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Olistostrome/mélanges – an overview of the problems and preliminary comparison of such formations in Yugoslavia and NE Hungary

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Abstract. The term "mélange" means simply a mixture and has itself no genetic significance without a descriptive adjective. Mélanges can be basically of two types of origin: tectonic ("autoclastic mélange") or sedimentary ("olistostrome"). The first type in the language of structural geology can be defined as transposition of S-surfaces, whereas the second one in that of sedimentology as deposit of debris flow. However, if an olistostromal formation suffers pervasive shearing, the distinction between the two types becomes practically impossible. Mélanges may result in different settings, but only those can be regarded as true subduction-related (accretionary) complexes, which contain amongst exotic blocks (chert, limestone, sandstone, etc.) also inclusions of basic and ultrabasic rocks in a matrix of different (mostly argillaceous) composition, e.g. the "ophiolite mélanges". It is essential to see the character of the matrix, as in poorly exposed terrains, like the hilly regions of the ALCAPA Megaunit, having random outcrops of hard rocks, even folded or imbricated, otherwise normal successions (like deep-water limestone - radiolarite - shale) can be misinterpreted (and, unfortunately, often are...) as either "tectonic mélange" or "olistostrome".

Ophiolitic mélanges (the "Diabase-Chert Formation" in the former literature) occur in two zones in Yugoslavia: in the Vardar Zone (VZ) on the East and in the Dinaridic Ophiolite Belt (DOB) on the West, separated by the Drina-Ivanjica Element (DIE) continental block/terrane. The DOB bears evidence of Middle Triassic opening and Late Jurassic closure, with inclusions of all formations of the Triassic DIE carbonate platform, some Permian rocks and blocks from the ocean floor: ophiolites (pillow lavas, gabbros, ultramafics) and radiolarites yielding both Triassic and Jurassic radiolarians. Large ultramafic masses are characterized by metamorphic sole.

The VZ is interpreted as a Paleotethyan oceanic remnant, existing already in the Paleozoic and closed in its most part during the Late Jurassic, with a back-arc basin in its western part, that closed in the Late Cretaceous. Mélanges occur in the central and mainly in the western subzone. They differ from those of the DOB in the absence of large olistoplakae of sedimentary rocks, rarity of limestone and abundance of sandstone blocks, intense shearing of the matrix and the lack of metamorphic sole of large ultramafic sheets. The western subzone, mostly in the Zvornik zone sector, contains blocks of Senonian limestones.

In NE Hungary, olistostromal formations in connection with ophiolites occur in the lower, sedimentary units (which seem to be identical: the Mónosbél Unit) of both the Darnó and Szarvaskő Ophiolite Complexes. As continuous drill cores revealed, they represent toe-of-slope setting, with all transitions between slumps-debris flows-turbidites. Exotic inclusions (Triassic red, cherty limestone and red chert with basalt, Upper Permian limestone) occur as slide blocks (olistothrymmata). Specific are the limestone-rhyolite olistostromes of the Telekesoldal Complex of the Rudabánya Mts., considered to be in connection with a Late Jurassic magmatic arc. The formerly generally accepted "evaporite mélange" character of the Bódva Valley Ophiolite Complex should be severely modified: true autoclastic mélanges occur only in local shear zones.

In the Yugoslavian-Hungarian area ophiolitic mélanges point to the existence of several oceanic domains (partial basins), which were in connection within the Tethys, but cannot be regarded as remnants of a sole oceanic branch. They differ in composition, depending on geotectonic setting and composition of surrounding continental blocks and oceanic areas. The few km^2 sized Darnó and Szarvaskő complexes can be regarded as small relics of Neotethyan accretionary complexes, displaced along the Zagreb-Zemplén Lineament from the NW Dinarides to NE Hungary. They show more conspicuous similarity to the western ophiolite belt (DOB), as indicated by some types blocks common in both areas: Triassic Bódvalenke-type red, cherty limestones with basalts, red cherts, both of Triassic and Jurassic age, also with basalts, and the carbonate-turbiditic ooidal Bükkzsérc Limestone and upper part of the Grivska Fm. (or a new formation).

Key words: olistostromes, mélanges, Yugoslavia, NE Hungary, Dinarides, Vardar Zone, "Bükkium".

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1. Birth of the notion

In the year 1895, three well-known geologists of the time, Griesbach, Diener and Middlemiss worked in the central Himalayan Kiogar area, in the larger area of Nanda Devi. They found there: "... a wild mixture of flysch type sediments, blocks of exotic rocks several meters to several kilometers in size, together with basite and ultrabasite blocks". Diener (1895) made a comparison with the "Klippenzone" of Swiss Alps and Carpathians, suggesting the connection of this mixture with overthrusting ("lambeaux de recouvrement" sensu Bertrand, 1884 and Schardt, 1893).

