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TECTONIC SETTING OF RECENTLY FOUND GYPSUM DEPOSITS OF MT. MEDVEDNICA (NORTHWESTERN CROATIA)

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In this paper two newly discovered locations with gypsum on Mt. Medvednica and the structural-tectonic setting are described. The first location with gypsum is situated 2 km S of Marija Bistrica and is associated with dolomites and clastic rocks of Permo-Triassic age, which were during the most recent Neotectonic events, together with Miocene sediments, intensely folded and reverse faulted under the influence of the main stress, oriented N-W. At the other location, in the upper course of the Vidovec stream, gypsum is also found in dolomite, which is in direct discordant contact with black Palaeozoic metapelites. On samples from both locations, sulphur isotope analysis was performed and an Upper Perm to Lower Triassic age was determined. Based on the results of the sulphur analysis it is assumed that investigated localities were connected with an open marine area during the Upper Permian. Therefore, and indirect conclusion concerning the age of the metamorphic rocks of Mt. Medvednica can be made. That is, gypsum occurs in both locations in non-metamorphic dolomites of the Upper Permian age.

Keywords: gypsum, tectonics, stress, Mt. Medvednica, Upper Permian, Lower Triassic.

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U radu su opisane dvije nove lokacije s gipsom na planini Medvednici kao i strukturno-tektonski položaj gipsa. Prva lokacija s gipsom nalazi se 2 km južno od Marije Bistrice i vezana je za dolomite i klastite permotrijaske starosti koji su tijekom najmlađih tektonskih događaja, zajedno s miocenskim sedimentima, intenzivno borani i reverzno rasjedani pod utjecajem djelovanja osnovnog stresa na pravcu sjever-jug. Na drugoj lokaciji, u gornjem toku potoka Vidovec, gips se nalazi također u dolomitu koji je u direktnom diskordantnom kontaktu s crnim metapelitima paleozojske starosti. Na gipsu s obje lokacije učinjena je izotopna analiza sastava sumpora i dobivene su starosti evaporita u rasponu gornji perm - donji trijas. Na temelju rezultata analize sumpora zaključuje se na povezanost istraživanih lokaliteta sa širim marinskim prostorom za vrijeme gornjeg perma. S tim u svezi može se posredno zaključiti i o starosti metamorfnih stijena Medvednice. Naime, gips se na obje lokacije javlja u nemetamorfoziranim dolomitima gornjopermske starosti.

Ključne riječi: gips, tektonika, stres, Medvednica, gornji perm, donji trijas

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INTRODUCTION

Gypsum occurs on Mt. Medvednica at four known localities: a) in Slani Potok stream where the occurrence of gypsum was described as »a beam of gypsum inserted in black clay« (KIŠPATIĆ, 1901 and ZAGORŠČAK, 1988); b) in Drenovac Potok stream near Novaki village where POLJAK (1937) observed a meter-thick gypsum outcrop overlain by finely grained Permian quartzitic sandstones while underlying deposits are unknown; c) in the neighbouring Dubovac stream also as a meter-thick gypsum outcrop (ŠIMUNIĆ, An., pers. comm.); d) in the locality of Planina, SE part of Mt. Medvednica, where gypsum forms fill the fractures within a coal layer (ČEPELAK *et al.*, 1986; ZAGORŠČAK, 1988).

In the wider area, gypsum deposits are also known from the Samobor Hills in the vicinity of Rude (a settlement). They were found within Upper Permian beds, and were thoroughly investigated by JURKOVIĆ (1962), ŠINKOVEC (1971), and ŠIFTAR (1989).

In the area of Mt. Medvednica during investigations for the preparation of the Geological Map of the Republic of Croatia, scale 1:50,000, two additional locations of gypsum deposits were discovered (Fig. 1). The first one is situated on the NE slopes of Mt. Medvednica, 2 km S of Marija Bistrica in an outcrop opened along the asphalt road to Nemec Hill (coordinates: X = 5093562, Y = 5586785 and Z = 235). The other occurrence of gypsum is in the upper course of Vidovec stream (coordinates: X = 5088166, Y = 5581144 and Z = 455).

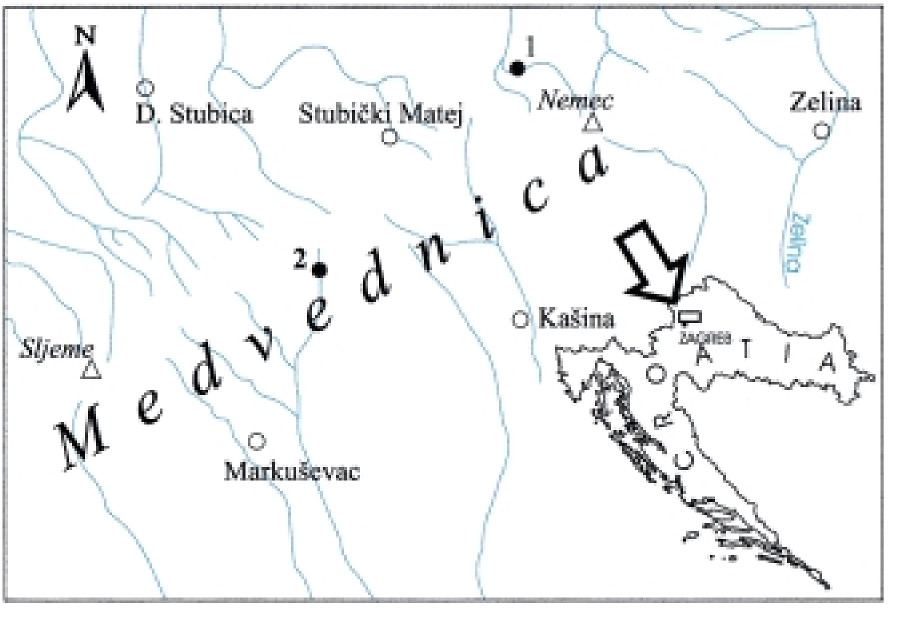

Fig. 1. Outcrop locations map.

Detailed structural-tectonic analysis of both gypsum occurrences was carried out, with the aim of determination of their positions in the structure.

