), Skarpelis (1999, 2006), Christidis and Skarpelis (2010) etc.

GEOLOGY OF THE RŽANOVO ORE DEPOSIT

The Ržanovo (Ržanovo–Studena Voda) deposit is located within the Kožuf ore district at the Kožuf Mountain near the Macedonian-Greek border. It is one of the largest Fe-Ni lateritic deposits in the Vardar zone and is situated close to the contact between the Vardar zone and the Pelagonian massif in a tectonically active area.

The investigated area is a part of the western ophiolite belt of the Vardar zone and essentially consists of several lithostratigraphic units with distinct mineralogy, petrology and history of development. The main units which comprise the geologic setting are: limestones (Alb-Cenomanian), lateritic Fe-Ni ores (Cretaceous), series of shales (probably Cretaceous), ultrabasic complexes (serpentinites) with gabbroic pegmatites and rodingites as well as series of Tertiary volcanic rocks and pyroclastics (Fig. 2).

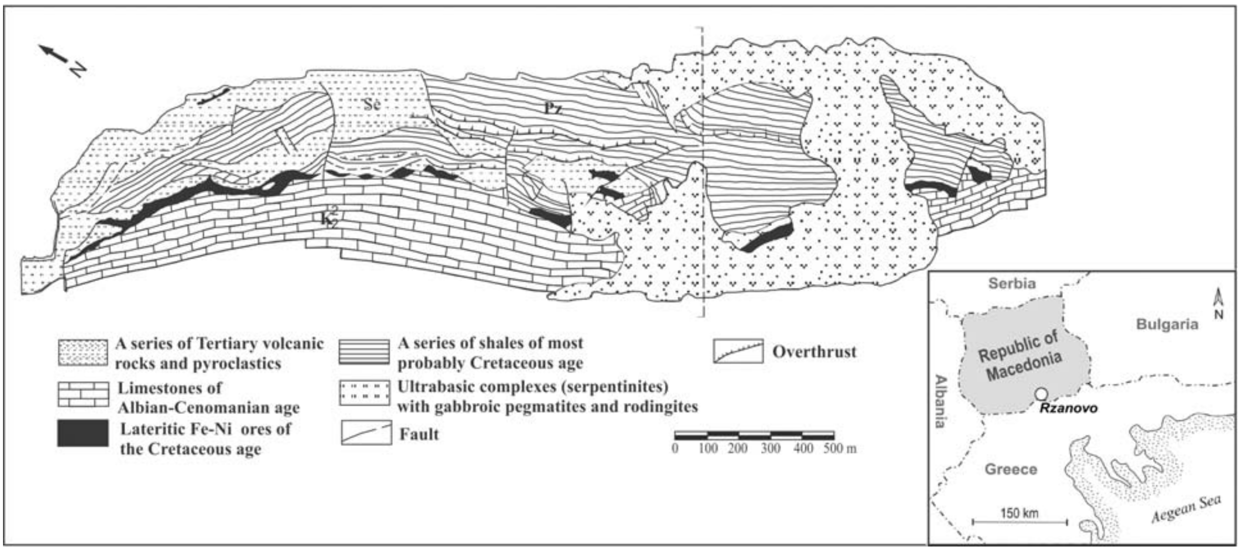


Fig. 2. Geologic map of the Ržanovo–Studena Voda zone

Several large dislocations pass through the host serpentinized ultrabasic masses. The Ržanovo overthrusting zone is present as several parallel thrusts in which in a series of alternating serpentinites, shales and marbles. The ore series in the thrusts are dismembered and disappears in some places. Tectonic movements younger than the thrusts were determined as radial structures.

The Ržanovo–Studena Voda ore-bearing series can be traced for more than 4 km with a thickness varying from 1 to 40 m. The ore-bearing series is not homogenous in texture and consists of several varieties of ores or rocks. The main rocks affected by weathering processes are ultrabasic rocks or serpentinites.

The gabbro-peridotite complex in the Ržanovo–Studena Voda zone is located in the western part of the Vardar zone. It consists predominantly of peridotites of gabbro and diabase.

Based on the chemical composition of olivine in the ultrabasic rocks and comparison with correlation diagrams Ni-Fe, Fe-Mn and Ca-Fe from published papers (Vinogradov et al., 1977 and Maksimović 1981), it is clear that they are of the Alpine type "ultra-metamorphites" i.e. ultramafics in the area of the Ržanovo–Studena Voda zone do not differ from other ultramafics on the Balkan Peninsula.