From the same area, von Kraft gave a new genetic explanation in 1902: the mix formed by volcanic explosions which intermixed sediments and basic volcanics.

In 1909, Suess wrote that "The Kiogar area represents the border of a movement surface of the first order, along which overlap sedimentary series of mutually dissimilar facies".

In the first fifteen years of investigation, the complex has thus been described chaotic in composition, containing blocks of "flysch-type" sediments, exotic rocks and basites to ultrabasites. Two explanations for its occurrence have been proposed, which will be of influence for a very long time - genesis as a volcanic-sedimentary formation, and position in front of regional nappes. Besides, similarity to flysch has been mentioned, also leaving traces in the history of the complex.

The term "*mélange*" still did not exist at that time. In 1919, Greenly published a very extensive explanation of the geology of Anglesey, a small island along the western coast of Scotland. Describing the fabric of the Gwna Group from the Mona Complex, Greenly coined the term "*autoclastic mélange*", writing:

"The essential characters of an autoclastic mélange may be said to be the general destruction of original junctions, whether igneous or sedimentary, especially of bedding, and the shearing down of the more tractable material until it functions as a schistose matrix in which the fragments of the more obdurate rocks float as isolated lenticles or phacoids".

"The term "*autoclastic*" originated by Smyth (1891) for a rock having a broken or brecciated structure, found in place where it was formed as a result of crushing, shattering, dynamic metamorphism, orogenic forces, or other mechanical processes" (from Bates & Jackson, 1980). It is clear that the fabric described by Greenly, in modern language of structural geology will be defined as a product of transposition of S-surfaces, representing a purely structural phenomenon.

However, the term "mélange" persisted. In 1950, Bailey & McCallien - two faithful former students of Greenly, investigated a chaotic complex in Anatolia and named it the "Ankara Mélange" in their mentor's honor, but unfortunately without any descriptive adjective. This complex has nothing to do genetically with Greenly's "autoclastic mélange", being not an issue of transposition of S-surfaces. In 1951, Shackleton applied the term "mélange" even for the lahars in Rusinga Island, giving no genetic significance to it.

The term "mélange" was further on used without distinction for all chaotic mixtures of various rocks not obeying the classical rules of sedimentary sequences (law of superposition, law of original continuity, law of faunistic associations; see Gilluly et al., 1959). Such complexes were found in all parts of the world and in rocks of all ages (Liguria, Alps, Iran, Beluchistan, Celebes, Oman...). Beside a chaotic fabric, one of the most outstanding features of these complexes of regional significance was the presence of the "Steinmann's trinity": blocks of chert, arkose and basites.

Comparing the Celebes ophiolitic complex with ophiolites of Turkey, Kurdistan and Oman, Kündig (1956, and especially 1959) systematized their general characteristics as follows:

- heterogeneity of hypoabyssal, plutonic and volcanic rocks,
- sharp facies differences from both sides of the ophiolite zone,
- association of metamorphic (especially glaucophane) and non-metamorphosed rocks,
- chaotic structure with frequent anomalous contacts,
- absence of roots and channels which would conduct magmatics to present position,
- mostly cold contacts of magmatics toward adjacent rocks,
- "large areas of the shelf edge coverage slid as huge exotics into a foreign environment".

The advent of the Plate Tectonics made a specific kind of mélange one of the very important features in the global architecture. This was the ophiolitic mélange – a mixture of matrix, different in composition, and exotic blocks of various size, where ophiolites, cherts and greywackes played an important role.

During the discussion at the Beneo's lecture at the 4th World Petroleum Congress, Flores (1955) introduced the term and notion of *olistostrome,* and Gansser (1955, 1959) used this mechanism to partly explain the origin of the ophiolitic "colored mélange" of Iran and Beluchistan (olistostrome + tectonics). Thus, two main branches of thinking were opened for the origin of ophiolitic mélange - tectonics and sedimentation ("mega-olistostrome").

General rules of the mélange organization were given by Hsü in 1968 (no stratal continuity; no normal superposition; time-range of deposition is not given by fossils found in the mélange) together with somewhat less important declarations that the lower and upper contacts of the mélange may be depositional or dislocational, and that the roof of the mélange can be autochthonous in one place and allochthonous elsewhere. Several years later, Hsü (1974) published another paper, making a distinction between the mélange (giving no genetic adjective!) and the olistostrome, strictly advocating the tectonic interpretation of the mélange.

