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The magnesites from the Dinarides

Ivan Jurković[1] & Jakob Pamić[2]

Abstract: **In the first part of the paper are presented all genetical types of magnesites from the Dinarides; vein-, network-, sedimentary-, detrital, and deluvial – alluvial.**

In the second part of the paper, oxygen and carbon isotope values are analysed in detail for 114 samples from 36 magnesite deposits of all genetical types. Two new genetical types: Oshve- and Greiner types are established.

In the third part of the paper is carried out correlation of oxygen and carbon isotope composition of the identical genetical group of the Dinarides and those over the world. Complete agreements are established for vein- and network-types deposits, except for the Oshve-type. Sedimentary and detrital magnesites from the Dinarides are different in isotope composition than those from the world. This can be explained by the fact that the Dinaridic sedimentary and detrital magnesite deposits are only of Miocene, whereas those from the world were originated from the Archean to Pleistocene-Quaternary. At the end are critically reviewed different opinions on the magnesite deposits of the Dinarides and proposed a new author's genetical model.

Key words: Dinarides, magnesite deposits, isotope compositions of carbon and oxygen, comparison with other world deposits, genetic model.

INTRODUCTION

All genetical types of magnesites in the Dinarides are spatially related to ophiolite formations wich make up most of the Internal Dinarides. First systematic and detailed petrological data on the Dinaridic ophiolites have been presented by *Kišpatić (1897)* in his monograph "Rocks from the Serpetinite Zone in Bosnia". He systematically sampled

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[1] Voćarska cesta 63/I, Zagreb
[2] Hrvatska akademija znanosti i umjetnosti, Ante Kovačića 5, Zagreb

all ophiolite and associated metamorphic rocks through out the Bosnia part of Dinaride Ophiolite Zone and gave first detailed petrographic descriptions of all main ophiolitic rock types, focusing his attention to the most predominant ultramafic rocks represented by lherzolites. Afterwards trough more then hundred years numerous petrological papers, including many Ph.D. Thesis were published on the Dinaridic ophiolites and in all of them ophiolite classification and rock determination given by Kišpatić were used.

Numerous and various, primary and secondary mineral deposits are spatially and genetically related to the Dinaridic ophiolites *(Janković, 1982; Jurković, 2000, 2001).* Among them, very important are magnesite deposits of various genetical types. Numerous papers were published on the Dinaridic magnesites from different separate areas *(Hiessleitner, 1934; Ilić, 1952; Donath, 1955, 1957; Ilić Jr., 1964, 1969; Zekić, 1972; Petrov et al., 1979; Vakanjac & Tomanec, 1982; Vakanjac et al., 1983; Lapčević, 1982, 1988; Sunarić – Pamić & Pamić, 1988; Fallick et al., 1991; Obradović et al., 1996),* however most of them were published in loco journals and languages and thus are not available to the international geological community.

The aim of this paper is to give the first overview and synthesis of the Dinaridic magnesites as a whole with the emphasize on their carbon and oxygen isotopic compositions which represented the basis for genetical consideration and conclusions.

Basic geological data on the Dinaridic ophiolites

All Dinaridic ophiolites are related to ophiolite mélanges which are included into the Jurassic Dinaride Ophiolite Zone (i) and Cretaceous/Early Paleogene the Sava-Vardar Zone (ii). In both zones, among ophiolites ultramafic rocks predominate over diabase-basalts and gabbros, in some places with amphibolites *(Pamić et al., 2000; Pamić, 2002).*

Predominant peridotite tectonites are represented mainly by fertil spinel lherzolite in the western and central part, both of the Dinaride Ophiolite Zone and Sava-Vardar Zone, and by depleted harzburgites in their southwestern parts.

In both the Dinaride Ophiolite Zone and Sava-Vardar Zone, ultramafics, which represent source rocks for the generation of magnesite deposits of all genetical types, predominantly occur as small, centimeter to decimeter-sized fragments or hectometre to kilometre-sized bodies included in the mélange, commonly completely serpentinized and cataclasized. There also occur large massifs (100-1000 km^2) corresponding to thrust sheets onto the mélange varying in thickness from a few hundreds up to 2000 m (e.g. Krivaja-Konjuh massif) as indicated by geophysical prospecting data *(Roksandić, 1971).*

Ophiolites from the Dinaridic Ophiolite Zone are genetically related to the open-ocean Tethyan realm, whereas highly dismembered ophiolites of the Sava-Vardar Zone are related to a back-arc basin. These two ophiolite zones continue without a break southeastwards into the Hellenides.

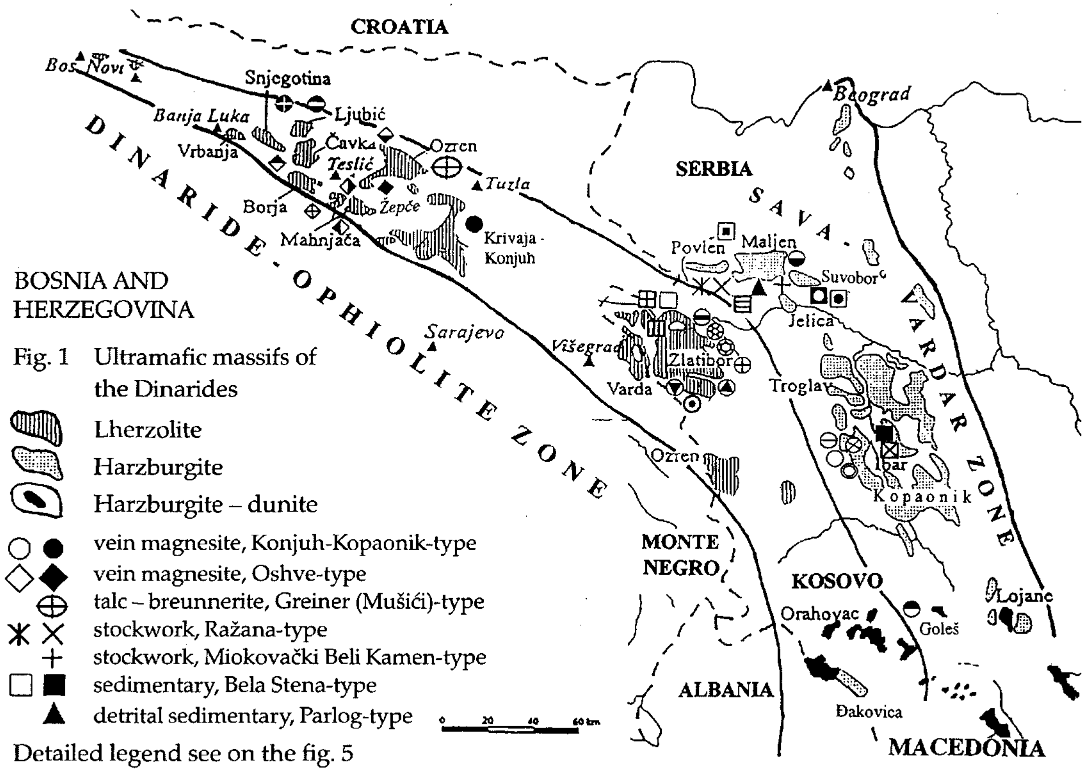

Fig. 1 Ultramafic massifs of the Dinarides

Detailed legend see on the fig. 5

MAGNESITE DEPOSITS AND OCCURRENCES

The most prominent systematics of the world magnesite deposits are those published by: *Redlich (1909, 1934), Bain (1924), Tatarinov (1946), Destombes (1956), Ilić, Jr. (1969), Pohl (1989) and Kralik et al. (1989).*

Based on synthetized data from all available published data on magnesites from the Dinarides the following genetical groups types of magnesites can be distinguished. **(Fig. 1, and fig. 5).**

A. Vein deposits: A_1 the Konjuh-Kopaonik-type; A_2 the Oshve type; **B. Network (Stockwork) deposits:** B_1 the Ražana-type; B_2 Miokovački Beli Kamen (MBK)-type; **C Greiner-type:** C_1 the Mušići talc-breunnerite-type: **D. Sedimentary deposits:** D_1 Bedded magnesites and dolomites of the Šilopaj-, Branešci- and Ražana-type; D_2-irregular magnesite bodies of the Bela Stena -type; **E. Resistates:** E_1 intraformational Miocene paleoresistates of the Parlog- and Janok-type; E_2 Recent resistates of the Badanj- and Kukavica-type. All these magnesite deposits are genetically and spatially related to ophiolites, e.g. ultramafic rocks.

A. Vein deposits (Kraubath-type)

A_1 The Konjuh-Kopaonik vein-type deposits **(Figs. 2a and 2b)**
A_2 The Oshve vein-type deposits **(Fig. 2c)**
The vein-type magnesites occur in the following peridotite massifs **(Fig. 1).**

I. Bosnia and Hercegovina: Ljubić (Tanasić Creek, Sigovac), Vrbanja, Snjegotina, Čavka (Čečava), Mahnjača (Kopice, Miloševo Jarak, Blatnica), Ozren (Moševac, Oshve), Konjuh (Miljevica) and Varda. References: *S. Ilić (1956), Ristić & Panić (1965), Živanović (1968), Ilić, Jr. & Jelić (1976), Ilić. Jr. & Đorđević (1980), Sunarić-Pamić & Pamić (1988).*

11. Serbia: Maljen (Brezak), Suvobor, Ibar-Kopaonik (Zimovnik, Poljane, Trnava), Troglav, Kopaonik, Zlatibor (Kadinjača, Čavlovac, Ćave, Liska, Stublo, Gola Brda, Draglica).