Dunites and *harzburgites* are the main members of the Alpine type ultramafics in the Ržanovo –Studena Voda zone. Harzburgites distinguish themselves by the presence of pyroxene (enstatite) 1 cm in size. Based on field relationships and microscopic studies the term dunite and harzburgite are conditionally used as they are heavily serpentinized. Serpentinized harzburgites generally occur as blocks, which are compact compared to other rocks. Pyroxene crystals up to 1 cm in size can be clearly seen. Their chemical analyses have shown the dominance of SiO_2 (37.81%) and MgO (36.51%) followed by H_2O (12.75%), total Fe_2O_3 (7.53%), Al_2O_3 (5.09%), CaO (0.33%), Na_2O (0.13%), TiO_2 (0.07%) and K_2O (0.06%).

Serpentine occurs as net-like serpentinite which originates from pyroxene and individual flakes and fibres of serpentine minerals are parallel to one another and possess primary mineral cleavage. In some places pyroxenes are not completely altered to serpentine minerals but are affected by bastitisation. Olivine is also affected by serpentinization and almost all has been graded into serpentine minerals.

Serpentinized dunite, unlike serpentinites are due to serpentinization of a harzburgite mass and occur as large blocks of compact bodies. Their chemical analyses have shown the dominance of SiO_2 (45.06%) and MgO (33.98%) followed by H_2O (12.46%), total Fe_2O_3 (7.53%), CaO (0.45%), P_2O_5 (0.09%), K_2O (0.06%) and Na_2O (0.01%).

Microscopic studies indicate that serpentinite originates from olivine. It is net-like and individual flakes or fibres of serpentinite minerals are arranged along irregular cracks within the primary olivine grains (the first generation serpentine) and as ring radial aggregates replacing individual parts of olivine grains (the second generation serpentine). The analyses show that the serpentinization process reduces with an increase in the amount of chemically connected water given an adequate decrease in amount of other components. A certain amount of magnetite develops as magnetite powder during the serpentinization process.

Based on the aforementioned data we can come to the conclusion that there are metamorphosed members of ultrabasic rocks in the Ržanovo–Studena Voda area.

Gabbropegmatite-rodingite in the Ržanovo area is elongated and cross-cuts the blocks of serpentinites. They are small in size and can easily be recognized on the field. Fresh gabbro-pegmatites which are usually altered and affected by rodingitization processes are rarely found. They are characterized by a large-grained texture. The size of monoclinic pyroxene grains in some places is up to 30 cm in size. Microscopic investigations show that they mainly consist of basic plagioclase and monoclinic pyroxene. Pyroxene alteration is seen as chloritization and prenitization, whereas in plagioclase they sometimes occur as prenite. This clearly points to the beginning of rodingitization. The chemical analyses of gabbropegmatite have shown the dominance of SiO_2 (48.31%) and Al_2O_3 (15.61%) followed by total Fe_2O_3 (6.56%), MgO (5.68%), P_2O_5 (0.13%), TiO_2 (0.07%), Na_2O (0.04%), and K_2O (0.02%).

Rodingite rocks are mainly located in the marginal parts of the serpentinite mass as elongate blocks of variable thickness. They formed from gabbros and gabbropegmatites during a postmagmatic phase of replacement due to calcium metasomation. The contacts with surrounding serpentinites are always sharp and clear and are grey and grey-greenish to white depending on the garnet and chlorite contents. Studies of rodingite rocks include both silicate chemistry and microscopic examinations. Microscopic studies determine that rodingites have a hypidiomorphic grain structure. They essentially consist of garnet (hydrogrossular hibschite), monoclinic pyroxene (diopside, xenomorphous grains), prenite and vesuvianite. Garnets are mainly replaced by plagioclase. Pyroxenes were affected by processes of prenitization, uralitization and chloritization. Chemical analyses of rodingites have shown the dominance of SiO_2 (47.89%) and Al_2O_3 (13.54%), MgO (1.83%) followed by total Fe_2O_3 (3.50%), TiO_2 (0.22%), P_2O_5 (0.20%), Na_2O (0.03%) and K_2O (0.01%). Chemical analyses clearly show an increase in calcium oxide relative to gabbroides as a consequence of Ca-metasomatism (rodingitization).