Both main explanations of the mélange origin - tectonic and olistostrome - connect this complex with the subduction troughs. A different opinion has been advocated by Belostockij (1978) - from his observations in Albania, the author concludes that the mélanges have their original place in front of large nappes, where the material of the front

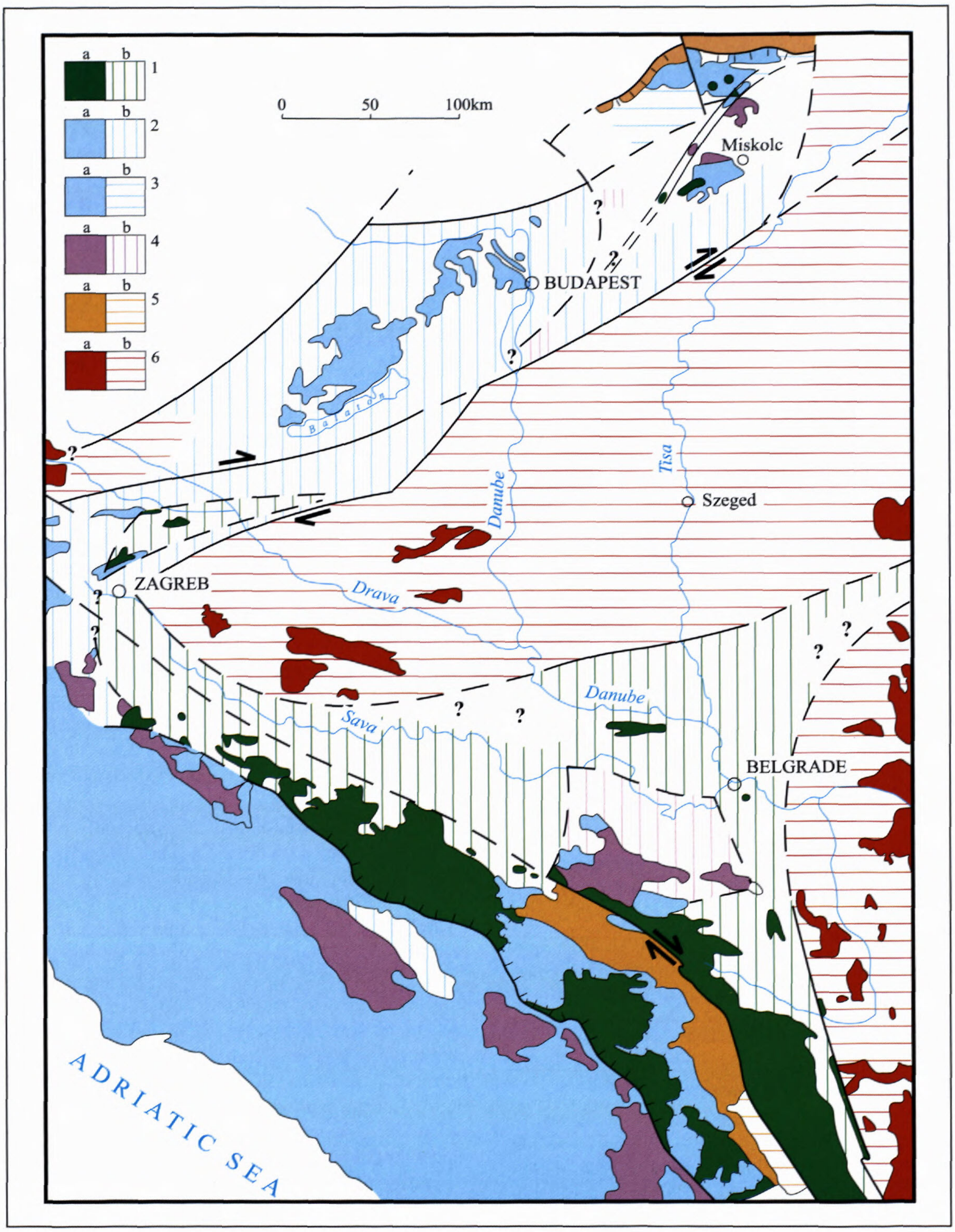

Fig. 1 Tectonic/terrane sketch map of the Dinarides+Vardar Zone and of the Pannonian area.

Legend. 1: Neotethyan ophiolite complexes (Vardar Zone, Dinaridic Ophiolite Belt, and in the Zagorje-Mid-Transdanubian and Bükk Composite Terranes); 2: Units related to the North Tethyan continental margin in the Pelsonia Composite Terrane; 3: Units related to the Adriatic/Apulian continental margin of the Neotethys in the Dinaridic+Vardar Zone and in the Pelsonia Composite Terrane; 4: Areas with marine Upper Carboniferous+Permian within 3. ("Noric-Bosnian Zone" in sense of Flügel, 1990); 5: Paleozoic Units without marine Upper Carboniferous and Permian in the Dinarides and Pelsonia Composite Terrane ("Betic-Serbian Zone" in sense of Flügel, 1990); 6: Units related to the Variscan Median Crystalline+Moldanubian zones (in sense of Neubauer & von Raumer, 1993) and to the North Tethyan (European) continental margin during the Mesozoic.