References: *Manojlović (1958), Ilić, Jr. & Manojlović (1962), Zekić (1977) Ilić, Jr. & Rubežanin (1978), Zekić & Joksimović (1978), Vakanjac & Tomanec (1982), Vakanjac et al. (1983), Janković (1990), Popević et al. (I 996).*

111. Kosovo: Goleš (Magura), Dubovac. References: *Ristić* & *Đorđević (1957), Škerlj (1965), Janković (1990).*

Characteristics of the Konjuh-Kopaonik vein magnesites

Country rocks of magnesite deposits and occurrences are largely serpentinites and locally amphibolites and gabbros tectonically included into serpentinites. The serpentinites are mainly made of lizardite and clinochrysotile *(Sijarić & Ščavničar, 1972)*. Only the Mt. Konjuh-type magnesite are included in fresh to moderately serpentinized lherzolites.

Mineral paragenesis. Magnesite and subordinately its ferroan variety, **breunnerite,** are the only major ore minerals of magnesite deposits. Silica minerals, represented by **quartz,** rarely **tridymite** and **chrystobalite,** fibrous **chalcedony** and **opal,** are commonly unevenly mixed with the magnesite. **Serpentinite xenoliths** also occur, particularly in marginal parts of magnesite veins close to the contact with host serpentinite.

Secondary postore **minerals,** which occur in veinlets, lenses, nests and irregular aggregates within magnesite bodies and the surrounding host serpentinite are also represented by the same **silica minerals,** and **dolomites** which predominate over **calcites,** and **sepiolites.** These minerals vary in proportions within magnesite. deposits and thus define, their quality.

Structure and texture. Micritic magnesite is the most common textural variety. It consists of minute (10- 15 microns) and cloudy magnesite unevenly included in the matrix of subordinate sparry magnesite in the form of crumbles and/or fine tubereles, 0.5 to 0.2 mm in diameter. Sparry magnesite is subordinate than the micritic variety and complete gradation between them are recognised. The size of grains varies between 25 to 100 microns averaging about 50 microns; as a rule, remnants of micritic cloudy magnesite is always preserved.

Intraclastic (detrital) magnesite is present in most of magnesite deposits. The irregular magnesite intraclasts with some serpentine admixtures are 0.2-0.5 to 2-5 mm in diameter. Cement both of fine-detrital magnesites and coarse-detrital magnesite is made up of cloudy micritic magnesite, slightly to moderately recrystallized with chalcedony admixtures.

Brecciated magnesites and magnesite breccias originated by cataclasation are in many places cemented by secondary dolomite and chalcedony.

Most of magnesite bodies are massive in **structure.** However, some magnesite deposits are **oolitic** and **pisolitic in structure** and contain rounded fragments, up to a few centimetre in diameter, which are concentrically zoned with internal magnesite embraced by outer dolomite ± quartz ± opal concentric zones. Cement of the oolites is composed either of scalenohedral dolomite mixed with subordinate silica minerals or cloudy micritic magnesites.

Mode of occurrence. The magnesite deposits and occurrences occur largely as veins commonly positioned along fault zones within ultramafic massifs or along their faulted margins. These are single, echalon and parallel to subparallel veins with morphologies depending on the characteristics of the fault zones **(Fig. 2a,2b).** Magnesite ore also occurs in form of lenses, networks, stockworks and irregular bodies.

Shapes of magnesite veins can be simple and complex with apophysal branching, locally in form of "rosary' and thickened lenses. Length of magnesite veins commonly

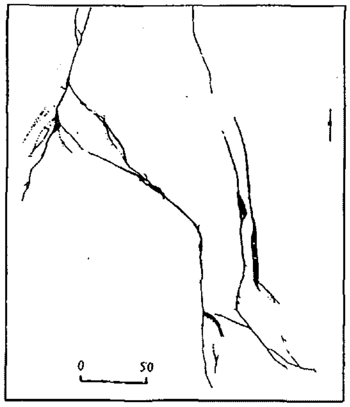

Fig. 2a. Distribution and shape of the **Miljevica** (Konjuh Mt.) vein magnesites in the underground horizon +960 m. *(Sunarić – Pamić & Pamić, 1988)*

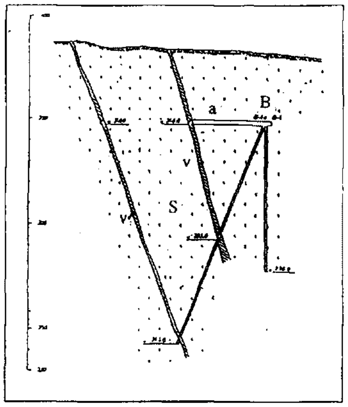

Fig. 2b. Profile of the **Brezak** magnesite veins (Maljen massif) v – vein, S – serpentinite, a – adit, B – borehole *(Ilić & Manojlović, 1962)*

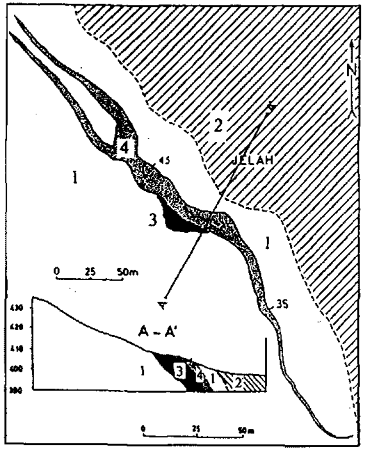

Fig. 2c. **Oshve** vein deposit A – A' profile 1 – serpentinite; 2 – Jurassic ophiolite mélange; 3 – dacite dyke; 4 – magnesite vein. *(Ilić & Đorđević, 1980).*

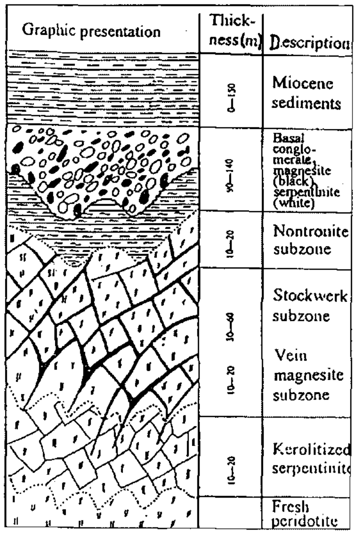

Fig. 2d. Stockwerk magnesite **Ražana-Ćosovac** (Maljen massif) *(Lapčević, 1988)*

varies from a few tens up to several hundred meters. However, some of them are very long, as for example, along the Mt. Konjuh fault zone which is about 8 km long and includes numerous separated magnesite veins, some of them 200 m to 1200 m long. The Magura vein (Mt. Goleš) is also 1200 m long. Thickness commonly varies from a few centimeters and tens of centimeters up to more than 1 metre, locally in the thickened parts of magnesite veins up 1 to 5 m, exceptionally up to 20 m; average thicknesses are commonly between 0.5 to 1.5 m.

Depths of magnesite veins depend on the size and thickness of ultramafic bodies and fault zones, respectively. The maximal exploited depth of the Mt. Konjuh magnesite vein is 220 m, however it continues further in depth. The depth of the Zimovnik vein is 400 m, of the Liska vein >200 m, and of the Magura vein 300 m. The depths of the magnesite veins in smaller ultramafic bodies is as high as 50—100 m as proved by drilling. Inclinations of magnesite veins are mainly between 45 and 80º.

On the basis of 13 oxygen and carbon isotope compositions and common occurrence of oolitic and pisolitic structures **the Oshve type** of deposits has been for the first time proposed under the term Teslić-Žepče by *Sunarić-Pamić & Pamić (1988)*, (see **Fig. 5**). Afterwards *Fallick et al. (1991)* carried out two additional isotope analyses of magnesites from the Oshve deposit and obtained very similar results and thus approved the earlier data which they did not know.

Based on data of *Đorđević (1973), Ilić, Jr. & Đorđević (1980)* and *Sunarić-Pamić & Pamić (1988)*, main signatures of the Oshve. magnesites are as follows. Vein is 450 m long, varying in thickness from 0.5 to >10 m and averaging 2.5 m; it was explored along the dip for 75 m but with its further prolongation. The deposit is located in marginal parts of strongly serpentinized peridotite close to its contact with Jurassic ophiolite mélange (**Fig. 2c**) and is directly underlain by partly exposed shoshonite dyke, which is strongly hydrothermally altered and crosscut by veinlets of magnesite and other carbonates. In the neighbourhood of Oshve there are several Oligocene shoshonite dykes and thermomineral springs *(Majer, 1961; Trubelja & Pamić, 1956; Pamić et al., 1964; 2000)*. Ore paragenesis is the same as in Konjuh-Kopaonik vein magnesites. Average chemical compositions vary from 2.5 - 3.8 for $Si0_2$, 3.7 – 4.4 for CaO and 40.5 - 42.5 (wt.%) for MgO.

B. Network (stockwork) — type magnesite deposits

This type of deposit occurs exclusively in crusts of weathering of ultramafics. The remnant crust of weathering is poorly preserved within ultramafic bodies due to erosion and it is much better preserved in their marginal parts, particularly those which are covered by Neogene fresh-water sediments. Host rocks are disintegrated, nontronized (or silicified) and cerolitized serpentinite. The crust of weathering has vertically zoned pattern consisting, if it is completely preserved, of four zones going downwards. 1) In the **ocher zone**, about 5-10 m thick, Fe-hydroxides and oxydes predominate (80%) over silica oxydes, Ni-silicates and carbonate veins 2) The **nontronite zone**, about 5-10 m thick, is composed going downwards of α-cerolite replacing Fe-cerolite (0.1 -0.3 m) and mixture of Fe-montmorillonite, locally with halloysite, Fe-halloysite and Mn-hydroxydes. Unlike the underlying zone, the nontronite zone is enriched in Ni and Fe accompanied by sharply increasing Mg. 3) The **leached serpentinite zone**, 10-20 m thick, is characterized by net serpentine in which chrysotile is significantly replaced by α-cerolite and microcrystalline magnesite. Veinlets of opal, chalcedony and Mg-, Ni-silicates are abundant in upper parts of the zone, and 2-5-10 cm, rarely to 30-50 cm thick veins in its lower parts. 4) The **disintegrated zone**, about 30-40 m thick. is characterized by the commence of formation of α-cerolite and carbonates in cracked bat still coherent serpentinite (*Lapčević, 1978, 1982, 1988; Ilić, 1969*).