Main characteristics of the schistose series. Schists in the Ržanovo–Studena Voda area together with other lithologic units comprise the main body of rock. Microscopic examinations determined that schists consist of: quartz, sericite (illite), chlorite, albite and talc. These minerals phases were determined by X-ray diffraction. The mineral composition indicates that primary clays were transformed into schists under conditions of green-schist facies metamorphism.

Metasandstone lenses occasionally occur in the series together with quartz grains, quarztite, rare microcline or plagioclase and very rare tourmaline in the metasandstones. The grains are slightly rounded to unrounded and often distorted indicating that mechanical deformations took place during metamorphism.

The matrix is completely recrystallized and mainly silicious, with small amounts of calcite indicating that the pre-cursor was an arkose originally comented by a quartz matrix or a poor clayey siliceous matrix. The chemical composition of the schists has shown dominance of SiO_2 (76.56%) and Al_2O_3 (8.89%) followed by total Fe_2O_3 (3.33%), K_2O (1.81%), MgO (1.71%), Na_2O (1.52%), CaO (0.37%) and MnO (0.03%).

The Albian-Cenomanian limestones represent the top part of the ore-bearing series in the Ržanovo area. Occasionally due to tectonic movements, they are inverted. The limestones are weakly metamorphosed. In places where tectonic activity is intense the carbonate base is completely recrystallized to calcite.

The Ržanovo–Studena Voda ore-bearing series is built of two large ore deposits of similar geologic and geochemical-mineralogic characteristics. In general the Studena Voda deposit is a southern continuation of the Ržnanovo ore deposit.

ANALYTICAL METHODS

For the necessities of this study were selected respectable number of representative samples from the Fe-Ni ore and surrounding rocks from the open pit of the Ržanovo ore deposit. All samples were pre-treated in laboratory and it was separated material for thin and polished sections, silicate analyses, quantitative X-ray spectrometry analyses and geochemical analyses.

The silicate analyses were conducted at the Eurotest Control Plc. Sofia, Bulgaria, while the control of some of them was performed at the Royal Holloway, University of London, UK. First of all, the samples were done by $LiBO_2$ (lithium metaborate) fusion. Preparation followed procedure that 20 mg of powdered sample was mixed with 1g $LiBO_2$ (lithium metaborate) powder (doped with 200 mg/kg Ga) in a graphite crucible, then fused at 950^{oC} in a muffle furnace. The molten bead was then dissolved in 200 ml 5% HNO_3. Sample solutions were then analyzed by ICP-AES. The samples were analysed for major and minor elements by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). The instrument used was a Perkin Elmer Optima 3300 RL, with an echelle spectrometer and a segmented-array charge-coupled-device detector. The sample was introduced using a cross flow nebuliser and a Scott type spray chamber. The power on the RF coil was 1.5 kW at 40 Hz; the plasma was viewed radially. Accuracy (assessed using an in-house standard) was better than 1% for the major elements, and better than 5% for the minor elements.

Also, systematic X-ray crystallographic study of the silicates was conducted at the Royal Holloway, University of London, UK. Samples were ground manually in a mortar and pestle to a fine powder. The powder was then mixed with water and stirred. The heavy minerals were allowed to sink and separate and the water containing the suspension of clays was poured off and evaporated to dryness. Some of the clay-rich material was then mixed with a bit of water and dried onto a glass slide as a thin layer. The analyses itself were performed on a Philips 1830 XRD spectrometer with use of a $Cu_{K\alpha}$ radiation. Analyses were performed at 2Θ angles between 2.5 and 45 degrees, in steps of 0.02 degrees, which was sufficient to define the major minerals in analyzed samples.

RESULTS AND DISCUSSION

Based on available knowledge of the Ržanovo ore body the following lithologic rock types are distinguished: compact magnetite ore, schistose magnetite ore, oolitic magnetite ore, schistose hematite ore, compact hematite ore, ribeckite schists, stilpnomelane schists, dolomite-talc schists, talc schists and serpentinites. A brief review of the most important chemical-mineralogical features of the individual ores is presented.

Massive magnetite ore: This member is found close to the hanging wall or the top part of the ore layer. It consists of massive compact magnetite ore in which magnetite dominates (Fig. 3).

a)

b)

Fig. 3. Micro-photographs of massive magnetite ore from the Ržanovo deposit

The chemical composition of the ore is shown in Table 1. The nickel content in the ore ranges from 0.69 to 1.17% Ni. Analysis of this type of ore indicates that it contains many elements derived from ultramafics, such as nickel, cobalt and chromium.