Green dots in NE Hungary indicate drill hole occurrences of the Neotethyan Bódva Valley Ophiolite Complex, whereas the green triangle the outcrops of the Upper Jurassic (?) Telekesoldal rhyolites in the Rudabánya Mts.

Area in the full colour (a) indicate surface occurrences, whereas those with hachures borehole proven ones in the pre-Tertiary basement slid down, possibly also forming olistostromes and being crushed posteriorly under the nappe by its movement. This explanation seems to be important for mélanges that are not bound to plate/microplate margins, being not necessarily connected with ophiolites. Such mélanges would more or less correspond to the "*chaos*", "a structural term proposed by Noble (1941) for a gigantic breccia associated with thrusting, consisting of a mass of large and small blocks of irregular shape with very little fine-grained material, in a state of semidisorder" (from Bates & Jackson, 1980).

A non-genetic definition of "mélange" has been proposed by Raymond (1984): "A body of rock mappable at 1:24,000 scale or smaller, characterized by a lack of internal continuity of contacts or strata and by the inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmental matrix of finer-grained material."

To overcome all problems connected with genetic aspects, Medley (1994) coined a practical engineering term "bimrock", defined as "a mixture of rocks, composed of geotechnically significant blocks within a bonded matrix of finer texture".

It is well known that olistostromes occur in a variety of geological bodies, ranging in thickness from a few decimeters to several tens of meters. In the terrains of Yugoslavia, these bodies vary in age - from at least the Paleozoic - e.g. Devonian of Eastern Serbia (Krstić & Maslarević, 1990) and the Carboniferous Ivovik Formation in the Jadar Paleozoic (Filipović, 1996), over the Uppermost Jurassic (Ruj Flysch, Dimitrijević & Dimitrijević, 1967) and Cretaceous flysches, up to splendid outcrops in the Upper Eocene of Pčinja (Dimitrijević & Dimitrijević, 1970). These deposits, being bound neither to the microplate boundaries nor to the large nappe fronts, and having no connection with the ophiolites, are not dealt with in this paper. Overviews for general characteristics of such deposits have been given in Yugoslavia by Dimitrijević & Dimitrijević (1973, 1974) and in Hungary by Kovács (1988). The main results of our cooperation were already given in the extended abstract by Dimitrijević et al., 1999.

2. Ophiolitic Mélanges of Yugoslavia

Deposits presently regarded as the ophiolitic mélange were first mentioned by Phillipson (1894) in Greece, and named the "Serpentin-Hornstein-Schiefer Serie". In 1906, Katzer named these deposits the "Ophiolite-Chert Beds", and the name "Diabas-Hornstein Formation" which has lasted up to the recent times, was given by Ampferer & Hammer in 1919. From the time of the first investigations, the main interest has been oriented toward the age of the deposits - Jurassic according to Katzer (1906), Triassic according to a long list of authors, or both (an older, Triassic, and a younger, Jurassic one). The origin has been unequivocally regarded as volcanic-sedimentary, the opinion which tragically persisted up to present times. It was considered a normal "bed-to bed" formation, all clearly visible irregularities being attributed to volcanic or tectonic forces. It seems that the first to see the chaotic fabric of the "Diabase-Chert Formation" was Jovanović (1963), who regarded it an issue of volcanic mixing. It is highly interesting that Kossmat, as early as 1924, pointed to the possible similarities of the depositional environment of the "Schieferhornstein-Gruppe, Radiolaritschiefer" to the deep trenches of the Sunda archipelago!

The ophiolitic mélange (OM) occurs in Yugoslavia mainly in the two broad geotectonic units - the Dinaridic Ophiolite Belt and the Vardar Zone.

2.1. The Dinaridic Ophiolite Belt

This belt starts northwest from the present national territory, at the Zagreb-Zemplin lineament, well-known in Hungary as a regional transcurrent zone. This microplate boundary was covered in Slovenia by the young Sava nappes during the Neogene movements. Excellent outcrops over large areas make it possible to study the complex in details, without ambiguities known from investigations bound to heavily covered areas or drill-hole cores.

The zone could be subdivided into three quite different segments, the middle one being situated in the present Yugoslav territory (from Tuzla to the Albanian boundary), the northwestern one in the western parts of the former Yugoslavia, and the southern one in Albania.

The middle segment bears the most typical ophiolitic mélange, with the following general characteristics:

The floor of the mélange is mostly represented by the Upper Triassic (less frequently the lowermost Jurassic) limestones or, in places, by a rather thick and conspicuous unit of red chert.