B_1. The Ražana-type (Figs. 2d and 3a)

The **Ražana-type** magnesites from four larger deposits: **Mramor-Ražana, Ćosovac-Ražana, Alin Creek** and **Mandić Creek**, all of them positioned in marginal parts of the Maljen ultramafic massif (**Fig. 1**) form the zone 3 km long and 2 km wide. These magnesite deposits contain (in wt.%): 3.5-8.7 SiO_2 0.4-2.1 CaO, 41.3-46.5 MgO and 46.0-48.7 CO_2).

The Glavica deposit in the Goleš massif and the Groot deposit in the small peridotite massif east of the town Velež (Macedonia), occurred during the Lower Cretaceous *(Ilić, Jr., 1988, Fallick et al., 1991)*. All other stockwork magnesite deposits originated in postorogenic stage when the Dinarides, were uplifted and affected by weathering and erosion. The Ražana-Ćosovac and Mramor-Ražana deposits are overlain by Miocene basal sediments, 80-135 m and 30-80 m thick, as indicated by drilling. The Miocene sediments are underlain by serpentinite crust of weathering represented by nontronite zone and partly leached serpentinites. References: *Luković & Petković (1929), Manojlović (1970), Ilić, Jr. (1968,1983). Lapčević (1978, 1980/81, 1982, 1988).*

In the Žepče area in Bosnia, complete peridotite crust of weathering is preserved and it is disconformably overlain by fresh-water Miocene sediments. Going upwards it is composed of three zones: 1) fresh to moderately serpentinized spinel lherzolites; 2) serpentinites crosscut by veins and veinlets filled by magnesite, dolomite, calcite and opal, and 3) brecciated and disintegrated serpentinites mixed with nontronite-bearing clays. *(Hamzabegović et al.. 2000).*

B_2 The Miokovići – Beli Kamen-type deposit

This type of magnesite deposit was separated because of its quite different oxygen and carbon isotope composition *(Fallick et al., 1991)*. Both stable isotopes, and particularly oxygen, have extreme values indicating specific origin conditions. In appearance, the

Fig. 3a. Stockwerk magnesite **Ražana-Skakavci** (Maljen Massif) *(Luković and Petković, 1929)*

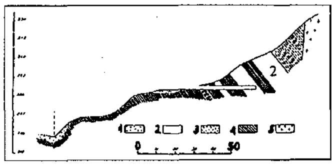

Fig. 3b. Bedded sedimentary magnesite deposits **Šilopaj** (Suvobor massif), locality Križ *(Ilić, 1969)*

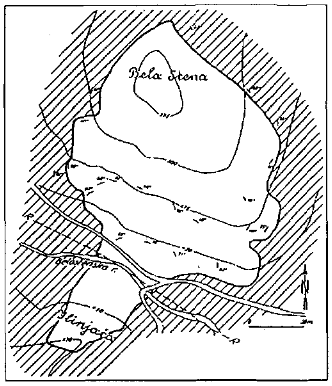

Fig. 3d. Geological sketch of the **Bela Stena** sedimentary magnesite deposit (Kopaonik Mt.) (white) in Miocene marls, shales and sandstones (hatched). *(Ilić, 1969)*

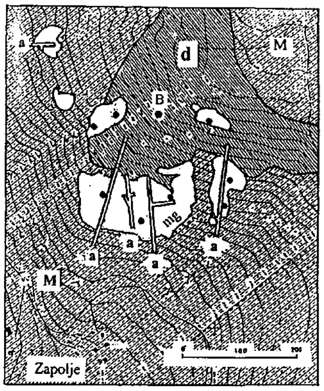

Fig. 3c. Geological plan of the **Strezovci Beli Kamen** sedimentary magnesite deposit (Kosovska Kamenica)
mg – magnesite; a – adit; d – dolostone; M – Miocene sediments; • B – borehole
(Ilić & Manojlović, 1967)

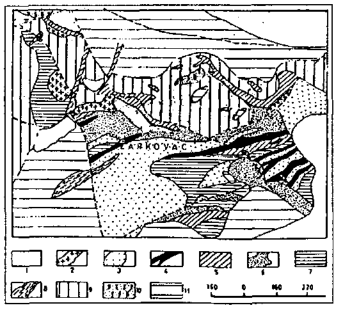

Fig. 3e. Geological map of the **Mušići-Žarkovac** talc – breunnerite deposit
1 – Pliocene – Quaternary; 2 – Granite porphyre; 3 – quartz – carbonate rocks; 4 – talc; 5 – serpentinite – carbonate – talc schists; 6 – carbonatized and talcitized serpentinites; 8 – serpentinitized schists; 9 – serpentinites; 10 – weathered lherzolites; 11 – serpentinitized lherzolites. *(Sunarić – Pamić et al., 1976)*

Miokovački-Beli Kamen deposit displays the same zoned pattern as the Ražana-type deposit. Here, the crust of weathering is a few hundred metres long with variable width and 40-60 m depth. Parts of the deposit is covered by Neogene sediments and preserved the uppermost ocher zone accompanied by nontronite zone, leached serpentinite zone, and cerolitization zone (mixture of yellow and green serpentinite and stevensite). In the leached serpentinite zone. shape and thickness of magnesite veins vary, most commonly from 10-50 cm and rarely up to 1-2 m penetrating the lowermost zone. Crude ore contains 7-23% magnesite averaging 15% with average chemical composition: 5.43% SiO_2, 1.17% CaO and 44.24% MgO. References: *Ilić, Jr. & Popević (1970), Ilić, M. (1959), Lapčević (1978).*

C. Breunnerite-talc deposits (the Greiner-type -Fig. 3c)

These deposits first described by *Vakanjac (1964.1965, 1967)*, occur with zoned contactmetamorphic pattern between albite granosyenite intrusion and host serpentinitized lherzolites of Mt. Ozren in North Bosnia **(Fig. 1)**.

In the Mušići and Žarkovac in the Mt. Ozren contactmetamorphic breunnerite-talc deposits the following zonation is developed: granosyenites → quartz-breunnerite rocks (23%) → talcites (33%) → talc-breunnerite (magnesite) rocks (20%) → serpentinites (24%) → serpentinized lherzolites. The hydrothermally metamorphosed zone wich is 150 m long and 40 to 75 wide and positioned between granitoids and ultramafics. inludes five talc beds, 5-10 m thick **(Fig. 3c)**. The ore contains talc (93%). chlorite (4.5%), pyrite (2.5 %) and some breunnerite with quite scarce chalcedony *(Đorđević, 1969)*.

Sunarić-Pamić et al. (1976) compiled all available data on the Mt. Ozren deposits and concluded that the ore paragenesis contain **talc, magnesite (breunnerite), chlorite, dolomite, calcite, Cu-bearing pyrite (1600 ppm Cu), magnetite** and **limonite.** In the ore zone comprising 200 x 70 x 80 m reserves of 3.100.000 t were calculated. On the locality Žarkovac mineralization covers surface 450m long, 250 m wide, and 77 to 134 m deep with reserves over 4 millions tonnes with 50% to 40% breunnerite and 2% pyrite. In both ore areas the reserves were supported by drilling.

D. Sedimentary magnesite deposits

After the last Eocene Alpine deformation the uplifted Dinarides were affected during the Oligocene by strong transcurrent and transtensional faulting which gave rise to the formation of disconnected intramontane basins scattered throughout the Dinarides.

Tensional tectonics in the early and middle Miocene produced fresh-water lacustrine basins **Ražana. Dobrinje, Pranjani, Čačak-Kraljevo, G. Milanovac** in the Šumadija area, **Jarandol, Rvati, Ušće basins** in the Ibar area, **Kremna, Kačer, Bioska, Mačkat, Branešci** basins in the Zlatibor Mt. area and **Strezovci basin** in the Kosovo area **(Fig. 1b).**

The lower parts of these fresh water sequences are built up of basal conglomerates, breccias and psammitic rocks, wich often hosts the Parlog-type detrital magnesite and dolomite deposits.

The upper part is built up of carbonates and marls which host marly magnesite or magnesite-bearing marls with 28-45% MgO and 7-30% SiO_2 In some basins there are cherts tuffs and subaquatic dacitoandesites. Some basins contain boron minerals or elevated boron content. In the Kremna basin occur numerous **searlesite pellets** ($Na, B [SiO_3]_2 \cdot H_2O$), and in sediments 1 km north of the Bela Stena deposit **colemanite** ($Ca_2B_6O_{11} \cdot 5 H_2O$) and **howlite** ($Ca_2B_5Si_9 [OH]_5$). Carbonates of the Bioska basin have increased boron content (800 to 3200 ppm B) and those of the Kačer basin over 3000 ppm B *(Ilić, Jr., 1969; Živković & Stojanović (1976); Obradović et al., 1992, 1996).*

Magnesites and dolomites from the upper part of the Miocene basins occur either as beds (Nevade, Šilopaj, Kačer, Branešci, Čerenje, Mačkat, Kremna, Ražana. Bioska) or as lensoid irregular bodies (Bela Stena, Strezovački Beli Kamen, Rvati) or as redeposited conglomerate (Janok).

References: *Ilić (1952,1959), Manojlović (1960), Ilić, Jr. & Manojlović (1967), Ilić, Jr. & Popević (1970), Joksimović & Zekić (1974), Dedić (1978), Ilić, Jr. (1969,1988), Obradović et al.(1992, 1996).*

D_1. Bedded sedimentary magnesite deposits-the Bela Stena-type (Figs. 3b,c,d).