Table 1

Chemical composition of iron-nickeliferous type of compact magnetite ore (%)

	I/l	V/2	VIII/1
Al_2O_3	1.78	4.92	1.86
tFe_2O_3	32.91	62.58	39.38
MnO	0.24	0.04	0.45
MgO	18.40	6.42	13.91
Na_2O	0.50	0.82	0.85
K_2O	0.10	0.23	0.18
P_2O_5	0.17	0.49	0.46
SiO_2	40.02	16.60	32.90
SO_3	0.47	1.71	0.79
CaO	0.98	1.31	3.92
TiO_2	0.02	0.12	0.03
LI	2.65	1.89	3.17
H_2O	0.24	0.97	0.28
NiO	0.90	1.17	0.69
Cr_2O_3	1.68	1.93	1.67

Table 2

Quantitative mineralogical composition of iron-nickeliferous type of compact magnetite ore (%)

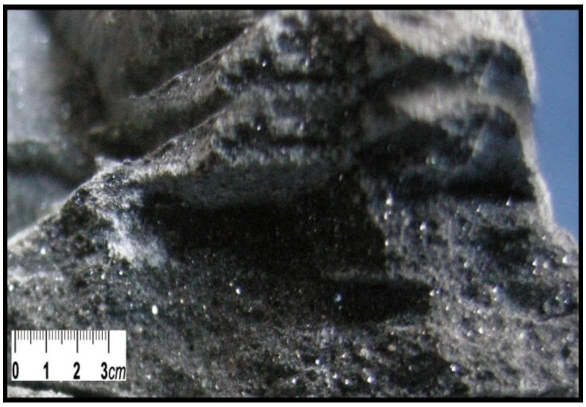
	I/l	V/2	VIII/1
Magnetite	34	68	22
Hematite	7	1	11
Clinochlore	15	9	14
Talc	42	9	40
Sepiolite		9	5
Amphibole		2	1
Dolomite			3

Quantitative mineralogical composition of iron-nickeliferous type of compact magnetite ore have shown that beside magnetite, other minerals are present, also (Table 2).

The most common other minerals are hematite, clinochlore, talc, sepiolite, dolomite and amphibole.

Schistose magnetitic ore: This type of ore is characterized by the relative relationship of individual minerals present, resulting in different chemical features as well as very distinctive physical appearance (Fig. 4).

a)



b)

Fig. 4. Micro-photographs of schistose magnetite ore from the Ržanovo deposit (*a)* and detail from schistose magnetite ore (*b*)

The chemical features of this type of ore indicate that it is relatively rich in nickel (Table 3). The nickel content ranges from 1.10 to 1.28% (Table 3).

The sodium content is also relatively high, between 0.55 and 0.84%. The sodium content indicates the presence of magnesioriebeckite amphibole present in it.

Table 3

Chemical composition of iron-nickeliferous type of schistose magnetite ore (%)

	II/1	IV/1	VII/2
Al_2O_3	5.41	3.89	2.43
T Fe_2O_3	59.86	41.01	34.64
MnO	0.16	0.32	0.44
MgO	8.27	11.37	15.98
Na_2O	0.55	0.84	0.69
K_2O	0.10	0.60	0.18
P_2O_5	0.29	0.53	0.48
SiO_2	16.05	32.38	35.19
SO_3	1.26	1.50	0.37
CaO	1.03	1.47	2.60
TiO_2	0.13	0.07	0.03
LI	2.18	3.00	3.55
H_2O	0.53	1.22	0.26
NiO	1.28	1.0	1.10
Cr_2O_3	3.86	2.26	2.10

Quantitative mineralogical analyses have shown that the ore includes magnetite, hematite, talc, clinochlore, amphibole and dolomite. Their ratios are shown in Table 4.