The OM consists of a matrix, normally of silty, less frequently sandy composition, dark gray or somewhat lighter in color, and of inclusions varying in size. This matrix is composed of the nonlithified debris from the Drina-Ivanjica Element (DIE), representing originally the sedimentary apron along the border of the DIE. This shows that the biggest part of the OM derived from the passive margin, opposite to the "conveyer" idea where the constituents of the mélange should be scrapped off from the oceanic bottom. Being mostly transported as unlithified, it contains, in places, bodies of strata already lithified at the sedimentary apron, representing blocks of turbidites. During the Alpine movements, the matrix in places obtained a slightly expressed schistosity of non-systematic orientation.

Inclusions in the matrix (cm-dm clasts, m-dam olistoliths, hm-km olistoplakae/olistonappe) represent (a) fragments of consolidated rocks from the Drina-Ivanjica Element (upper slab in the collisional system, situated presently to the NE and E), and (b) fragments of rocks from the oceanic bottom.

In the first group, fragments from all the Triassic carbonate formations deposited originally over the Drina-Ivanjica Element have been recognized. These are: the Lower Triassic Bioturbate Formation, Middle Triassic Ravni, Bulog and Wetterstein Formations, and Upper Triassic, Dachstein and Ilidža Formations, together with the Grivska

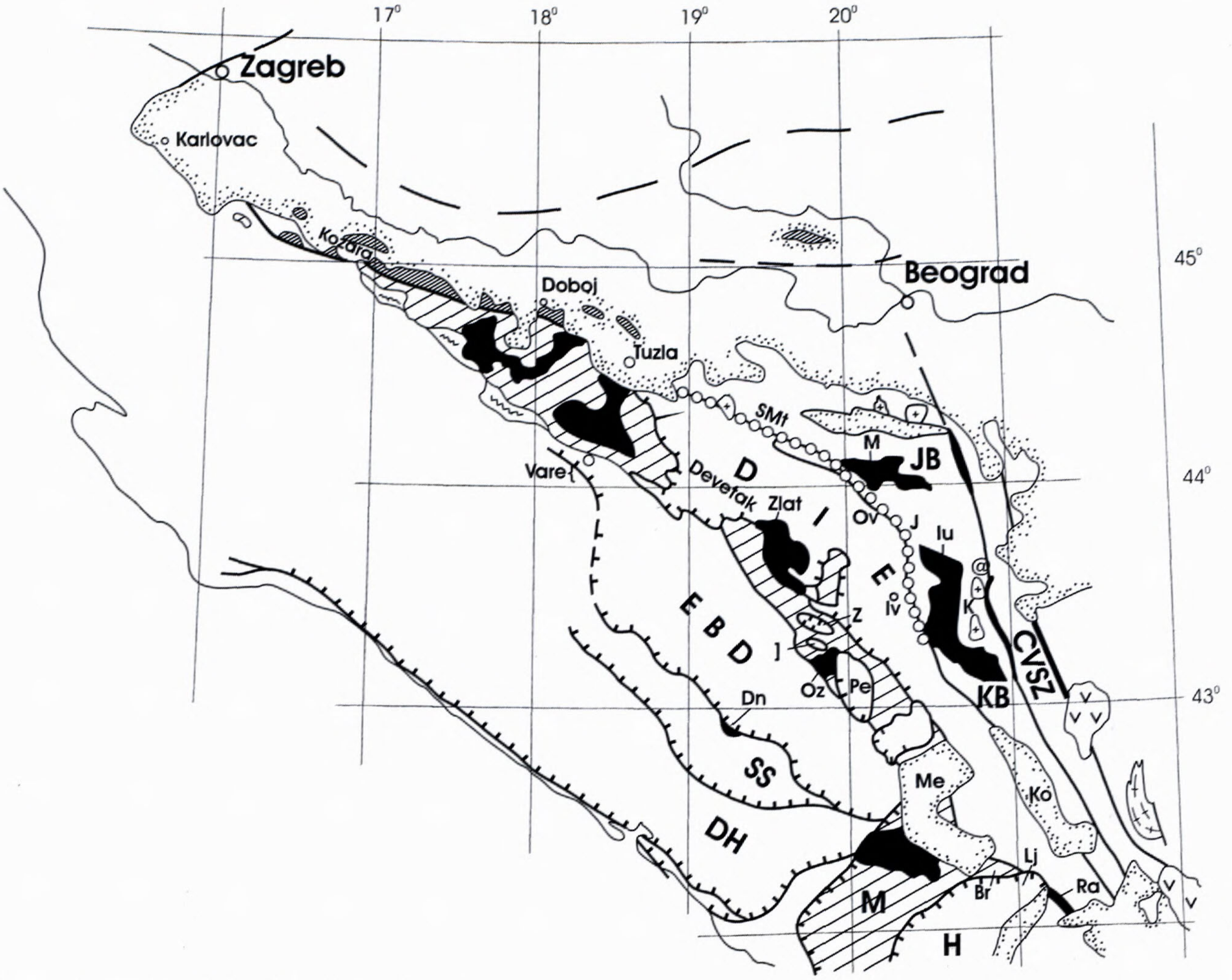

Fig. 2 Sketch of the ophiolite belts in Yugoslavia.
Legend. broad hachure – Dinaridic Ophiolite Belt; close hachure – tectonized mélange; saw-line – radiolaritic floor of the mélange; circles: the Upper Cretaceous mélange of the Vardar Zone; black – ultramafites; vigneted – the Tertiary; M – Mirdita; EBD – East-bosnian-Durmitor Terrane; SS – Sarajevo Sigmoid; DH – Dalmatian-Herzegovinian Terrane; H – Hellenides; DIE – Drina-Ivanjica Element; JB – Jadar Block; KB – Kopaonik Block; CVSZ – Central Vardar Subzone; SMt. – Sokolske Mts.; M – Maljen massif; Ov – Ovčar Mt.; Oz – Ozren Mt.; J – Jelica Mt.; Ž - Željin granodiorite; Iv – Ivanjica; Zlat. – Zlatibor massif; Z – Zlatar Mt.; Ć - Ćetanica; Pe – Peštera; Dn – Durmitor nappe front; Me – Metohija; Ko – Kosovo; Lj – Ljuboten; Br – Brezovica; Ra – Raduša ultramafite; IU – Ibar ultramafite.

Formation regarded as the former blanket of the continental slope, ranging in age from the uppermost Middle Triassic to the (Middle?) Jurassic, (Dimitrijević & Dimitrijević, 1991). Huge olistoplakae (=olistonappe) of Triassic limestones cover parts of the Dinaridic Ophiolite Belt (in the national territory e.g. Pešter, Ćetanica, Zlatar... and Devetak as the westernmost, largest one), and the whole Triassic cover of the Drina-Ivanjica Paleozoic and OM shows traces of gravitational movements, with characteristic local folding along the movement surfaces (Dimitrijević, 1996). Exotic blocks of older rocks, not known from the present surroundings (blocks of *Schwagerina* limestone, conglomerate blocks with Permian clasts, etc.) have also been found.