The intramontane Neogene basins positioned within the Dinaridic ultramafic massifs include bedded and/or lensoid sedimentary magnesite deposits which are interstratified in upper parts of fresh-water Middle Miocene sequence. The main deposits are as follows: **Bela Stena** with **Ilinjača (Fig. 3d)** and **Slane vode, Strezovački Beli Kamen (Fig. 3c), Rvati, Nevade, Šilopaj (Fig. 3b), Kremna, Bioska, Mačkat, Kačer, Branešci** and **Čerenje.**

Bela Stena which is included in the Jarandol intnamontane fresh-water basin of the Mt. Kopaonik area is the largest sedimentary magnesite deposit with 5.000.000 t reserves **(Fig. 3d)**. The deposit represents a dome with dimensions of 250 x 190 x 94 m, containing: 0.63-1.32 % SiO_2 0.36-1.71 % CaO, 46.00-47.09 % MgO and 48.42-50.34 % CO_2. The ore body was affected by young tectonic movements and the southern subsided block represents the **Ilinjača** deposit with 76 x 56 x 39 m, which is largely composed of brecciated magnesite.

The **Rvati** magnesite deposit, which is also positioned in the Jarandol Neogene basin. is lensoid with dimensions: 120 x 130 x 20 m and reserves of 300.000 t; however, the ore contains increased quantities of SiO_2 and CaO.

Sedimentary deposits **Šilopaj** and **Nevade** are situated in the Gornji Milanovac area, the Suvobor ultramafic massif. The Šilopaj deposit includes two occurrences, Ciganka with two beds and Križ with 3 beds. The beds are 250 m long and 1-3 m thck **(fig. 3c)** Crude ore is low-quality.

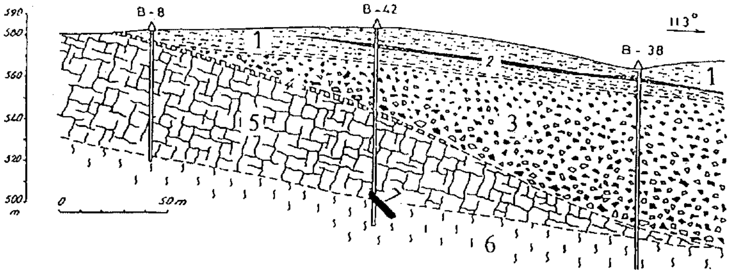

Fig. 4a. Geological profile of the **Ražana – Ćosovac** stockwork magnesite deposit
1 – sandy clays; 2 – magnesite bed; 3 – magnesite (black) – serpentinite (white) conglomerate; 4 – nontronite zone; 5 – altered serpentinite with magnesite stockwork; 6 – fresh serpentinite; 7 – magnesite vein *(Pavlović & Čvorović, 1970)*

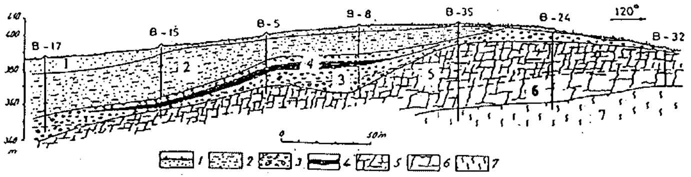

Fig. 4b. Geological profile of the **Parlog** detrital sedimentary deposit
1 – humus; 2 – Miocene marl, shale, sandstone; 3 – magnesite (black) – serpentinite (white) breccia – conglomerate; 4 – compact magnesite; 5 magnesite stockwork (< 30%); 6 – magnesite stockwork (< 10% of $MgCO_3$); 7 – fresh serpentinite
(Vanić, 1978; Ilić, 1983)

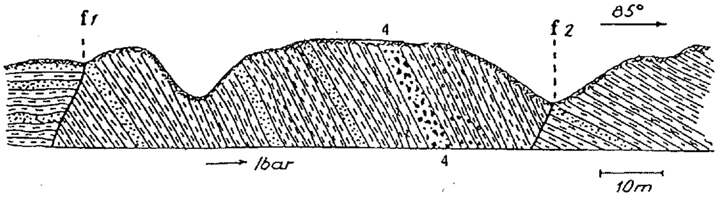

Fig. 4c. geological profile of the **Janok** detrital sedimentary deposit (Ibar River)
1 – 3 Miocene sediments: 1 – marls, 2 – shales, 3 – sasndstones; 4 – magnesite conglomerate; f – fault *(Ilić, 1963, 1983)*

In the Mt. Zlatibor area, beside larger vein magnesite deposits, there are also several smaller sedimentary magnesite deposits which are interlayered in several smaller intramontane basins. e.g. **Kremna, Bioska, Mačkat, Kačer** and **Branešci.** All these magnesite deposits are low quality *(Ilić, M. 1959; Pavlovć & Radukić 1961; Ilić Jr. & Popević, 1970; Manojlović, 1960; Obradović et al., 1992, 1994, 1996, Popević et al. 1996).*

E. Detrital magnesites

These sediments can be subdivided into two groups.

1) The Euboea-type deposit wich occur in basal parts of Neogene fresh-water sediments represented by conglomerates and breccias composed of magnesite and serpentinite fragments included in red clay and carbonate-silica cement. The magnesite and serpentinite pebbles derived from adjacent stockwork magnesites, located in ultramafics. The most important are **Ljetovnik, Parlog** and **Ražana Basin** occurrences **(Figs. 3 and 4).**

The Parlog magnesite deposit is positioned in marginal parts of Neogene basin at Čačak which are close to Brezak (Mt. Maljen) vein-type magnesites and Miokovački Beli Kamen stockwork-type deposits. As distinguished from the Janok magnesites, the Parlog deposit is located in Miocene basal conglomerates and breccias, with dimension 400 x 200 x 15 m. Proportions between magnesite and serpentinite vary from 70:30 to 95:5 with carbonate or silica cement. The Parlog magnesites, which are underlain by stockwork magnesites, are of low quality (e.g. 10.0% SiO_2 and 4.1% CaO - Fig. 4b). In the same area (the Pranjani basin) occurs large (150 m x 50 m x 10 m) **Ljetovnik** magnesite deposit of the same genetical type. This deposit has been completely exploited *(Ilić, 1980).*

In the NE part of the Ražana Miocene fresh-water basin several detrital magnesite deposits occur in its basal series, 130 m thick. These are **Rosići, Alin Creek, Mandić Creek, Ražana River, Ražana village,** and **Veliko brdo (Fig. 4a).** Average chemical composition varies from 0.7 to 2.5% for $Si0_2$ 0.5 to 8.67% for CaO and from 1.0 to 1.6% for R_2O_3. In the footwall of the deposits, the network-type deposits Ražana, Mramor and Ražana-Ćosovac are found.

2) Intraformational detrital deposits of the Janok-type (Fig. 4c) the only representative of this subgroup, is represented by bed, 120 m long and 4 m thick which is interlayered in the Čačak-Kraljevo Miocene intramontane basin. The bed is wich is composed of mm-cm-dcm-sized pebbles of magnesites, dolomites and marls of Tortonian-Sarmatian age, is disconforrnably underlain by Lower Miocene sediments. Subordinate pebbles are composed of chert, quartz and volcanics and matrix is calcareous-clayish *(Ilić, Jr. 1963).*

E_2. Recent residual deposits

Within the Mt. Kopaonik ultramafic massifs, small **eluvial-deluvial** magnesite deposit **Kukavica** and **alluvial Badanj** crop out. The magnesite fragments wich vary from

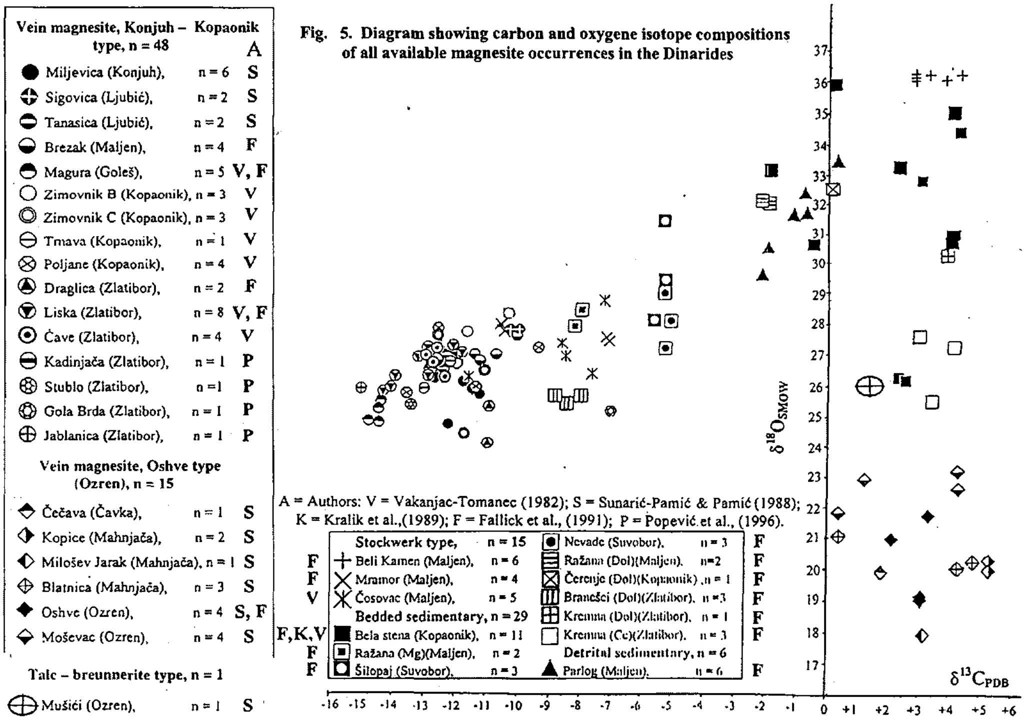

Fig. 5. Diagram showing carbon and oxygene isotope compositions of all available magnesite occurrences in the Dinarides

A = Authors: V = Vakanjac-Tomanec (1982); S = Sunarić-Pamić & Pamić (1988); K = Kralik et al.,(1989); F = Fallick et al., (1991); P = Popević et al., (1996).