Table 4

Quantitative mineralogical composition of iron-nickeliferous type of schistose magnetite ore (%)

	I/1	V/2	VIII/1
Magnetite	61	25	34
Hematite		18	10
Clinochlore	22	20	9
Talc	15	16	42
Dolomite			3
Sepiolite		5	
Amphibole		14	

Oolitic-hematitic ore: This type of ore is very common in the Ržanovo ore deposit. It has a clear oolitic-pisolitic structure (Fig. 5).

a)

b)

Fig. 5. Micro-photographs of oolitic hematite ore from the Ržanovo deposit (*a)* and detail of the oolitic hematite ore (*b*)

The chemical composition of this type of ore is given in Table 5. The nickel content in the ore is between 0.91 and 1.25%.

The sodium content ranges from 0.37 up to 0.93%. This lithologic type of ore is very rich in iron because of the large presence of hematite in the ore. Spectrochemical studies for the presence of microelements (Boev and Janković, 1996) have shown that the ore is enriched in elements originating from ultramafics. Their studies confirmed abundance of zirconium (275 ppm), which indicates its source from more acidic rocks, probably schists.

Table 5

Chemical composition of oolitic hematic nickelferous iron type of ore

	I/2	I/9	I/10	I/11	I/12	I/13
Al_2O_3	3.18	2.83	2.92	1.81	3.34	2.74
tFe_2O_3	59.30	65.67	58.37	35.87	34.70	38.09
MnO	0.20	0.38	0.35	0.33	0.58	.0.46
MgO	9.15	6.91	8.21	17.06	8.32	9.61
Na_2O	0.37	0.60	0.93	0.59	0.92	0.50
K_2O	0.10	0.19	0.10	0.10	0.10	0.10
P_2O_5	0.17	0.26	0.32	0.25	0.34	0.32
SiO_2	19.80	15.75	19.84	36.39	22.45	19.90
SO_3	0.48	0.43	0.50	0.50	0.45	0.45
CaO	2.00	2.03	2.57	1.21	2.14	2.00
TiO_2	0.05	0.05	0.03	0.01	0.05	0.03
LI	1,94	2.00	2.17	3.39	2.52	2.69
H_2O	0.70	1.01	0.86	0.34	0.86	0.74
NiO	0.91	0.94	1.21	0.98	1.25	1.08
Cr_2O_3	1.99	2.07	2.26	1.68	2.83	2.10

Investigations carried out on this type of ore show the presence of magnetite, hematite, talc, clinochlore and amphibole with minor sepiolite (Fig. 6). Relations of individual minerals are given in Table 6.

Table 6

Quantitative mineral composition of oolitic hematitic nickelferous iron type of ore

	I/2	I/9	I/10	I/11	I/12	I/13
Magnetite	11	5	44	5	5	
Hematite	56	70	55	37	56	71
Clinochlore	13	12	11	10	11	10
Talc	13	12	11	40	17	17
Sepiolite	5				4	
Amphibole			17	16	5	

Schistose hematitic ore: This lithologic type of ore is most common in the Ržanovo deposit. It is characterized by its explicit schistosity (Fig. 6).

General chemical composition of this ore type is given in Table 7. Nickel content ranges from 0.70 to 1.27% and sodium from 0.50 to 0.82%. Iron content is relatively high and the magnesium content is between 12 and 17%.

a)

b)

Fig. 6. Micro-photographs of schistose hematite ore from the Ržanovo deposit

Table 7

Chemical composition of schistose hematite nickelferous iron ore (%)

	I/3	I/7	II/2	II/3	III/2	III/3
Al_2O_3	2.68	4.33	2.36	2.59	2.23	2.52
tFe_2O_3	40.51	43.69	43.97	34.08	40.57	37.95
MnO	0.48	0.75	0.37	0.34	0.27	0.26
MgO	17.66	12.27	13.94	14.97	14.55	15.42
Na_2O	0.50	0.82	0.58	0.64	0.73	0.73
K_2O	0.10	0.10	0.10	0.20	0.10	0.10
P_2O_5	0.17	0.25	0.53	0.29	0.32	0.34
SiO_2	30.30	26.69	26.64	36.37	32.59	33.63
SO_3	0.47	0.51	0.74	0.81	0.61	0.71
CaO	0.99	1.27	2.30	4.16	2.03	1.49
TiO_2	0.03	0.09	0.03	0.07	0.03	0.03
LI	3.39	3.14	3.24	2.66	2.53	3.64
H_2O	0.40	0.83	0.38	0.43	0.34	0.46
NiO	1.27	1.24	1.08	0.70	1.09	1.11
Cr_2O_3	1.93	4.50	1.79	1.80	2.15	1.96

Spectrochemical analyses indicate high contents of elements of ultramafic origin as well as increased zirconium contents (Boev and Janković, 1996). The most common minerals in this type of ore are: magnetite, hematite, talc, clinochlore and amphibole with sporadic pyrite. The quantitative relationships of minerals are given in Table 8.