From the second group, important are fragments of ophiolites, in some places with the original relations conserved (cumulates, sheeted dikes complex, pillow lava), with especially frequent and well-preserved pillow-lava bodies (Karamata & Popević, 1996). Together with large ultramafic bodies, fragments of crystalline schists are transported to the surface (Popević & Pamić, 1973; Karamata et al., 1996). Large bodies of the "Zlatar Chert" (mostly reddish silicified siltstones) are regarded as oceanic sediments, together with blocks of red and green chert, which were formerly considered to represent members of the Triassic volcanic-sedimentary sequence, but yielded, besides Triassic, also Jurassic microfauna (Obradović & Goričan, 1988; Dimitrijević et al., 1996). The Zlatar Chert bears volcanic injections in places; its original position is still under discussion.

Highly enigmatic are lonely dam- to hm-bodies of granitic rocks, disseminated throughout the mélange, occurring also as pebbles in conglomerate olistoliths. One of these bodies (the Straža Granite) gave the age of at least 315 Ma

(Karamata et al., 1996). The original position of these granites remains completely obscure in this segment of the Dinaridic Ophiolite Belt.

Characteristic of the Dinaridic Ophiolite Belt are large bodies of ultramafites - Zlatibor as the largest one, together with Ozren, Brezovica-Kodža Balkan and others. These bodies were introduced as hot masses, producing a conspicuous metamorphic layer in their floor. Zlatibor is interpreted as obducted toward the present NE from its original position below the trough, with subsequent local Alpine movements towards SW. A specific position has the Ozren massif, transported upwards as a hot body without important horizontal movements (Popević, 1985).

The OM is regarded as a deposit of a deep subduction trough. Nevertheless, it is found also some 100 km southwest from the Dinaridic Ophiolite Belt, in normal succession over the Triassic, which opens the problem of its transport to the present place.

The belt had a digitation along the border between the Dalmatian-Herzegovinan and the East Bosnian-Durmitor terranes, shown by a narrow lens of the OM immediately below the front of the Durmitor nappe (Karamata et al., in press) and abnormally high heat flow in the Junik area, where in the Jurassic a rather important body of anatexis-granite was formed, surrounded by high-grade metamorphic rocks within slightly metamorphosed Carboniferous strata (Antonijević et al., 1978).