10-30 cm in diameter, originated by erosion of adjacent vein-type and network-type magnesite deposits. Similar magnesite occurrences are found in **Mionica River** and **Čemernica River** within the Mts. Maljen and Suvobor ultramafic massif *(Ilić, Jr. 1964, 1969, 1980, 1983, 1984).*

CARBON AND OXYGEN ISOTOPE COMPOSITIONS

First stable isotope measurements were carried out on 18 magnesite samples from **Strezovac Beli Kamen,** 8 magnesite samples from the **Bela Stena** and **Rvati** sedimentary deposits, and 4 vein-type magnesites from the **Trnava-Zimovnik** area *(Ilić, Jr. & Popević, 1970).* Based on calculated $\delta^{13}C/\delta^{18}C$ and $\delta^{18}O/\delta^{16}O$ ratios, they concluded that the Strezovac Beli Kamen magnesites contain heavier carbon and lighter oxygen relative to magnesites from Bela Stena and Rvati, but also significantly heavier carbon and oxygen relative to the Zimovnik magnesites from Mt. Kopaonik massif.

In this paper are compiled all available stable isotope data published by *Vakanjac & Tomanec (1982); Schroll et al. (1986); Sunarić-Pamić & Pamić (1988); Kralik et al. (1989); Fallick et al.(1991); Popević et al.(1996)*

Sampling for stable isotope determination was carried out on 36 magnesite deposits and occurrences and total of 114 samples were measured. Most of them come from the Dinaride Ophiolite Zone and, to a lesser extent, from the Sava-Vardar Zone **(Fig. 1).** Spatial distribution of analyzed magnesite samples is demonstrated in **Figs. 5, 6 and 7.**

Based on stable isotope data presented in **Fig. 5.** it can be concluded as follows.

1) There are two quite different vein-type magnesite deposits: a) Widespread **Mts. Konjuh-Kopaonik** higher quality magnesites have interval of variation from –15.08 to-7.06‰ averaging –12.21‰ (n = 48) for carbon isotope and from +28.36‰ to +24.13‰, averaging +26.44‰ (n = 48) for oxygen isotope. b) Much more subordinate **Oshve-type** magnesites are spanned in the interval +0.25 to +5.26‰, averaging +3.08% (n = 15) for carbon isotope and +23.16 to +17.87‰, averaging +20.70% (n = 15) for oxygen isotope. The difference is 15‰ for carbon and 5-6‰ for oxygen relative to the Konjuh-Kopaonik type magnesites.

2) There are tw o quite different stockwork-type magnesite deposits: a) **Ražana-type** show variations spanned between -11.64 and -7.13 ‰ averaging -8.82 ‰ (n = 9) for carbon isotopes and +26.33 and +28.75‰ averaging +27.65‰ (n=9) for oxygen isotope; b) **Miokovići-Beli Kamen** display variations spanned between the interval of +2.78 to +4.25‰, averaging +3.15‰ (n = 6) for carbon isotope and +36.01 to +36.22 ‰, averaging +36.12‰ (n = 6) for oxygen isotope. These two stockwork types differ for 15‰ for carbon isotope and 8‰ for oxygen isotope. Based on the isotopic values, the Ražana-type magnesites are very close to the Konjuh-Kopaonik-type magnesites, indicating si-

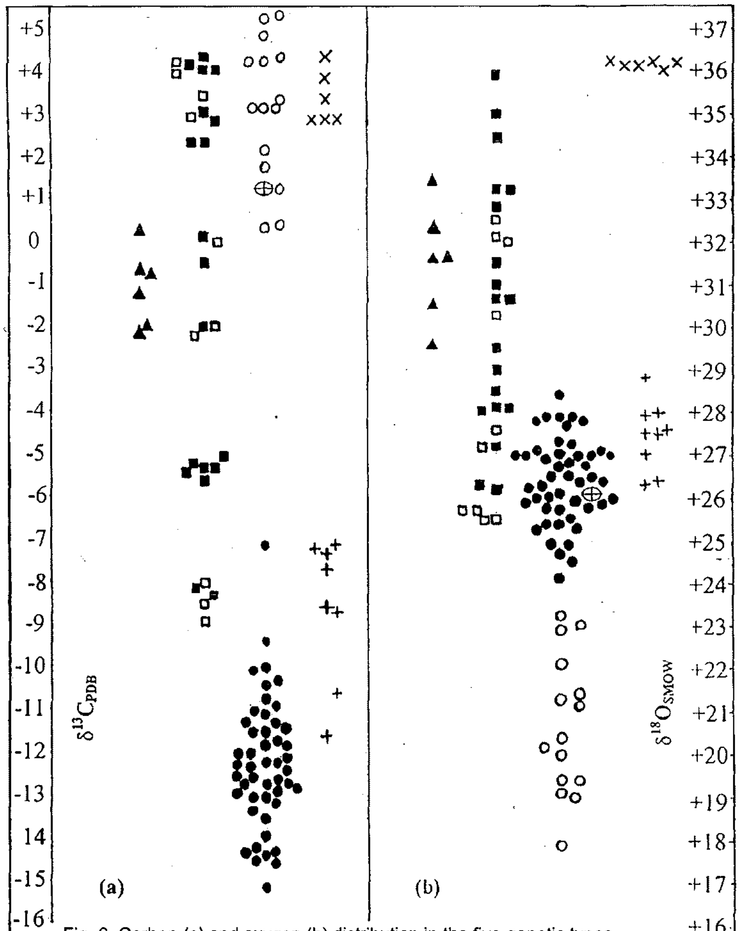

Fig. 6. Carbon (a) and oxygen (b) distribution in the five genetic types of magnesite occurrences in the Dinarides;

● vein magnesite, Konjuh type; ○ vein magnesite, Oshve type; ⊕ Talc – breunnerite, Mušići type;
+ × stockwork magnesite; ■ bedded sedimentary magnesite;
□ bedded sedimentary dolomite/calcite; ▲ detrital sedimentary

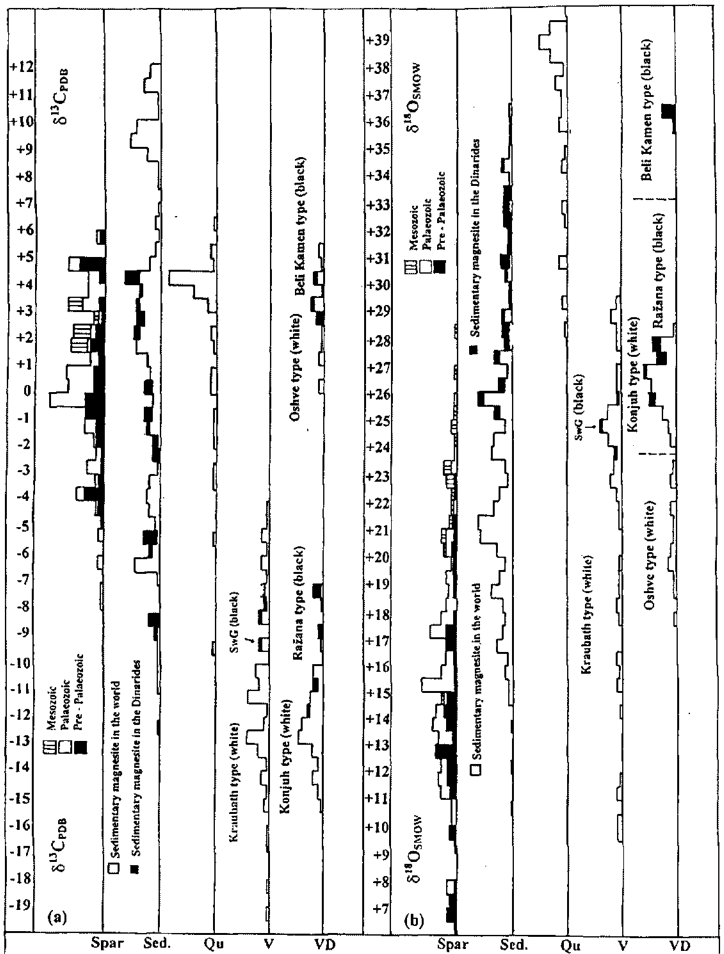

Fig. 7. Carbon (a) and oxygen (b) distribution in the four genetic types magnesite deposits in the world and in the Dinarides (a comparison)

Legend: Spar = Coarse – grained sparry magnesite Veitsch type; Sed = Cryptocrystalline – fine – grained sedimentary deposits Bela Stena type; **Qu** = Quaternary to Recent fine – grained magnesite deposits Coorong type; V = Cryptocristalline – microcrystalline vein magnesite in ultramafic rock Kraubath type; **VD** = Kraubath type in the Dinarides; **SwG** = Goldaki stockwork: analyses milar origin. Mioković-Beli Kamen magnesites are isotopicaly close to the Bela Stena-type magnesites, however they are characterized by more extreme isotope values.

3) For the first time in the Dinarides registered the **Greiner-type magnesite** deposits *(Redlich (1909).* This is supported by $\delta^{13}C$ value of +1.33‰ and $\delta^{18}O$ of +26.06‰ obtained on breunnerite e.g. magnesite from Mušići talc deposits *(Sunarić-Pamić & Pamić, 1988)* which is of hydrothermal origin *(Đorđević, 1969, 1973; Vakanjac, 1964; Jurković, 2001).*

4) Sedimentary deposits of the Bela Stena-type display large variations spanned between -9 to +4.5‰ (Δ= 13.5 ‰), for carbon isotope and +25.5 to +36‰ (Δ= 10.5‰) for oxygen isotope, indicating significant differences in origin. Detailed analysis of the results indicates four genetical subgroups: a) Ražana-Branešci magnesites and dolomites; b) Nevada and Šilopaj magnesites; c) Ražana, Čerenje Kremna dolomites, Bela Stena magnesites, and d) Kremna calcium carbonates **(Figs. 5 and 6).**

5) The Parlog-type detrital deposit is very similar in stable isotope composition to Ražana and Čerenje and partly Bela Stena dolomites. Its values vary in the interval from -2.19 to +0.24‰ for $\delta^{13}C$ and from +29.61 to +33.41‰ for $\delta^{18}O$.