Table 8

Quantitative mineral composition of schistose hematite nickelferous iron ore (%)

	I/3	I/7	II/2	II/3	III/2	III/3
Magnetite	12	6	22	32	5	18
Hematite	58	60	28	28	38	36
Clinochlore	13	13	14	13	7	14
Talc	15	10	28	26	42	21
Amphibole		10			7	10
Pyrite			6			

Massive hematite ore: This type of ore is also common in the Ržanovo ore deposit. It is characterized by a massive texture and a greater hardness (Fig. 7)

a)

b)

Fig. 7. Micro-photographs of massive hematite ore from the Ržanovo deposit

Analyses of the chemical composition of the ore (Table 9) indicate that it is relatively rich in nickel – from 0.93 to 1.49% NiO. The large sodium contents from 0.53 to 1.35% indicate the abundance of amphibole in the ore. Spectrochemical analyses of micro-elements identify high contents of nickel, chromium and cobalt.

Table 9

Chemical composition of compact hematite nickelferous iron ore (%)

	I/4	I/5	I/6	I/8	II/4	III/4
Al_2O_3	3.39	2.96	2.91	2.35	3.44	4.11
T Fe_2O_3	48.57	26.36	42.32	49.20	49.34	50.11
MnO	0.58	0.62	0.64	0.39	0.47	0.41
MgO	12.82	17.59	15.31	10.27	9.10	11.41
Na_2O	0.53	0.91	0.63	1.35	1.35	0.57
K_2O	0.10	0.10	0.10	0.20	0.33	0.10
P_2O_5	0.24	0.21	0.31	0.32	0.31	0.44
SiO_2	25.23	40.37	28.59	27.52	25.99	23.71
SO_3	0.61	0.43	0.50	0.51	0.55	0.63
CaO	1.03	2.52	1.26	3.14	2.11	1.09
TiO_2	0.05	0.05	0.03	0.01	0.05	0.08
LI	2.95	3.12	3.36	2.22	2.47	3.48
H_2O	0.61	0.56	0.48	0.51	0.70	0.76
NiO	1.14	1.10	1.06	0.93	1.18	1.49
Cr_2O_3	3.25	3.31	3.23	1.88	3.04	2.96

Examinations carried out determined the following mineral association: magnetite, hematite, clinochlore, talc, and amphibole. The abundance of individual minerals is given in Table 10.

Table 10

Quantitative mineral composition of compact hematite nickelferous iron ore (%)

	I/4	I/5	I/6	I/8	II/4	III/4
Magnetite	15	12	15	9	8	6
Hematite	59	29	60	51	59	60
Clinochlore	13	14	12	8	12	9
Talc	14	28	12	15	11	13
Amphibole		16		15	9	11

Riebeckite and stilpnomelane schists: This type of ore is less common in the Ržanovo deposit. It can easily be recognized compared to other types because it differs both in colour and structure. It can be considered as a typical metamorphic rock. Riebeckite rocks are blue and stilpnomelane are yellowish in colour. *Riebeckite schists* are mainly composed of riebeckite, talc, lizardite, phlogopite, digenite and pyrrhotine, while *stilpnomelane schists* are built of stilpnomelane, talc, maghemite, lizzardite, dolomite, quartz and pyrite.

Chemical analyses indicate that both riebeckite and stilpnomelanite schists are rich in nickel (Table 11). Nickel content in riebeckite schists is over 2% and in stilpnomelanite within 1.1%. It is worth mentioning that stilpnomelanite amount is lower relative to that of riebeckite.

Table 11

Chemical composition of riebeckite and stilpnomelane schists (%)

	II/8	III/1	V/1
Al_2O_3	6.60	5.92	1.88
T Fe_2O_3	16.72	43.89	40.05
MnO	0.73	0.18	0.23
MgO	7.62	9.35	8.36
Na_2O	5.07	0.66	0.80
K_2O	0.22	0.79	0.81
P_2O_5	0.36	0.49	0.38
SiO_2	46.33	27.06	25.37
SO_3	2.82	3.48	3.72
CaO	1.98	1.27	2.90
TiO_2	0.28	0.20	0.18
LI	0.16	3.40	9.08
H_2O	0.28	1.27	1.31
NiO	2.13	0.79	1.10
Cr_2O_3	7.00	2.93	2.66

Quantitative relations between individual minerals are given in Table 12.