The gypsum occurrences studied are in contact with non-metamorphic Lower Permian dolomites and Lower Triassic clastic rocks (the Nemec locality), and Devonian-Carboniferous (?) parametamorphites (the Vidovec locality) (BASCH, 1983; ŠIKIĆ *et al.*, 1979; ŠIKIĆ, 1995). Parametamorphites are rocks that underwent regional progressive metamorphosis up to the stage of the greenschist facies. Their protholites were deposited in different marine environments with the characteristics of a magmatic-sedimentary complex (ŠIKIĆ, 1995). These low-metamorphic rocks in the wider area of the Vidovec stream are represented by black metapelites, slate-phyllites and metapsammites, marble slates and marble limestones cut by diabase veins. In the NE part of Mt. Medvednica (the wider area of the Nemec locality) the prevailing rocks are carbonates (marbles, marble schists, and to a lesser extent dolomites) in relation to metapelites, metapsammites and carbonates and clastic rocks of the Lower Permian age (ŠIKIĆ, 1995). These rocks are mainly masked by younger Tertiary sediments.

Opinions on the age of metamorphites, as well as on the metamorphism itself, vary. According to the investigations of ĐURĐANOVIĆ (1968, 1973), which have been accepted in the Basic Geological Map, Zagreb sheet (ŠIKIĆ *et al.*, 1979) and Ivanić-Grad sheet (BASCH, 1983), a major part of Mt. Medvednica metamorphites are Devonian-Carboniferous in age (?). KOCHANSKY-DEVIDÉ (1981) wrote about the Carboniferous age of the crystalline limestones of Markuševac, whereas SREMAC & MIHAJLOVIĆ-PAVLOVIĆ (1983) mention a Silurian age for the schists of the Marija Snježna locality. Recent results by BELAK *et al.* (1995) indicate an Upper Palaeozoic age (Middle Carboniferous - Lower Permian) for the marble schists and marble limestones in the area of the Vidovec stream. However, on the basis of conodonts present, a Triassic age (Ladinian and Karnian) for part of the Mt. Medvednica metamorphic rocks was also determined (ĐURĐANOVIĆ, 1973 and BELAK *et al.*, 1995a). The assumption of a Lower Permian age for the metamorphic complex of the NE part of Mt. Medvednica, where the studied Nemec locality is situated, derives from its contact with non-metamorphic Lower Triassic sedimentary rocks. The only proof of this age is an unaltered secondary block of Neoschwagerina limestone in the spring area of the Slani Potok stream (NEDELA-DEVIDÉ & KOCHANSKY-DEVIDÉ, 1990).

BELAK *et al.* (1995; 1995a), on the basis of recent investigations and results of K/Ar isotopic analyses showing values for ortho- and parametamorphites ranging from 110 to 122 Ma, point to Lower Cretaceous metamorphism. These authors considered that the geodynamic evolution of metamorphic complex of the Mt. Medvednica should be referred to some of the earlier orogenetic phases of the Alpine Wilson cycle.

The aim of this paper is to determine the sequence of tectonic events, the age and position of gypsum mineralization in the structure, as well as the origin of the sulphate component, on the basis of recent geological, structural and tectonic facts, as well as sulphur isotopic analyses. This investigation has been undertaken because of the assumed possibility of the variable ages of gypsum mineralization within several tectonic events.

METHODOLOGY

At the Nemec locality an approximately 250 m long geological profile was studied and the structural position of gypsum was defined. Along the profile, the linear and planar structural elements of the gypsum and the surrounding rocks were observed and defined. Measured structural data were classified according to their shape and genesis. For some fault planes with linear records of the tectonic transport, the direction of regional stress were calculated ($\sigma 1$) and strike axes of folded units were determined.

On the Vidovec locality, due to the significant tectonization caused by the proximity of reverse faults with Cretaceous-Palaeogene deposits, structural and tectonic observations enabled only definition of the position of the gypsum with respect to the surrounding rocks.

In the investigation the following methods were applied: optical microscopy, X-ray powder diffraction analysis (XRD), partial chemical analysis and isotopic analysis of the sulphur in the gypsum.

Optical microscopy enabled petrographic determination, as well as classification of gypsum samples, carbonate and clastic rocks from both localities studied. For isotopic analysis, 5 gypsum samples (3 from the Nemec locality, and 2 from the Vidovec locality) were firstly transformed to $BaSO_4$, and then analyzed at the Umweltforschungzentrum Leipzig-Halle GmbH. The same samples were chemically analyzed at the Institute of Geology, Zagreb, where the samples were firstly treated with HCl 1:3. After dilution, the content of total oxides in the filtrate was determined: (R_2O_3), CaO, MgO and SO_3. The insoluble residue was not analyzed. The share of CO_2 was determined by a Leco analyzer. After heating of the sample at 230 °C, the mass loss was expressed as H_2O^+ content. X-ray powder diffraction analysis was carried out by the Philips diffractometer (graphite monochromator, CuKα emission, proportional counter), at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb. The samples of gypsum, dolomite with gypsum and mylonite matrix and pelites from both localities were analyzed.

RESULTS

Geological and structural-tectonic setting of the Nemec locality

At the Nemec locality, which is situated along the outcrop of an asphalt road, the geological profile was studied, which is schematically shown in Fig. 2. It is composed of Upper Permian to Lower Triassic and Tertiary rocks. Due to intense tectonization during the folding, the aforementioned members are reduced considerably.

The Upper Permian is represented by cataclastic fine-crystallized dolomites and calcite-quartz schists which are regionally positioned below the palaeontologically proven Lower Triassic. The deposits of Lower Triassic age (the older part, usually referred to as »Seiser Schichten«) are composed of finely grained subarkose with