These differences in stable isotope composition for each of the five genetic types are even more pronounced in **Fig.** 6 on which are grouped all isotopic values for each genetic type of magnesites. a) This holds for the Konjuh-Kopaonik and Oshve vein-type magnesites, particularly in respect to carbon. b) It is more distinct the difference between stockwork-types of Ražana and Miokovački Beli Kamen. c) It is very noticeable wide span of isotopic values of Δ = 13‰ for carbon and Δ = 10.5‰ for oxygen of sedimentary magnesites. Carbon isotope indicates four subgroups as mentioned above, whereas oxygen displays gradual scattering of points. d) isotope values for the Parlog detrital magnesites are very close to those of Bela Stena. e) Carbon isotope values for the Mušići magnesite (breunnerite) fit the Oshve-type magnesites and those of oxygen fit the Konjuh-Kopaonik vein-type magnesites.

Correlation of stable isotope composition of the Dinaridic and world magnesite deposits

In the preparation presented in **Fig. 8** the papers published by *Kralik & Hoefs (1978), Taylor et al., (1986), Rosen et al. (1988), Kralik et al. (1989), Gartzos (1990), Jedrysek & Halas (1990), Spötl & Burns (1994), Hoefs (1997)* and *Melezhik et al. (2001)* were used, as well as those in which stable isotope data for the Dinaridic ophiolite- related were published. In the diagram are presented boundaries of isotopic fields for different genetical types of the Dinaridic magnesites (straight full lines) and of world magnesites (curved dashed lines) to pointing possible genetical conclusions.

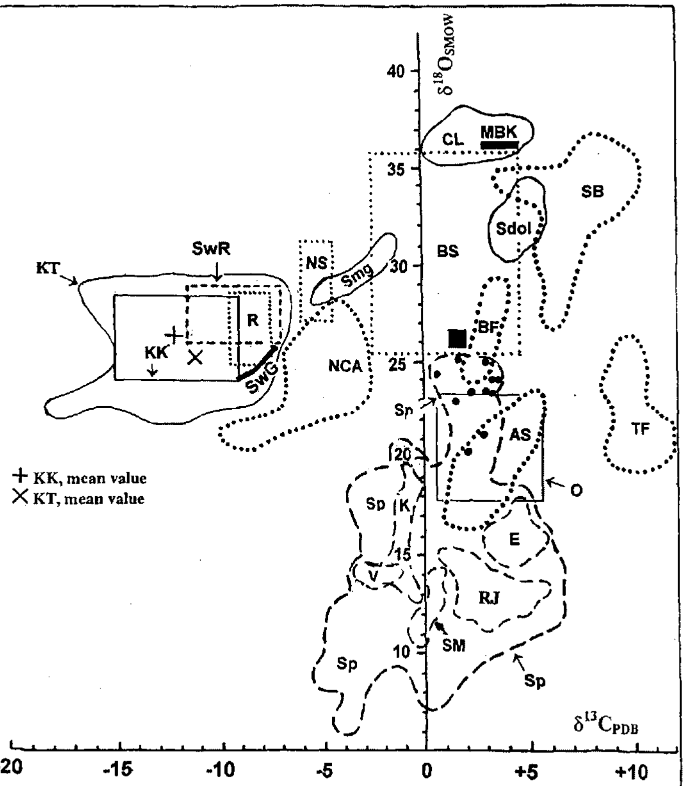

Fig. 8. Comparison of the carbon and oxygen isotope values between the Dinaridic (regular figures) and world (irregular figures) types of magnesite deposits.

KK – Konjuh-Kopaonik vein type; **KT** – Kraubath vein type; **O** – Oshve vein type; **Sw** – stockwork type: **SwR** – Ražana, **SwG** – Goldaki; – **MBK** – Miokovački Beli Kamen; bedded sedimentary type: **BS** – Bela Stena; **NS** – Nevade-Silopaj; **R** – Ražana; **SB** – Servia Basin; **NCA** – Northern Calcareous Alps; **BF** – Barton Farm; **AS** – Adelaide Syncline; **TF** – Tulomozerskaya Formation; recent sedimentary type: **CL** – Coorong Lagoon; **Smg; Sdol** – Sebkha el Melah; **Sp** – spar magnesite: **V** – Veitsch; **E** – Eugui; **RM** – Rum Jungle; **K** – Kumaun; **SM** – Serre de Monter St. Laurent; **G** – Greiner type: ■ Mušići; .•. Diebgrub and NCA breunnerite isotope values.

1) Oxygen and carbon isotope values for **the Konjuh-Kopaonik** vein-type magnesites fit the span of maximal values for the same genetical type over the world (the Kraubath-type) indicating the same origin. Comparatively high values of $\delta^{18}O_{SMOW}$ ranging between +28.4 and +24.1‰ in Konjuh-Kopaonik magnesites and between +29.0 and +22.3‰ in Kraubath-type magnesites indicate low temperature of mineralizing solutions. The conclusion was first proposed by *Barnes & O'Neil (1973)* and afterwards *Aharon (1988)* based on isotope values of surface waters and coefficient of isotope fractionation, calculate the temperature span of +13 to +42ºC. Carbon comes from CO_2 in surface waters.

2) The Dinaridic **stockwork-type** magnesite deposits: **Ražana, Mramor** and **Ražana-Čosovac** and Austrian **Goldaki deposit** *(Kralik et al., 1989)* have similar $\delta^{13}C$ values of –11.64 to –7.13‰, averaging -8.8‰ in the Ražana deposit and –9.4 to -7.8 ‰ averaging - 8.6 ‰ in the Goldaki deposit. These values are for 2-3‰ heavier than in vein-magnesites. *Kralik et al. (1989)* explain this difference by position of these deposits closer to the surface and thus more important influence of atmospheric water with $\delta^{13}C$ of –7‰. Their explanation can be used in the interpretation of the Dinaridic stockwork-type magnesite deposits. In the Ražana deposits, $\delta^{18}O$ values are from +28.75 to +26.33‰ and in the Goldaki deposit are from +25.7 to +24‰, e.g.differing for 3‰, however values are within limits of vein magnesites pointing to cold source solutions in the formation of network magnesites.

3) The Miokovački-Beli Kamen network-stockwork type magnesites have the most extreme values of carbon isotope and particularly of oxygen isotope which are much closer to extreme values of lacustrine magnesite deposits. The closest type is recent Coorong Lagoon sedimentary deposit in Australia *(Botz & Von der Borch, 1984: Schroll et al., 1986)*. High $\delta^{18}O$ can be explained by evaporitic conditions of formation. Heavy carbon isotope can be explained either by anaerobic fractionation under anaerobic conditions or by enrichment at evaporization under sabkha conditions. Analyzing these samples *Fallick et al. (1991)* concluded that the deposit originated from mixed solutions according to the model in which Mg continues in a hydrothermal updraft after loss of CO_2 and meets HCO_3^- charged lake water just below the lake bottom.

4) The Oshve vein-type magnesites have $\delta^{13}C$ from +0.25 to +5.26‰ and $\delta^{18}O$ from +23.16 to +17.87‰ differing the Konjuh-Kopaonik-type for 5.7‰ lighter oxygen isotope. Most similar isotope values **(Fig. 10)** have Austrian Triassic sparry magnesites enriched in Fe (breunnerite) from the **Diebgrub area,** breunnerite-type magnesite deposits from the Northern **Calcareous Alps** *(Spötl & Burns, 1994),* **Triassic sparry magnesites from Kaswassergraben, Hall in Austria** *(Schroll et al., 1986; Götzinger & Tapesch, 1987)* **and pre-Cambrian Adelaide (South Australia) magnesite deposit** *(Lambert et al.. 1984).* **All these sedimentary magnesites fit the Oshve-type magnesites from the Dinarides (Figs. 9 and 10).**

In the diagram **(Fig. 9)** on wich are plotted stable isotope data for all 15 magnesite samples of the Oshve-type, shows that they was originated at elevated temperatures of 70 to 150°C, averaging 110°C. *Fallick et al. (1991)* calculated temperatures of 105°C. These increased temperature can be explained as the result of increased geothermal gradients due to numerous adjacent andesite volcanic bodies which are very abundant in this area *(Trubelja & Pamić, 1956; Majer, 1961; Pamić et al.,1964; 2000; Ilić, Jr. & Đorđević, 1980).*

5) Bedded sedimentary magnesites over the world are very different in ages whereas the Dinaridic ones are only of Miocene age. **The Ražana** bedded sedimentary magnesites and adjacent **Ražana stockwork** have very similar δ^{13}C values of –8.86 and –8.15‰, respectively indicating atmospheric CO_2 contribution. δ^{18}O values are also similar, e.g. +27.73 and +28.20‰ and fluids in both magnesite types were low temperatured. The distal Ražana sedimentary dolomite deposits have heavier carbon and oxygen isotope values approaching those of sedimentary end members. This group also includes sedimentary dolomites from Branešci deposits in the Mt. Zlatibor.