Dolomite-talc schists: This lithologic type of mineralization is relatively less common in the Ržanovo deposit. It differs from other types in its colour. Types with large contents of iron minerals have a reddish colour.

Table 12

Quantitative mineral composition of riebeckite and stilpnomelane schist (%)
(II/8 riebeckite schist; III/1 stilpnomelane schist; V/1 stilpnomelane schist)

	II/8	III/1	V/1
Magnetite			
Hematite			
Clinochlore		20	
Talc	6	15	20
Stilpnomelane		29	42
Maghemite		35	7
Lizardite	6		10
Dolomite	5		3
Phlogopite	2		
Albite	10		
Amphibole	53		
Quartz			11
Pyrite			5
Digenite	6		
Pyrhotite			

Chemical analysis indicates that this type of ore contains less nickel than other types (Table 13). It is characterized by its large content of calcium, sodium and magnesium. The nickel content is from 0.80 to 1.06% NiO.

Table 13

Chemical composition of dolomite-talc schists (%)

	VI/1	VIII/3	VIII/4
Al_2O_3	1.47	1.20	1.92
tFe_2O_3	35.55	19.72	42.01
MnO	0.43	0.81	0.59
MgO	14.73	18.88	14.46
Na_2O	1.23	0.84	0.74
K_2O	0.19	0.18	0.18
P_2O_5	0.43	0.34	0.40
SiO_2	32.23	48.79	29.96
SO_3	0.72	0.32	0.30
CaO	6.73	3.79	2.09
TiO_2	0.01	0.01	0.01
LI	2.61	4.13	3.21
H_2O	0.18	0.14	0.24
NiO	0.80	0.87	1.06
Cr_2O_3	1.49	0.95	1.90

The mineral composition of this type in includes talc, dolomite, hematite, magnetite, amphibole, lizardite and clinochlore. A qunatitative relationship between individual minerals is given in Table 14.

Table 14

Quantitative mineral composition of dolomite-talc schist (%)

	VI/1	VIII/3	VIII/4
Magnetite		8	5
Talc	24	38	37
Hematite	18	26	42
Lizardite	6		
Dolomite	26	15	5
Amphibole	24		
Clinochlore		10	10

Talc schists: This lithologic type of ore occurs sporadically in the Ržanovo deposit. It can be seen along tectonic zones and tectonic mirrors. It is greenish in colour and contains small magnetite crystals.

The chemical composition shown in Table 15 indicates that the ore is rich in magnesium and silica, whereas the iron content is relatively low compared to other ore types. The nickel content ranges from 0.34 to 0.75%. Most probably there are several generations of talc, but each is nickeliferous. Only talc, as a product of non-metamorphic reactions, is a nickeliferous.

Table 15

Chemical composition of the talc schist (%)

	VI/6	III/8
Al_2O_3	1.05	0.37
tFe_2O_3	11.17	7.50
MnO	0.26	0.11
MgO	28.64	27.90
Na_2O	0.59	0.70
K_2O	0.18	0.10
P_2O_5	0.40	0.50
SiO_2	48.77	55.67
SO_3	0.26	0.63
CaO	1.63	1.08
TiO_2	0.01	0.01
LI	5.67	4.16
H_2O	0.30	0.16
NiO	0.75	0.34
Cr_2O_3	0.36	0.31

It is mostly composed of talc, clinochlore, magnetite, hematite and lizardite. Quantitative relationships between individual minerals are given in Table 16.

Table 16

Quantitative mineralogical composition of the talc schists (%)

	VI/6	III/8
Magnetite	15	8
Hematite	7	
Clinochlore		
Talc	64	89
Quatz		
Siderite		
Lizardite	9	

Serpentinite: Serpentinite is a common member of the Ržanovo deposit (Fig. 8).

It occurs as lenses or detritus which is a constituent part of the ore reserve. This type is poor in iron and nickel, but rich in magnesium and silica (Table 17).

It is built of several minerals such as lizardite, hematite, dolomite, talc and magnesite.