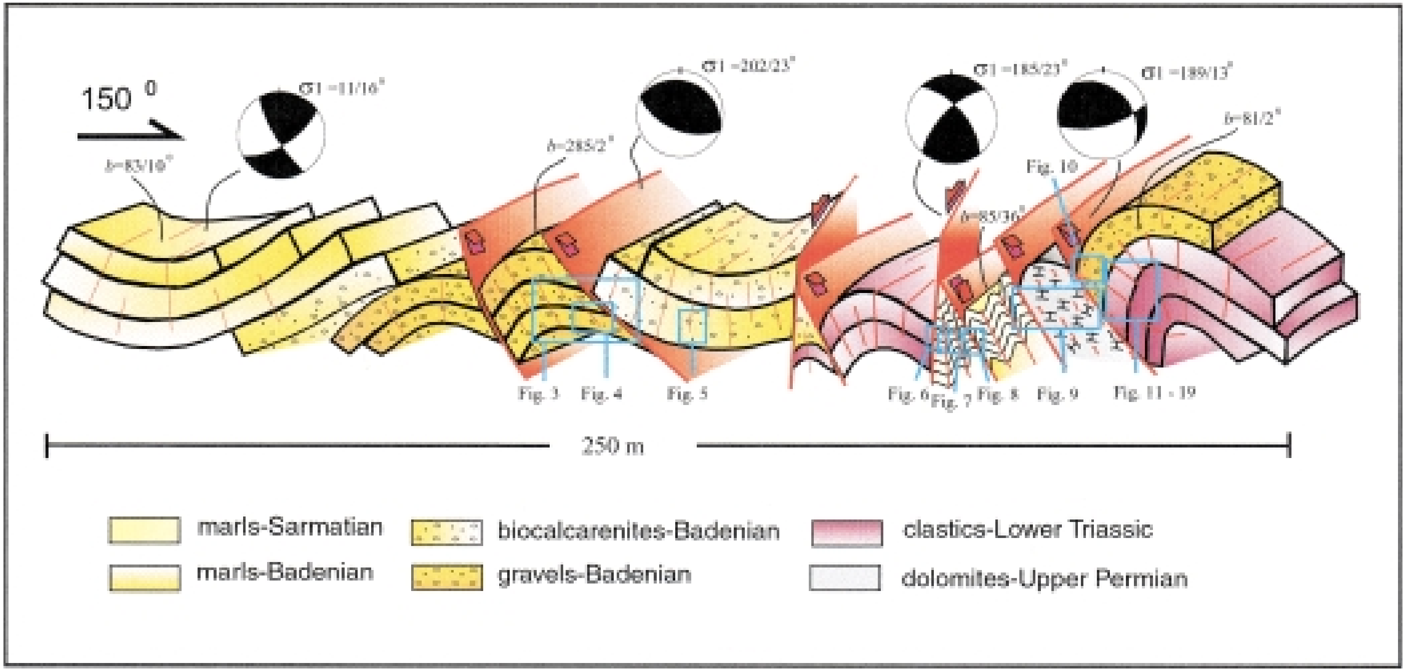

Fig. 2. Schematic representation of the Nemec profile

laminae of siltites, and violet and greenish siltites and sandstones in alternation, and predominately violet siltites containing the gypsum occurrences. The zone of the Lower Triassic stretches towards the SE (to the area of the Nemec peak), where in its uppermost parts Lower Triassic deposits contain platy crystalline limestones with remnants of *Pseudomonotis* (*Eumorphotis*) sp., and in the sandstones *Anodontophora fassaensis* Wissman (determination: M. Brkić).

Tertiary overlying limestones are represented by Badenian deposits. The base of the Badenian is composed of subrounded to rounded gravel, partly clayey, with pebbles of metamorphic rocks from the wider area of Mt. Medvednica Within clayey gravels there are some layers with oysters. Gravel deposits are covered by the lithotamnium limestones and conglomerates up to 1 meter thick. They uppermost part of the Badenian is represented by grey to grey-bluish, thick layered (up to 1.5 m) marls. As the youngest Tertiary deposits, in part of the Nemec profile, platy calcitic marls were determined, which could be, on the basis of the lithological correlation with the wider area of Mt. Medvednica, of Sarmatian age (?).

The sequence of structural forms along the Nemec profile (Fig. 2) has been determined: synforms, antiforms, reverse and normal faults with accompanying fracture systems. In the NW part of the profile gentle folding of the Badenian marls in the form of synclines was noticed, with the *b*-axis being oriented 83/10°. The beds are 1–1.5 m thick. Accompanying fracture systems, formed during syncline formation, appear every 40–100 cm and belong to the fan cleavage of the axial plane. Fracture systems from the zone perpendicular to the *b*-axis of the structure are less pronounced. At the surfaces of infrequent dextral transcurrent faults within marls, measured elements of *a*-lineation indicated the orientation of local stress $\sigma 1 = 11/16°$, which corresponds to the measured *b*-axis of the syncline. Below the marls there is a 1.5 m thick layer of organogenic Badenian limestone with infrequent pebbles reworked from metamorphic rocks of Mt. Medvednica. Deformations in these rocks remained in the form of the fracture systems from the zone of the axial plane.

Further up in the Nemec profile, there is a 30 m thick zone of poorly cemented conglomerates, gravels and sands folded in the form of an anticline and cut by a reverse fault. In the hanging wall of the reverse fault the layer with oysters occurs (Fig. 3), which during the deformation processes formed an oblique anticline (b = 285/2°) with northern vergence of the axial plane. The northern limb is steeper, while the southern one is more gently inclined and under the influence of the reverse fault present, due to the movement of the hanging wall, strongly schistoid (Fig. 4). Schistosity corresponds to the bedding, and in the narrow zone (30 cm) along the reverse fault, mylonite clays occur. A measured orientation of $\sigma 1$ is 202/23° on the reverse fault plane shows that the local stress that caused the formation of this fault corresponds to the previously calculated value for $\sigma 1$, i.e. that both faults were formed during the same kinematic act.