A remnant of the easterly situated Vardar (Tethys) ocean is present on Brezovica (Kodža Balkan area). Karamata and his associates worked in this area from 1967 to 1996, and they wrote numerous papers considering this area. It is partly covered by the Ljuboten (Kučibaba) nappe, appearing again in the East with the Raduša ultramafic massif. Toward the Vardar zone, it is truncated by young longitudinal faults. It seems to be a former part of the southern, Mirdita segment, presently clenched between the Hellenidic microcontinent and the Dinaridic Drina-Ivanjica Element.

In the national territory, the oldest sediments covering the OM are of the younger Lower Cretaceous age. Further NW, in Bosnia, the "Pogari Series", the first "normal" sediments over the mélange, is reported to be of the Uppermost Jurassic-Lowermost Cretaceous age.

The central segment is interpreted as the site of subduction in an oceanic tract between the main Dinaridic trunk and the Drina-Ivanjica Element - its part separated by the Middle Triassic rifting. The final collision took part in the Uppermost Jurassic, with gravity transport of huge olistoplakae into the mélange and over it.

The northwestern segment shows mostly the same characteristics of the mélange itself. It differs from the central segment in complete absence of olistoplakae, very rare occurrences of tuffs (?) with plagioclase and quartz grains, and specific position of granitic bodies. These bodies, lonely and without clear connections with adjacent rocks in the central segment, occur here together with gabbro-dolerite, representing its acidic differentiates. The age of these granites is not known. Such position, with assumption that the age data for Straža granite are correct, open additional questions, with even a bold hypothesis on the very old age of the astenosphere the magma came from.

Two features are particularly distinct in the zone:

- The floor of the mélange is along the best part of the SW zone boundary represented by a conspicuous unit of varicolored radiolarites over the Triassic limestones. These rocks, up to several hundreds of meters thick, bear intercalations of greywackes, siltstones and silicified limestones. Regarded mostly as the uppermost Triassic/lowermost Jurassic (frequent Upper Triassic conodonts), if correlated with similar radiolarites from the central segment (Obradović & Goričan, 1988), they could be even of a higher Jurassic age.
- In the southeastern part of this zone boundary, near Vareš, the radiolarites are covered with conformable siltstones and silicified marlstones ("Zvijezda formation" of Dimitrijević & Dimitrijević, 1973). These strata are regarded to be of the same age as their radiolaritic floor. The mélange follows with a transitional boundary.

The northern part of the mélange zone, from Kozara Mt. over Doboj to north of Tuzla, is characterized by a mélange described as "tectonized" by Mojićević et al. (1977), Jovanović & Magaš (1986) and others. The composition of the mélange is essentially the same as in the southern belt, with the prevalence of chert and subgreywackes over the basites. Limestone olistoliths are not very frequent, but they seem to correspond to the same Triassic formations as in the southern belt. The complex is pervasively tectonized, and ascribed to the Vardar Zone. It is important that the transgressive roof of this complex is represented by the Upper Cretaceous clastics and *Globotruncana* limestone, not known from the southern belt.

The Tuzla-Zagreb sector is presently the most questionable. The Drina-Ivanjica Element in its present form seems to disappear there, thus making very problematic the boundary between the Dinaridic Ophiolite Belt and the Vardar Zone, which are in immediate contact. The following hypotheses could be discussed:

- Block of continental crust, the present remnant of which is the Drina-Ivanjica Element, had an original continuation west of Tuzla. Material for the matrix originated from the miogeocline of the Drina-Ivanjica Element, as in the Tuzla-Metohija area, and the western part of the element was detached or it disappeared due to tectonic movements.
- This sector represents a remnant of the subduction of the oceanic crust under oceanic crust. Matrix is composed mostly of the material from the oceanic crust, or its terrigenous component originated from the subducted margin.

Data to judge the validity of these hypotheses are insufficient. As the most important, data are lacking on the quantitative relationships between various sediment types and ophiolites as the mélange ingredients. Indicative might be the presence of numerous olistoliths of Triassic limestones in the Kladanj-Stupari section; the domain is, however, too close to the front of the Devetak nappe to be of a sufficiently heavy validity as an argument. According to all the available data, the northwestern segment of the Dinaridic Ophiolite Belt might be interpreted as the site of subduction of oceanic crust under oceanic crust, without intervening the Drina-Ivanjica Element.

2.2. The Vardar Zone

This is a composite terrane with a typical collage tectonics. From the West to the East, it consists of the three subzones: external, central and internal one, with the external subzone being the largest one. The external subzone consists of three blocks (suspect terranes?) highly differing in composition: the Srem block (between the Danube and the Sava rivers), the Jadar block (south of the Sava, bordering the Dinaridic Drina block in the South; truncated by the young faults along the Western Morava depression further SE); and the Kopaonik block in the South. Presence of the ophiolitic mélange in the Srem block is still under question, whereas it represents an important part of the two other blocks.