Two spatially close **Nevade** and **Šilopaj** sedimentary deposits are characterized by very narrow δ^{13}C span (–5.27‰) and comparatively wide δ^{18}O (+27 to +31‰) span. Tran-

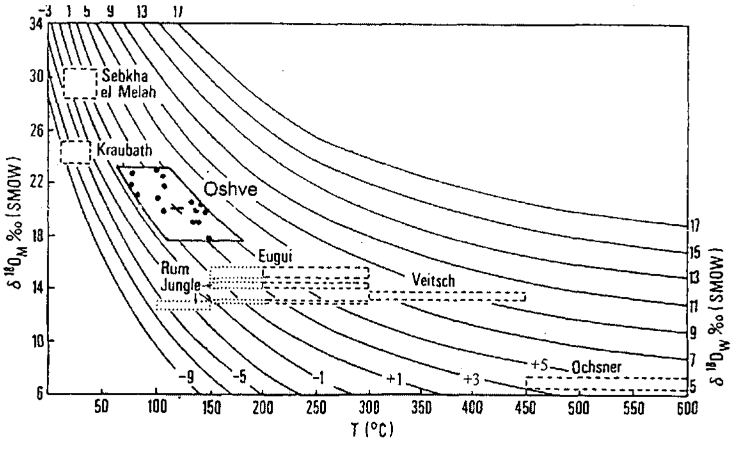

Fig. 9. d^{18}O distribution of the fluids as indicated by the δ^{18}O composition of the magnesite and temperatures of regional metamorfism or fluid inclusion homogenisation (draw by Aharon, 198 8). ••• Carbon and oxygen isotope values of six Oshve type magnesite veins.

sport of $Mg(HCO_3)_2$ was carried out by atmospheric waters of identical and unchangeable carbon isotope composition. Oxygen isotope variations indicate some temperature changes of mineralizing solutions or lake waters and the samples with the heaviest oxygen isotope composition ($\delta^{18}O$ = +31‰) might originated under evaporitic conditions *(Fallick et al., 1991).*

The $\delta^{13}C$ values of the **Bela Stena magnesites** and the neighboring **Čerenje dolomites** range from -1.95 to +4.4‰. These extreme values constitute the heavy end member, together with the Miokovići-Beli Kamen stockwork and the Oshve vein-type, of the carbon isotope ratios in the entire Dinarides. The $\delta^{18}O$ for the **Bela Stena** deposit also have wide range from +35.9 to +26.2‰, however there is no correlation with the $\delta^{13}C$ data for Bela Stena deposit. There is a small possibility that it originated by surface magnesium input in the Jarandol Lake. It is more probable that mineralizing waters came running along vertical channels from the basin basement. Mg was leached from adjacent ultramafics as indicated by very low REE content *(Morteani et al.,1983).*

Very wide $\delta^{18}O$ span (+26 to +36 ‰) indicates variations in temperatures of mineralizing solutions. Influence of volcanic CO_2 cannot be excluded because in the surrounding Čerenje sedimentary dolomite deposit with similar stable isotope composition boron minerals were found. Small bedded sedimentary magnesite and dolomite, deposits in higher parts of Kremna Miocene fresh-water sediments (Mt. Zlatibor) have extreme values of carbon isotope, indicating evaporite conditions of formation. This basin also has increased boron content and contains boron minerals *(Obradović et al.. 1996).*

6) **The Mušići talc-magnesite** (breunnerite) deposits overlap significant parts of the isotopic field of the Oshve-type deposits, indicating enhanced temperature of formation of the Greiner-type magnesite deposits.

7) **Detrital magnesites.** *Ilić, Jr. (1983)* thinks that Janok magnesite deposit originated by erosion of older bedded Bela Stena deposit.

Fallick et al. (1991) were first ho presented the opinion that Parlog detrital deposit originated by erosion of adjacent Mioković Beli Kamen stockwork-type deposit because it is made up both of serpentinite and magnesite pebbles. However, very different oxygen and carbon isotope values contradict to this hypothesis and they are closer to those from Bela Stena and thus they reinterpret Parlog deposit as a product of completely eroded adjacent Bela Stena deposit. However, it is more probable that it originated by erosion of an old stockwork because it is positioned in basal parts of Miocene fresh-water basin.

Origin of the Dinaridic magnesites, current ideas

In the past all geologists working on the Dinaridic ophiolite-related magnesites were divided into three groups concerning their genesis.

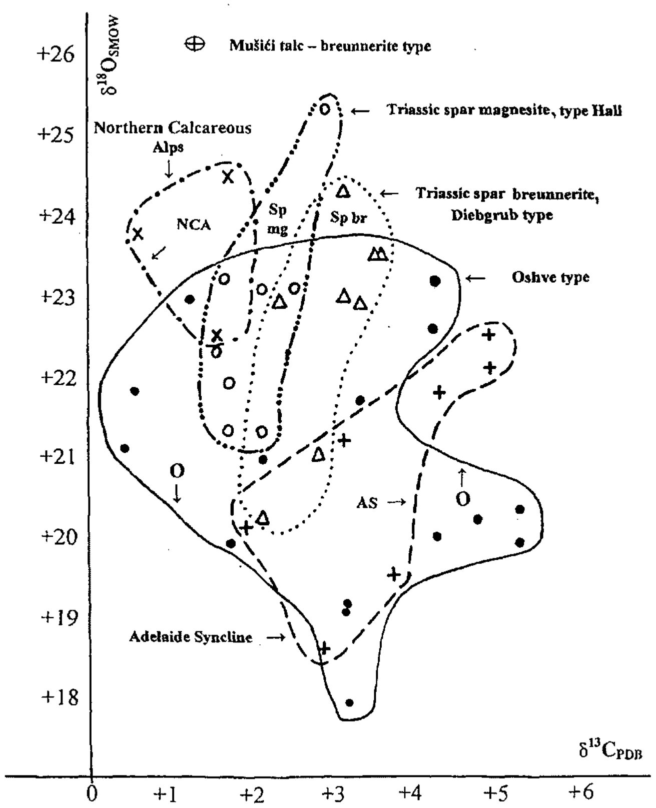

Fig. 10. Carbon and oxygen isotope crossplot of following magnesite deposits

● O – Oshve type; ⊕ Mušići talc – breunnerite; ○ **Sp mg** – Hall Triassic spar magnesite; Δ **Sp br** – Diebgrub, Triassic iron magnesite deposits; × **NCA** – Northern Calcareous Alps, Permian breunnerite deposits; + **AS** – Adelaide Syncline, bedded sedimentary magnesite deposits.

Hydrothermalists were of the opinion that both vein and sedimentary magnesites originated penecontemporaneously during the Miocene. Magnesium was leached by lateral secretion from serpentinized ultramafics by the influence of hydrothermal solutions genetically related to young Tertiary andesite-dacite volcanic activity *(Ilić, 1954; Ilić, Jr., 1964,1965, 1969; Đorđević, 1973).*

Infiltrationists (hydatogenists) are of the opinion that vein- and stockwork-type magnesites originated in the crust of weathering of ultramafics during the Tertiary, mainly Neogene and during the Late Jurassic / Early Cretaceous continental phases under very warm and humid climate. *Petrov, (1967), Petrov et al. (1969), Zekić et al. (1976), Lapčević (1978, 1982, 1988), Petrov et al. (1979), Janković (1990), and Popević et al. (1996). Sunarić-Pamić & Pamić (1988)* subdivided vein magnesites into two age groups; the vein magnesites of the first group started their genetical evolution immidiately after first emplacement of ophiolites during the Late Jurassic/Early Cretaceous, whereas the second generation of magnesites is postorogenic and originated during the Tertiary, mainly Neogene. Sedimentary magnesite deposits accumulated in fresh-water Miocene basins. *Kralik et al.(1989), Pohl (1989), and Jedrysek & Halas (1990)* favoured also a meteoric origin for the fluids feeding world vein magnesites.

Vakanjac et al. (1984) presented the opinion that magnesite-bearing solutions represented a mixture of atmospheric and connate waters and thus proposed a hypothesis of **hydrothermal-metamorphic origin** of the Dinaridic ophiolite-related magnesites. However subsequent researches of magnesites did not accept this idea. *Gartzos (1990)* favored also mixing model for the Greek vein magnesites as an explanation for the mineralization. He presumed mixing of ascending CO_2 – rich fluids with descending meteoric water and the deposition of magnesite below 60°C.

M. Ilić, Jr. (in Fallick et al., 1991), changed his earlier opinion *(Ilić, Jr. 1969)* and proposed a new hypothesis. Extensional stresses operating in the Miocene lead to basin formation and also to intermediate and felsic magmatism. Meteoric water gravitated down normal faults to be heated at depth by crustal heat and igneous intrusion. CO_2 generated by thermal decarboxylation of organic-rich sediments mixed with the hot waters. This strong carbonate solution reacted exothermically with serpentinite as it moved laterally and then upward along permeable faults, Magnesium was dissolved with the bicarbonate. As this bicarbonate solution approaches the surface, pressure loss leads to devolatilization and rapid precipitation of cryptocrystalline magnesite. The relatively constant isotope ratios within individual vein deposits, and the overall correlation between $\delta^{13}C$ and $\delta^{18}O$ values argue against significant isotopic fractionation associated with CO_2 loss. The fine-grained magnesites were carried upward in the fluid to be deposited in the open channelways as vein, in the newly fractured and broken ground near the surface as a certain type of stockwork, and into fresh-water Miocene lakes as a sediment. It is probable that hydraulic drive is artesian and the hydrothermal fluid is meteoric.

DISCUSSION AND CONCLUSION

All magnesite deposits of the Internal Dinarides are genetically related to peridotites tectonites represented largely by spinel lherzolites and harzburgites, most commonly moderately serpentinitized.

Almost all genetical types of magnesites are products of exodynamic processes, which were taking place at the surface or near-surface. Only Mušići-type breunnerite-talc deposit (the Greiner-type) is of contactmetasomatic hydrothermal origin.

Based on signatures of CO_2-containing water solutions which carried out the serpentinitization, on carbon and oxygen isotopic composition, on tectonic setting and the age, magnesite deposits can be subdivided into following genetical subgroups.

1. **Upper Jurassic** contactmetasomatic **breunnerite-talc deposits** which originated by plagiogranite activity, **Mušići (Greiner) type**;
2. Sporadic remmants of **Lower Cretaceous stockwork (network) magnesite deposits, Glavica-type** (Kosovo);
3. **Oligocene** vein magnesites of **the Konjuh-Kopaonik (Kraubath)-type** and stockwork magnesites of **the Ražana-type**; whereas the stockwork magnesite, **the Miokovački Beli Kamen-type**; is probably younger. Miocene in age.
4. **Miocene** lacustrine sedimentary magnesite deposits, **the Bela Stena-type**;
    - 4.1. Detrital sedimentary magnesite deposits, **the Parlog-type** located in the basal parts of lacustrine sequences;
    - 4.2. Intraformational detrital magnesite deposits, **the Janok-type**;
    - 4.3. **Middle Miocene** bedded sedimentary magnesite deposits, **the Nevade-Šilopaj-type**;
    - 4.4. **Middle Miocene** irregular sedimentary magnesite bodies, **the Bela Stena-type**;
    - 4.5. Small eluvial-deluvial and alluvial **Pleistocene-Quaternary** magnesite deposits, **the Euboea-type**.