Along the described reverse fault a syncline composed of lithotamnium limestone is brought into contact with the aforementioned sequence. The syncline is structurally characterized by fracture systems indicating a gently folded structure. The fractures are from the zone perpendicular to the *b*-axis; some are oblique to the *b*-axis, and most frequent are fractures parallel to the *b*-axis. The first ones are closed with rough surfaces, almost vertical, striking N-S. The second group is represented by fractures with records of *a*-lineation, but with uncertain determination of tectonic transport. Their strike is NE-SW (the records of *a*-lineation with probable sinistral transport) and NW-SE (the records of *a*-lineation with probable dextral transport). The third fracture system from the zone parallel to the *b*-axis belongs to the fan cleavage fractures of the axial plane. These fractures are compressed on the limbs of

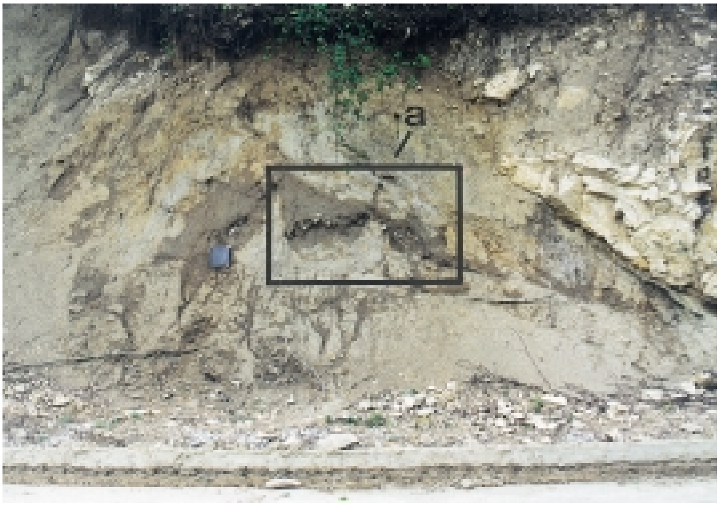

Fig. 3. Poorly cemented Badenian conglomerates, gravels, and sands with occurrences of oysters (a) in the southern limb of the oblique anticline. Nemec profile

Fig. 4. Intense schistosity of the Badenian gravels caused by movement of the hanging wall of the reverse fault. Nemec profile

the syncline (upper right part of Fig. 4), while in the central part of the structure (Fig. 5) they are opened (up to 10 cm) and gently bent. The spreading of fracture walls and their bending is caused by deformations of the structure after its formation.

Further towards the south in the profile, a mylonitized and schistoid zone follows, containing clayey Badenian gravels and angular fragments of the Lower Triassic rocks. A cataclastic zone with mixed rock fragments of different ages was formed along the reverse contact of the Lower Triassic oblique anticline and clayey gravels of Badenian age. The presence of a sinistral transcurrent fault with NE-SW strike also contributed to cataclasis. The exact amount of the sinistral horizontal movement along this fault was not possible to determine. However, the following fault, subparallel to the aforementioned, brought into contact platy calcitic marls and Sarmatian marls (?) with the Lower Triassic deposits. Along the fault (Fig. 6), clayey mylonites appear. According to records of linear elements on the fault plane, the value of orientation of local stress $\sigma1 = 185/23°$ was obtained. Along this fault in the marls, conjugated systems of dextral faults (Fig. 7) formed during the same deformation phase, with clear *a*-lineation, are noticed. The orientation of the local stress ($\sigma1 = 156/8°$) for this fault deviates from the aforementioned value by a minimal 29°, which could be explained by the subsequent rotation of the block measured.

Fig. 5. Open fractures of the fan cleavage of the axial plane from zone parallel to the *b*-axis in the central parts of the syncline. Nemec profile

Fig. 6. Faulted contact of platy calcitic marls and Sarmatian marls with the Lower Triassic sediments; sinistral transcurrent fault. Nemec profile

Fig. 7. Conjugated system of dextral faults from the same deformational phase (as in Fig. 5) in Sarmatian marls (?). Nemec profile

Nevertheless, both measurements showed that stress generally acted along the N-W direction. Under the influence of reverse faulting, the platy Sarmatian marls (?) are intensely folded (Fig. 8). The folds have northern vergence of the axial plane with E-W striking of the *b*-axis (85/36°). More distinct inclination of the *b-axis* from the horizontal plane occurred during the movements of the entire structure of the Nemec profile and the left rotation of some of its parts.

Between the two following reverse faults finely crystalline Upper Permian dolomites crop out (Fig. 9), and are pushed over the described Sarmatian marls (?). They are characterized by intense tectonization in the form of tectonic breccias and weak schistosity parallel to the reverse faults. Frequent fragments in tectonic breccias are dolomites along with black metapelites, which originated from metamorphic rocks of Mt. Medvednica. This implies that dolomites brought to the surface by this reverse fault originated from the deeper parts. On the reverse fault plane with strike 165/59°, the measured *a*-lineation ($\xi = 121°$) gave the main stress axis orientation of $\sigma 1 = 189/13°$.

During the deformation processes along the Nemec profile, discordant Badenian elements (gravel, clayey sandy gravels and sands) were considerably schisted and folded, as shown in Fig. 10. Pebbles from gravels were crushed while schistosity

Fig. 8. Platy Sarmatian marls (?), intensely folded due to the reverse faulting. Nemec profile

Fig. 9. Finely grained tectonized dolomites and tectonic breccias of the Upper Permain on the Nemec profile

Fig. 10. Considerable schistosity and folding of Badenian gravels, clayey sandy gravels and sands

was formed in the initial phases of deformation in the clay material which was subsequently folded. Fold axes are horizontal and in the apical parts of some folds more solid material was pushed up.

At the end of the Nemec profile (Figs. 2 and 11) there is an oblique anticline, which has been pushed onto dolomites along with the aforementioned reverse fault and a mylonite zone. In the approximately 10 m wide mylonite zone (detail shown in Fig. 12), Tertiary (Badenian) sediments have been preserved, which indicates the remnants of a squeezed synform under the reverse contact. The anticline is composed of violet and greenish siltites and pelites, sandy finely crystalline dolomites, dolomitic breccias and medium grained limestones. Along the reverse fault, there is the appearance of grey to bluish mylonite clays, with clear schistosity. Intense tectonization during the folding and reverse pushing of the Lower Triassic and Permo-Triassic sedimentary rocks caused mylonitization and considerable interbedding schistosity. Schistosity has an approximately E-W orientation with inclinations contouring the antiform, and bedding is mainly visible exclusively by the differences in colour and the hardly detectable lithological alternations. Fault systems from the axial plane zone with a reverse transport character have been defined, as well as smaller fracture systems which are parallel to or subparallel to the axial plane and were formed by extensional processes. The movements along reverse faults are cm- to dm-sized, and along them a sigmoidal banding of schistosity has been noticed.

At the Nemec locality, gypsum appears in three forms: grainy, schistoid and crystalline.