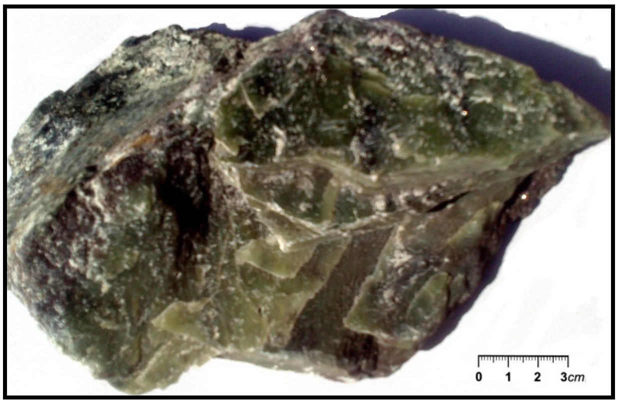


Fig. 8. Macro-photograph of serpentinite from the Ržanovo deposit

Tabela

Quantitative mineralogical composition of serpentinite in %

Sample	V/6
Mgnetite	11
Talc	30
Hematite	21
Lizardite	30
Dolomite	6
Amphibole	–
Clinochlore	–

Table 17

Chemical composition of serpentinite (%)

Al_2O_3	$Fe_2O_{3(t)}$	MnO	MgO	Na_2O	K_2O	P_2O_5	SiO_2	SO_3	CaO	TiO_2	LOI	H_2O	NiO	Cr_2O_3
1.39	12.35	0.16	31,67	0.83	0.20	0.40	41.31	0.26	1.37	0.01	9.68	0.73	0.37	0.39

CONCLUSIONS

Lateritic Fe-Ni ores within the Ržanovo ore deposit were produced within the lateritization processes of ultrabasic complexes, which took place during the Upper Cretaceous. The Ržanovo deposit is a typical represent of redeposited type of lateritic ores, which ore layer during the Alpine tectonics was disturbed and overturned.

Main types of ores within the Ržanovo deposit are schistose hematite ores, massive magnetite ores as well as compact hematite ores that represent the major economic type of ore, too. Quantitative ratios of major ore phases is illustrated by the presence of the most abundant minerals: magnetite, hematite, hromite, sulfides, talc, chlorite, amphibole and stilpnomelane. Quantitatively the most abundant is hematite with a total amount of 41.61% and of course it has the utmost importance as a nickel carrier at the Ržanovo deposit. In the chemical composition of the allocated types of ores within the Ržanovo deposit dominated iron oxides and silica. From the genetic aspect the Ržanovo deposit is a typical sedimentary deposit of redeposited laterites.

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Р е з и м е

НЕКОИ КВАНТИТАТИВНИ АСПЕКТИ НА ГЛАВНИТЕ ТИПОВИ РУДИ ВО ЛАТЕРИТСКОТО Fe-Ni НАОЃАЛИШТЕ РЖАНОВО, Р. МАКЕДОНИЈА

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Клучни зборови: преталожени латерити; железо-никлоносни руди; хемиски состави; квантитативни минерални состави; минерални фази

Резултатите од деталните лабораториски испитувања на рудите од латеритското Fe-Ni наоѓалиште Ржаново, Република Македонија, овозможија издвојување 9 типа руда и на дефинирање на нивниот хемиски состав и на квантитативната минерална застапеност нив. Во сите типови руда содржината на никел е дефинирана во граници од 0.34 до 3.1% NiO. Сепак, за најпродуктивни типови се сметаат масивните магнетитски, шкрилестите магнетитски, шкрилестите хематитски и масивните хематитски руди. Економски најважна е компактната хематитска руда со содржини на никел во опсег од 0.93 до 1.49% Ni. Главни минерални фази (носители на никелот) во наоѓалиштето Ржаново се магнетит, хематит, клинохлор, талк, сепиолит, магнезиорибекит, лизардит, доломит, флогопит и стилпномелан. Процентуално најзастапен минерал во рудата од наоѓалиштето Ржаново е хематитот со 40.61%, потоа талкот со 20.90%, амфиболот со 13.60%, магнетитот со 11.16% и клинохлорот со 10.65%. Високата содржина на железо, над 55% Fe_2O_3, е карактеристична за магнетитските и хематитските руди, додека високата содржина на силициум, преку 50% SiO_2 е карактеристична за магнезиорибекитот, талкните шкрилци и др.