1. **The Mušići-type**, localized in the Ozren peridotite massif **(Fig.1)**, represents the oldest Dinaridic magnesite deposit which originated during the final stage of Jurassic oceanizations (cca 145 Ma), Comparatively small intrusions of albite granosyenites e.g. generators of the magnesite-talc deposits **(Fig. 3e)**, can be interpreted as product of fractional crystallization from primary olivine-tholeiite magma which gave diabase-dolerite sheeted complex *(Pamić et al., 2002)*. After consolidation gave such individualized alkali granosyenite magmas also hydrothermal CO_2 enriched solutions which produced magnesite-talc paragenesis by metasomatic replacement. This is in fact a contactmetamorphic deposit originating through complete serpentinitization of primary lherzolite at temperatures of about 400°C. Genetical connection between ultramafics and breunnerite-talc final paragenesis is evidenced by chemical composition shown in MgO/FeO ratio

which is the same both in lherzolite-serpentinite and breunnerite-talc paragenesis (*Sunarić-Pamić & Pamić,1988).*

2. **The Glavica-type** of stockwork magnesite deposits *(Mulina, 1988).*

In the geodynamic evolution of the Dinarides *(Dangić & Đorđević, 2000),* the continental phase came into existence after the first obduction of the Dinaridic ophiolites wich took place in Late Jurassic / Early Cretaceous. The emplaced ophiolites were partly uplifted above sea level and were affected by erosion and weathering in humid and very hot climate. At the time were forming crusts of weathering on uplifted ophiolites including predominant peridotites and large deposits of bauxites (Vlasenica), Ni-Cr low-grade iron ores (Vardište) and Ni-Co silicate ores (Čikatovo, Glavica, Velućc) *(Janković, 1990).*

So far only in the western part of the large blanket-type Ni-silicate deposit Glavica (Kosovo) was found bigger magnesite stockwork accompanied by some magnesite veins *(Mulina, 1988).* Similar type of deposit, but much smaller were found at Groot near Veleš (Macedonia). Outcrops of preserved Late Jurassic/Early Cretaceous crusts of weathering are poorly preserved at the present surface of the Central Dinarides.

3. Late Oligocene/lowermost Miocene magnesite deposits

3.1. Stockwork (network) deposit, the Ražana type;

3.2. Vein magnesite deposits, the Konjuh-Kopaonik (Kraubath) type.

These two types are the most common magnesite deposits in the Internal Dinarides, completely comparable with other world known microcrystalline magnesite deposits (e.g. in Austria, Poland, Greece, Turkey, USA).

3.1. **Stockwork magnesites** formed by lateritization of serpentinized peridotites are characterized by typical vertical zoning of their parageneses and marked processes of nontronitization. Chemical composition is slightly different than that of vein magnesites brought about by extensive post-ore dolomitization and silicification.

The $\delta^{13}C$ varies from –11.64 ‰ to -7.13 ‰ (averaging –8.82 ‰) and $\delta^{18}O$ from +28.75 ‰ to +26.33 (av. + 26.75 ‰). The isotopic composition of the vein magnesites is: $\delta^{13}C$ from –15.08 ‰ to –7.06 ‰ (av. –12.21 ‰), $\delta^{18}O$ from +28.36 ‰ to +24.13 ‰ (av. +26.41 ‰). The $\delta^{18}O$ values are almost identical suggesting that deposits originated from relatively cold solutions, below 60°C. Slightly heavier $\delta^{13}C$ (D=3.4 ‰) of the stockwork magnesites indicates the predominant influence of atmospheric CO_2 in subsurface mineralizing fluids.

Exceptional type is **the Miokovac Beli Kamen** characterized by extreme isotopic composition $\delta^{13}C$ from +2.78 ‰ to +4.25 ‰ (av. +3.15 ‰) and $\delta^{18}O$ from +36.01 ‰ to +36.22 ‰ (av. +36.12 ‰).

This stockwork deposit formed later, probably simultaneously with sedimentary lacustrine magnesites under changed climate sabkha environments.

3.2. **Vein magnesites** formed after Pyrenean peak metamorphism (Late Eocene, 40 Ma) and after Main Alpine peak metamorphism (Middle Oligocene, 29.3 Ma) when a still hot Dinaridic metamorphic complex, uplifted and extensionally tectonized, was flooded and cooled by waters from outside. Through the convection cell system, open to the surface, circulated the mineralizing water composed of various components, including meteoric, metamorphic and connate sources, evidenced by widely varying dD values. These waters in Dinarides contain CO_2, $CH_4(\pm N_2)$ and localy NH_4 ions *(Jurković & Palinkaš, 1996, 1999)* and characterized by low to moderate salinity and by ambient pressure of < 2 kbars.

Very similar, almost identical span of the isotopic compositions of the Dinaridic Konjuh-Kopaonik-type and of the world Kraubath-type indicates highly homogenized mineralizing fluids largely indepedent of metamorphic grade and lithology, suggesting that the most of fluids was pervasive and that the amounts of fluid from an external source were large enough to wipe out the characteristics of locally produced fluids. What ever the source of these fluids, they migrated over large distances of hundred and thousand kilometers through the rocks. *(Pohl, 1992); Pohl and Belocky (1994)* described this curious phenomenon in the Eastern Alps, *Jurković & Palinkaš (1996, 1999)* in the Dinarides and *Kreulen (1980)* and *Gartzos (1990)* in the Hellenides.

Through the joints, fissures, fractures, faults, and shear zones in the serpentinized peridotites circulated mineralizing waters stocked up with partly atmospheric CO_2, partly with CO_2 originated by decarbonation of carbonaceous sediments underlying ophiolites, leaching magnesium ions. Deposition of cryptocrystalline magnesite took place in the upper parts of feeding channels from the relatively low temperatured fluids, below 60°C after *Barnes & O'Neil (1978)* or between +13 to +42°C *(Aharon, 1988)*.

The vein magnesites are largely made of pure micritic magnesites without or with minimal admixtures of silica minerals and dolomite. In addition, the vein magnesites are located in slightly to moderately serpentinized lherzolites indicating long and deep transport of mineralizing waters from the surface.

3.3. **The Oshve-type** magnesite deposits, with its $\delta^{18}O$ averaging +20.7 ‰ **(fig. 5)** differ significantly from all other Dinaridic and world ophiolite related magnesites. In this region shoshonite and andesite extrusive bodies, Oligocene in age (31 Ma), are very common *(Pamić, et al., 2000)*. The isotope composition of the Oshve-type magnesites indicated that they originated by solution warmed between 70 and 150°C **(fig. 9)**. In the $\delta^{13}C$ vs. $\delta^{18}O$ diagram, points of these magnesites plot close to the Mušići (the Greiner-type) hydrothermal contactmetasomatic magnesites **(fig. 5)**.

4. Sedimentary (lacustrine) magnesite deposits

$MgH(CO_3)$ enriched solutions which originated by superficial serpentinization under normal temperature, feeded river waters and fresh water intramontane lakes and thus gave rise to the origin of bedded magnesites interlayered with Miocene fresh-water sediments (Nevade, Šilopaj, Ražana, Kremna, Branešci, Čerenje) or gave very large interstratified inrregular lenticular magnesite bodies (Bela Stena, Strezovac Beli Kamen), which were formed along vertical or subvertical feeding channels from lake bottoms.

Carbon and oxygen isotopic values of the Dinaridic sedimentary deposits, Miocene in age, have very similar pattern with regard to the isotopic values of world Pleistocene and Quaternarie sedimentary magnesites, but there is a noticeable schift toward heavier carbon and oxygen isotope values. Authors explain this phenomenon by change of climate and by more marked sabkha environments.

Detrital types of magnesite deposits occur mainly in the basal parts of the Miocene lacustrine sediments (Parlog, Ljetovnik) or later as an intraformational conglomeratic horizon (Janok-type).

5. Small **eluvial-deluvial and alluvial magnesite deposits**, Pleistocene and Quaternaire in age formed by erosion of older magnesite deposits.

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Sažetak

Magneziti Dinarida

U prvom dijelu rada autori su prikazali postojeće tipove magnezitskih ležišta u Dinaridima: žična, mrežasta, sedimentna, detritarna i deluvijalno-aluvijalna.

U drugom dijelu detaljno su analizirane izotopne vrijednosti ugljika i kisika 114 uzoraka magnezita iz 36 ležišta svih genetskih tipova pri čemu su izdvojena dva nova genetska tipa, Oshve i Greiner tipovi.

U trećem dijelu rada izvršena je komparacija izotopnih vrijednosti ugljika i kisika istovrsnih genetskih tipova magnezitskih ležišta u Dinaridima s onima u drugim dijelovima svijeta. Utvrđene su ptpune podudarnosti kod žičnih i mrežastih tipova uz izuzetak Oshve tipa. Kod sedimentnih i detritarnih ležišta utvrđene razlike u sastavu izotopa su u većem dijelu uzrokovane činjenicom što su u Dinaridima tipovi miocenske starosti, a u svijetu u rasponu od arhaika do pleistocena - kvartar.

U zadnjem dijelu rada prikazan je kritički osvrt na ranije hipoteze o postanku magnezitskih ležišta Dinarida i izložen je vlastiti model.

Ključne riječi: Dinaridi, magnezitna ležišta, izotopne vrijednosti ugljika i kisika, komparacija sa svjetskim ležištima, genetski model.