Grainy gypsum is white to pale yellow, connected to the surrounding early diagenetic dolomites and breccias (Fig. 11, a). These rocks were folded in the form of r-tectonites during the deformation processes of the Nemec structure into the Tri-

Fig. 11. Oblique anticline from the southern end of the Nemec profile with gypsum occurrences. (a) Grainy gypsum connected to early diagenetic dolomites and tectonic breccias; (b) part of mylonite zone with preserved Badenian sediments

assic clastic rocks. For grainy gypsum it could be assumed with high certainty that it is syngenetic; it was formed before the deformation processes that resulted in the folding of the Nemec structure.

Schistoid gypsum appears in the form of fibrous transparent crystals elongated parallel to the schistosity striking (Figs. 13 and 14). Primarily, it appears within the Lower Triassic rocks. These gypsum occurrences (Fig. 13) are mainly lensoid with a longer axis parallel to the axis of the structure. At the schistosity planes (330/66°), the lineation of gypsum minerals (*lm*) has been measured ($\xi = 38°$). The obtained values of mineral grain strike and inclination (258/34°) approximately correlate with the striking of the anticline axis (81/2°) as well as with the orientation of the main stress axis ($\sigma 1 = 189/13°$), which caused the formation of the structure.

Lensoid forms were, during and after schisting, reversely separated along the faults parallel to the axial plane cleavage (Fig. 14) forming sygmoidal forms. Macrolithons of gypsum have been folded along these faults, marking the reverse transport of the hanging wall.

Crystalline gypsum is composed of completely transparent and clean elongated crystals, up to 3 cm in size. It often occurs in twin forms (the swallowtail type) which, in the form of cm-sized bent irregular veins, fill the space inside the crushed,

Fig. 12. Detail c from the Fig. 11.

Fig. 13. Lensoid forms of schistoid gypsum within Lower Triassic sediments of the Nemec profile

Fig. 14. Detail from Fig. 13. Sigmoidal shape of lenses of schistoid gypsum

partly mylonitized violet-green pelitic matrix (Figs. 15–18). It is present only along the open fractures formed by extensional processes and it has been, obviously, crystallized as the latest form. Two types of open discontinuity planes are associated with the origin of the crystalline gypsum.

The first (older) type of open fracture was formed during the initial phases of the structure formation (Fig. 15a), when the gradual separation of discontinuity planes parallel and subparallel to schistosity took place. In such open spaces, gypsum crystallized in phases as the fracture opened (widened). The polyphase character of the crystallization is visible in the gypsum sample taken from such fracture (Fig. 16), where three stripes (laminae) of crystallized gypsum were observed. In the first phase (F–I, Fig. 14, a and b), the fracture was approximately 0.6 cm wide. In the interstices of the crystallised gypsum, small pieces of remnant surrounding rocks were also found (violet to greenish siltites) which remained aggregated on the fracture planes as cataclastic material (the left stripe in Fig. 15). During further widening of the fracture (F–II, Fig. 15, c) new gypsum crystallisation took place. However, the crystals from this phase contain less particles of surrounding rocks, while the width of the lamina is 0.6 cm as well (right stripe in Fig. 16). The final phase of gypsum crystallisation (F–III, Fig. 15, d) occurred after reopening of the fracture, by separating the previously formed gypsum laminae, up to the width of approximately 1 cm. In this phase, the »pure« gypsum crystallised, between the two previously crystallised gypsum laminae (middle stripe in Fig. 16).

During the final phases of the anticline formation, when the schisting and mylonitization of surrounding rocks were completed, all three gypsum laminae were cut, separated and sigmoidally bent (Fig. 15, e) along the contact with the reverse

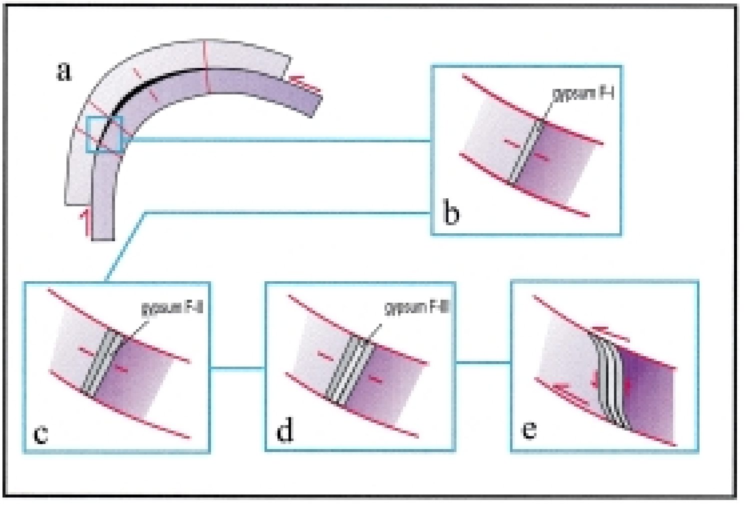

Fig. 15. Schematic representation of sequence of discontinuity surfaces opening and phases (F–I to F–III) of gypsum crystallization (crystalline gypsum, older type) within the Lower Triassic clastic rocks during the formation of the Nemec structure.

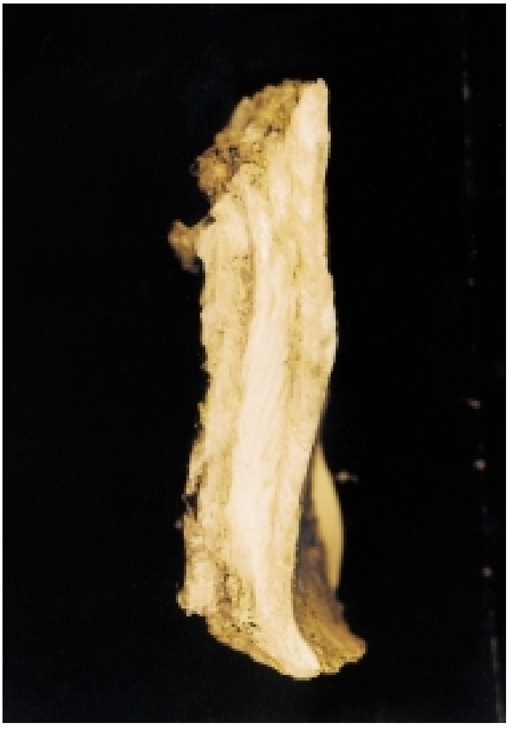

Fig. 16. Sample of crystalline gypsum (older type), with visible laminae of all three phases (F–I, F–II, F–III). Compare with Fig. 15, e

faults. On the outer surfaces of the crystalline gypsum laminae, at the contact with the mylonitized matrix, linear records (Fig. 17) were observed, formed due to the reverse tectonic transport.

Through detailed investigation of the fracture systems with gypsum, formed by separation along the bedding planes, it was found that not all of them underwent the presented sequence of crystallization and deformation of gypsum laminae. The majority of the fractures studied remained preserved at the level of one phase (F–I, F–II or F–III), out of the three previously presented. For example, in Fig. 18, thin »layers« (0.5 cm thick) of gypsum (white stripes) can be noticed. The envelope of these »layers« follows the schistosity in the violet and green matrix, which was transformed into mylonitic clays. At the bottom of the picture, clean, white gypsum is visible which also crystallized in the subsequently opened fracture.

The second (younger) type of open fractures was formed during the final deformational phases of the structure formation after the folding, interbedding schisting and mylonitization of the pelitic matrix. At this point, tension processes occurred, which were active perpendicular to the *b*-axis of the structure. By these processes, fractures were opened (Fig. 19) which are in the zone of the *b*-axis and are perpendicular to schistosity. In these fractures, gypsum crystallized subsequently. As seen

Fig. 17. Linear record on outer planes of crystalline gypsum laminae.
Detail from Fig. 16

in the photograph, the fractures opened in the lower part (up to 2 cm) while they are closed towards the top. Gypsum crystallized in the swallowtail twin form, and there are no traces of deformations on the crystals, which implies that the gypsum crystallized after the final formation of the structures of the Nemec profile.

Geological and structural-tectonic setting of the Vidovec locality

In the upper stream of the Vidovec creek, occurrences of gypsum were found within secondary blocks. Gypsum appears in two forms (Fig. 20). The first form (grainy gypsum) is found in grey early diagenetic dolomite (Fig. 20, b) which is in direct contact with black metapelites (Fig. 20, a). This grey, finely grained, allotriomorphic gypsum is, most probably, syngenetic with the accompanying dolomite. The second (crystalline gypsum) occurs as white, completely clean, hypidiomorphic, middle to coarse crystalline gypsum, which is in direct contact with black metapelites (Fig. 20, c). Black metapelites belong to the wider zone of low-metamorphic rocks of the Bliznec member from the Sljeme metamorphic unit (JAMIČIĆ, 2000). Pelitic sediments of the Bliznec member were intensely folded during the period of metamorphic changes and became schistoid with the appearance of foliation along the axial plane cleavage. During later (post-Cretaceous and Neo-

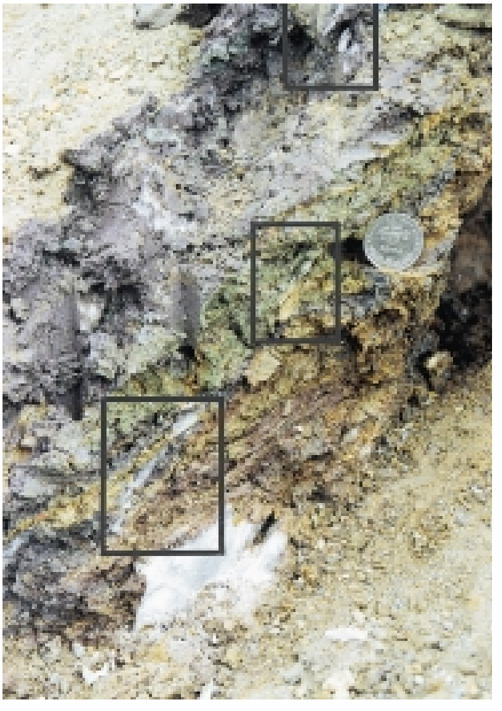

Fig. 18. Fractures filled with gypsum crystallized during only one phase. Detail from Fig. 15, a

Fig. 19. Crystalline gypsum in the Lower Triassic mylonite matrix of the Nemec structure, connected to the second (younger) type of opened discontinuity planes from the zone perpendicular to schistosity and parallel to the antiform axis.

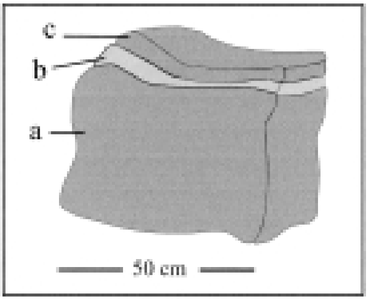

Fig. 20. Schematic representation of the secondary block from the Vidovec stream built of: a) black metapelites; b) clayey dolomite with gypsum, and c) crystalline gypsum

tectonic) deformation events, metamorphic rocks with gypsum were additionally intensely tectonized and mylonitized (under the influence of the reverse fault with Cretaceous-Palaeogene deposits). Recently, only the outcrops of separated blocks in the mylonitic matrix of metapelitic rocks have been found. On the blocks of black metapelites it is clearly visible that dolomite with gypsum has not been deformed (Fig. 20, b). It has discordantly covered the previously folded black metapelites, suggesting that clayey dolomites were deposited on a metamorphized and tectonically shaped palaeorelief. In later (?) deformational phases of the tectonic formation of this area, gypsum crystallized within the opened fissures (Fig. 20, c). These fractures appear along the predisposed discontinuity planes parallel to the clayey dolomite layer. The aperture of the fractures, according to gypsum crystal size, is up to 8 cm.

Chemical composition of gypsum and isotopic composition of sulphur

Chemical analysis (Tab. 1) showed that samples 1 (grainy gypsum), 2 (schistoid gypsum) and 3 (crystalline gypsum) from the Nemec locality represent a practically pure gypsum with a crystal water content of 19.06 to 20.54 wt.%. This in particular refers to sample 3, the value of which is close to the ideal, of 20.93 wt.%. The results obtained by X-ray analysis for sample 3 confirm that the gypsum is completely clean, while samples 1 and 2 showed traces of anhydrite and semi-hydrate (basanite). X-ray analysis also gave the composition of the mylonitic violet-green pelitic matrix, which is predominantly composed of illite, chlorite and dolomite, as well as of some gypsum and quartz.

Samples 4 and 5 from the locality in the Vidovec creek were chemically analyzed. Sample 4 is early diagenetic dolomite with gypsum (Fig. 20, b). XRD analysis showed that this rock mainly consists of gypsum, less of quartz and dolomite and some K-feldspar. According to the results of chemical analysis, this sample consists of somewhat more than 50 wt. % of gypsum, somewhat less than 20 wt.% of dolomite and contains considerable amount of residue insoluble in HCl 1:3. Unlike sample 4, sample 5 represents completely clean gypsum (Fig. 20, c) with 20.80 wt.% of total amount of crystalline water (Tab. 1). The results of X-ray analysis of black metapelites showed that they mainly consist of illite and chlorite, with some share of quartz and plagioclase, gypsum and anhydrite (?).

Tab. 1. Parcel chemical analyses of samples (wt.%). * - Insoluble residue in HCl 1:3.

Broj uzorka Sample No.	1	2	3	4	5
Lokacija Location	Nemec	Nemec	Nemec	Vidovec	Vidovec
R_2O_3	0.14	0.10	0.04	2.51	0.02
CaO	32.34	32.41	32.70	22.98	32.64
MgO	0.23	0.48	0.05	3.09	0.07
SO_3	45.48	45.59	46.35	23.90	46.02
CO_2	n.d.	n.d.	n.d.	8.27	n.d.
H_2O^+	19.06	19.28	20.54	10.75	20.80
$\sum$	97.25	97.86	99.68	71.50	99.55
Ir^*	2.27	2.14	0.15	28.30	0.14

Samples: 1 – grained gypsum; 2 – schistose gypsum; 3 – crystalline gypsum; 4 – dolomite with gypsum; 5 – crystalline gypsum.

The obtained values of isotopic sulphur composition in all five analysed samples are remarkably even (Tab. 2) and range from 11.46 ‰ to 12.6‰. Isotope values from the Vidovec locality vary in a narrow range of 0.25‰ as do the isotopic values of the samples from the Nemec locality, which are in a range of 0.32‰. Even though minor differences in values of isotopic content are noticed between these two localities, with a maximum range of 1.15‰, they are still negligible.

DISCUSSION

The uniform sulphur isotopic values obtained in the analysed gypsum samples from the Nemec and Vidovec localities suggest they originated by the deposition of marine sulphates under reductive conditions, with the absence of lighter sulphate isotopes of continental origin. Since all of the isotopic values are very similar, it can be concluded that the sulphate isotopic composition was relatively homogenous in

Tab. 2. Sulphur isotope composition.

Broj uzorka Sample No.	Lokalitet Location	$\delta^{34}S$ ‰	std. dev.
1	Nemec	+12.29	0.10
2	Nemec	+12.41	0.03
3	Nemec	+12.61	0.02
4	Vidovec	+11.46	0.01
5	Vidovec	+11.71	0.03

the sedimentary basin, and that during the sulphate deposition, i.e. the genesis of evaporites, the conditions were uniform.

By the method of isotopic sulphur analysis it is possible to determine and correlate the age of evaporites. This is based on the fact that sulphur has had variable isotopic composition in oceanic sulphates during the Earth's geological history. The changes in isotopic values of the ocean sulphates were of the global range. The result of this is a relatively continuous »isotopic-age curve« (NIELSEN, 1978; CLAYPOOL *et al.*, 1980, cit. ŠIFTAR, 1986). On the basis of the »isotopic-age curve« (Fig. 21) and comparison with values obtained from sedimentary basins of central and western Europe, the Russian platform, western parts of USA, and other areas (THODE & MUNSTER, 1964; ERMENKO & PANKINA, 1971; NIELSEN, 1978; CLAYPOOL *et al.*, 1980, cit. ŠIFTAR, 1986), all the isotopic values obtained within the range from 11.46‰ up to 12.6‰, suggests by values close to the Permian minimum (δ^{34} S around 10‰) a Permian age, i.e. a transitional Permian-Triassic age for the evaporites analysed.

Nevertheless, it is important to emphasize that by recrystallization of gypsum, the sulphate isotopic values would not change (ŠIFTAR, pers. comm.), which implies that sample 3 (Nemec profile), i.e. recrystallized gypsum which appears in the form of completely transparent crystals (Figs. 15–18) within the violet to green mylonitic matrix, is in fact, a younger one. This corresponds to the results obtained by the structural-tectonic analysis.

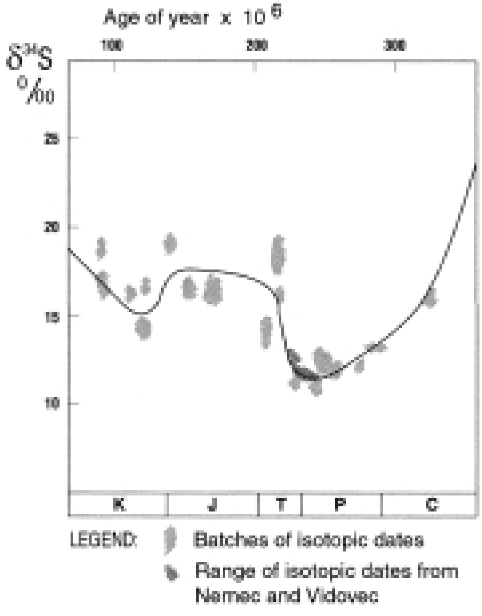

Fig. 21. Curve of the marine evaporites age according to isotopic composition of sulphur, for the period from Carboniferous to Cretaceous (CLAYPOOL *et al.*, 1980).

The palaeotemperatures studied by POLŠAK & PEZDIĆ (1978) showed that during the Permian in the Dinaric-Alpine area, due to the favourable conditions, there were optimal conditions for deposition of evaporites. This refers mainly to the Upper Permian age, with which the results of the sulphur isotopic analysis acquired in the gypsum of Mt. Medvednica can be correlated. During this period the Dinaric-Alpine area belong to the hot arid belt, and the average sea temperature was almost 26 °C. Due to this fact, strong evaporation was enabled in lagoons, which caused deposition of the evaporites.

If we compare the obtained values of δ^{34} S with the existing isotopic values of sulphur in samples of evaporites analysed from the Ruda locality near Samobor, which range from 9‰ to 12‰ (ŠIFTAR, 1989), with samples from the wider area of the Sinj-Una belt with an average value 10.7‰, it can be concluded that the isotopic composition of the source marine sulphate was the same, as well as that both occurrences of the evaporites were of the same age (Upper Permian). This indicates the completeness and correlation of the marine area during the Upper Permian, namely the presence of a large and unified sedimentary basin with a high concentration of diluted salts, and deposition of evaporites during the general regressive tendency with a permanent reduction of the marine area during the Upper Permian.

The presented results of the structural-tectonic analysis of the Nemec and Vidovec localities indicate the polyphase character of gypsum crystallization in the area of Mt. Medvednica. In the first phase, synsedimentary gypsum was formed, connected to the early diagenetic Upper Permian dolomites (grainy gypsum). In this gypsum type, important tectonic deformations were not observed, because smaller blocks of dolomites were, as less ductile elements, during the subsequent deformations torn off and folded into the Lower Triassic deposits where they behaved as r-tectonites. Recrystallization of grainy gypsum from dolomites into the Lower Triassic clastic rocks, in the shape of beds and lenses, marks the second phase of its crystallization. The sequence of deformation processes during the initial phases of the Nemec structure formation caused the considerable schistosity of the Lower Triassic sediments, Permian-Triassic dolomites and gypsum from the second phase, when schistoid gypsum was formed. By opening of the fracture systems, in parallel and perpendicularly to schistosity, the space for gypsum crystallization was produced, and during this period of the structure formation crystalline gypsum was formed, indicating that it had the third and the youngest phase of crystallization. The described structural forms were created under the influence of the regional main stress oriented N-S, which was active during the Tertiary and Quaternary in the wider area of the present day Pannonian Basin (JAMIČIĆ, 1995).

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SAŽETAK

Tektonski položaj novih nalaza gipsa na Medvednici (sjeverozapadna Hrvatska)

Jamičić, D. & Slovenec, Da.

U radu su opisana dva nova lokaliteta s gipsom u Medvednici i prikazan je njihov geološki i strukturno-tektonski položaj u naslagama gornjeg perma i donjeg trijasa, te u dijelu metamorfnih stijena Medvednice. Prvi lokalitet nalazi se na sjeveroistočnim obroncima Medvednice, 2 km južno od mjesta Marija Bistrica u zasjeku asfaltne ceste koja vodi za brdo Nemec (koordinate: X 5093562, Y 5586785 i Z 235) dok se druga pojava gipsa nalazi u gornjem toku potoka Vidovca (koordinate: X 5088166, Y 5581144 i Z 455). Na oba lokaliteta su obavljena detaljna strukturno-tektonska istraživanja i uzorkovanje pojava gipsa s ciljem utvrđivanja geneze gipsa i njegovog položaja u strukturi. Izotopne analize sumpora u gipsu su pokazale izrazitu ujednačenost vrijednosti $\delta^{34}S$, koje se kreću u rasponu od 11,46‰ do 12,61‰, što ukazuje na permsko-trijasku starost analiziranih evaporita. Dobivene vrijednosti $\delta^{34}S$ se mogu usporediti s poznatim vrijednostima iz područja Ruda kod Samobora i sa širim područjem Sinja i Une što ukazuje na povezanost marinskog prostora tijekom gornjeg perma.

Na prvoj lokaciji (Nemec) s gipsom snimljen je geološki profil Nemec u dužini od 250 m. Profilom su zahvaćene stijene tercijara, donjeg trijasa i gornjeg perma. Rekonstrukcijom izmjerenih strukturnih elemenata dobiven je niz strukturnih oblika; sinformi i antiformi, reverzih i normalnih rasjeda, s pratećim pukotinskim sustavima. Ustanovljeno je da su borane i rasjedne strukture nastale pod utjecajem regionalnog osnovnog stresa koji je djelovao tijekom tercijara i kvartara na približnom pravcu N-S. U dijelu profila Nemec koji je zahvatio kosu antiklinalu, izgrađenu iz donjotrijaskih naslaga, javlja se gips. Ustanovljena je polifaznost kris-

talizacije gipsa. U manjim blokovima ranodijagenetskih dolomita, koji su tijekom boranja i tektonskog oblikovanja strukture Nemec kao r-tektoniti utisnuti u milonitski matriks donjotrijaskih klastita, utvrđen je tip zrnatog gipsa. Ovaj gips je primaran i kristalizirao je sinsedimentacijski u vrijeme nastajanja gornjopermskih dolomita. Tijekom sedimentacije donjeg trijasa gips je iz dolomita rekristalizirao u donjotrijaske klastite. U početnim fazama tektonskog oblikovanja strukture Nemec gips je, zajedno s okolnim donjotrijaskim klastitima, uškriljen kada nastaje drugi tip gipsa, škriljavi gips. U kasnijim fazama razvoja strukture Nemec, uslijed daljnjeg djelovanja kompresije, sužavanjem prostora i izduženjem strukture okomito na os *b*, otvaraju se paralelno pukotinski sustavi škriljavosti i pukotinski sustavi iz zone osi *b* u kojima se javlja treći tip gipsa, kristalinični gips. I kod ovog tipa gipsa zapažaju se razlike u vremenu kristalizacije. Naime, gips koji je kristalizirao uzduž razdvojenih ploha škriljavosti većinom je daljnjim procesima tektonskog oblikovanja presječen i sigmoidalno svijen uz prazeće reverzne rasjede. Za razliku od njega, gips koji je nastao u otvorenim pukotinama iz zone osi *b* ne pokazuje znakove naknadnih tektonskih deformacija što znači da je kristalizirao posljednji nakon završnog formiranja strukture Nemec.

Na drugoj lokaciji (Vidovec potok) pojave gipsa ustanovljene su na sekundarnim blokovima crnih metapelita. Gips se ovdje javlja u dva oblika. Prvi oblik (zrnati gips) nalazimo u sivom ranodijagentskom dolomitu koji je u direktnom kontaktu s crnim metapelitima. Taj sivi, sitnozrnati, alotriomorfni gips je singenetski s dolomitom s kojim se nalazi. Drugi (kristalinični gips) pojavljuje se kao krupnokristalinični gips nastao kristalizacijom po naknadno otvorenim pukotinama.