In the Srem block, which is mostly covered with the Neogene and Quaternary deposits, the Mesozoic is visible at Fruška Gora Mt. only. Čičulić-Trifunović & Rakić (1977) describe here a "highly distorted complex" of argillites, slightly metamorphosed sandstones and quartzites; the part considered by these authors as upper consists of argillite, slates and limestones. Several bodies of "melaphyre", hectometric in size, are also reported from the complex. According to the description and close relations with ultramafic lenses, this complex might represent an ophiolitic mélange of the Jurassic age.

In the Jadar block, the mélange appears only along its SW border, from the Drina river, over Sokolske Planine Mts. and the area of Maljen ultramafic massif, to Jelica Mt. west of Kraljevo.

A large area NW and north of the Maljen ultramafics consists of the ophiolitic mélange, in places over the Lower Jurassic limestone which forms a veneer covering a thick Upper Triassic sequence (Mojsilović et al., 1975). Mélange is there reported to be composed of argillites (most probably the matrix), sandstones, variegated chert, conglomerate, breccia, oolitic limestone, together with bodies of diabase, spilite, porphyrite, as well as gabbro, dolerite and "melaphyre". Several limestone bodies yielded the Middle Dogger forams, and others show sections of tiny ammonites or megalodonts. The mélange is overlain by transgressive Lower Turonian clastics, followed by massive limestones (Filipović et al., 1978). Such position seems to affirm the Jurassic age of the mélange.

At the southwestern boundary of the Jadar block, along the Zvornik suture (boundary toward the Dinarides), a fringe appears of the Upper Cretaceous mélange from the Drina river to the Jelica Mt. (Sokolske Planine - Đuričković & Oršolić, 1988). The main body of the mélange is similar to that in the Jurassic complex, differing in the composition of inclusions (Jelica. Mt. - Brković et al., 1978; the Sklapijevac creek east of Ivanjica - Luković, 1925, Brković et al., 1977) and rounded clasts (Ovčar Mt.) of Senonian limestones, frequently with globotruncanids. East of Ivanjica (Sklapijevac), the outcropping column of the mélange starts with conglomerate bearing fragments of rudist limestone; these are followed by finer-grained sediments passing gradually upward into the mélange of a normal habitus. According to the new observations, in the very complicated area of Gornje Košlje (southernmost part of the Povlen Mt.) both mélanges are present – Jurassic and Upper Cretaceous. This fringe continues further SE into the Kopaonik block.

In the Kopaonik block, the ophiolitic mélange appears in several zones.

At the eastern boundary of the Studenica slice, a discontinuous belt of the mélange is visible beneath the Ibar ultramafite. A very instructive section is seen along the road from Ušće toward the Studenica Monastery, along the Studenica River. In the eastern part of the Studenica slice (Maglić) the mélange contains also diabase, chert and limestone inclusions. Matrix is silty, highly schistose, particularly beneath the ultramafics, with fragments of similarly schistose sandstones. All fragments bear traces of deformation. Well developed turbidites (mostly truncated sequences) are also found. Magmatic rocks and chert inclusions are rare, together with lenses of calcschists and greenschists. This mélange is interpreted as being deposited in a marginal basin, without important influence of the oceanic crust.

In the southern Kopaonik, east of Kosovska Mitrovica up to the northern edge of Kosovo Polje, a lens of mélange metamorphosed in low P-T conditions occurs (the "Kopaonik metamorphites" of Vukanović et al., 1982), being in a tectonic contact with the surrounding formations. These rocks have been formerly regarded as equivalents of the Paleozoic Veleš Series, but these authors cite a "very poorly preserved microfauna of calcisponges, hydrozoans and algal structures" pointing to the Jurassic age, and consider these as metamorphosed Ophiolitic mélange. The complex consists of phyllitoids, meta-sandstones, calc-schists, epidote-actinolite-chlorite schists and meta-basites. It is interesting that a lens of similar rocks occurs further east, in the Central Vardar Subzone, tectonically jammed in the Lower Cretaceous subflysch. This occurrence might indicate a significant underthrusting of the External below the Central Vardar Subzone.

The western boundary of the Central Vardar Subzone bears rather highly tectonized and in places metamorphosed Ophiolitic mélange, tectonically mixed with the Lower Cretaceous paraflysch along the contacts. The matrix consists of schistose fine-grained silt with some sandy component. In this matrix cm-m bodies of highly silicified limestone of unknown age, diabase, Upper Jurassic limestone, greywacke and chert are inserted. Chert blocks contain numerous radiolarians which cannot be determined, and limestones are shallow marine biosparites with ample organic detritus. Such limestones are found along the borders of the mélange trough.

Some parts of the mélange are slightly metamorphosed. The silty matrix is transformed into sericite-chlorite schists, partly also intensely carbonized and silicified, with some sulfide mineralization.

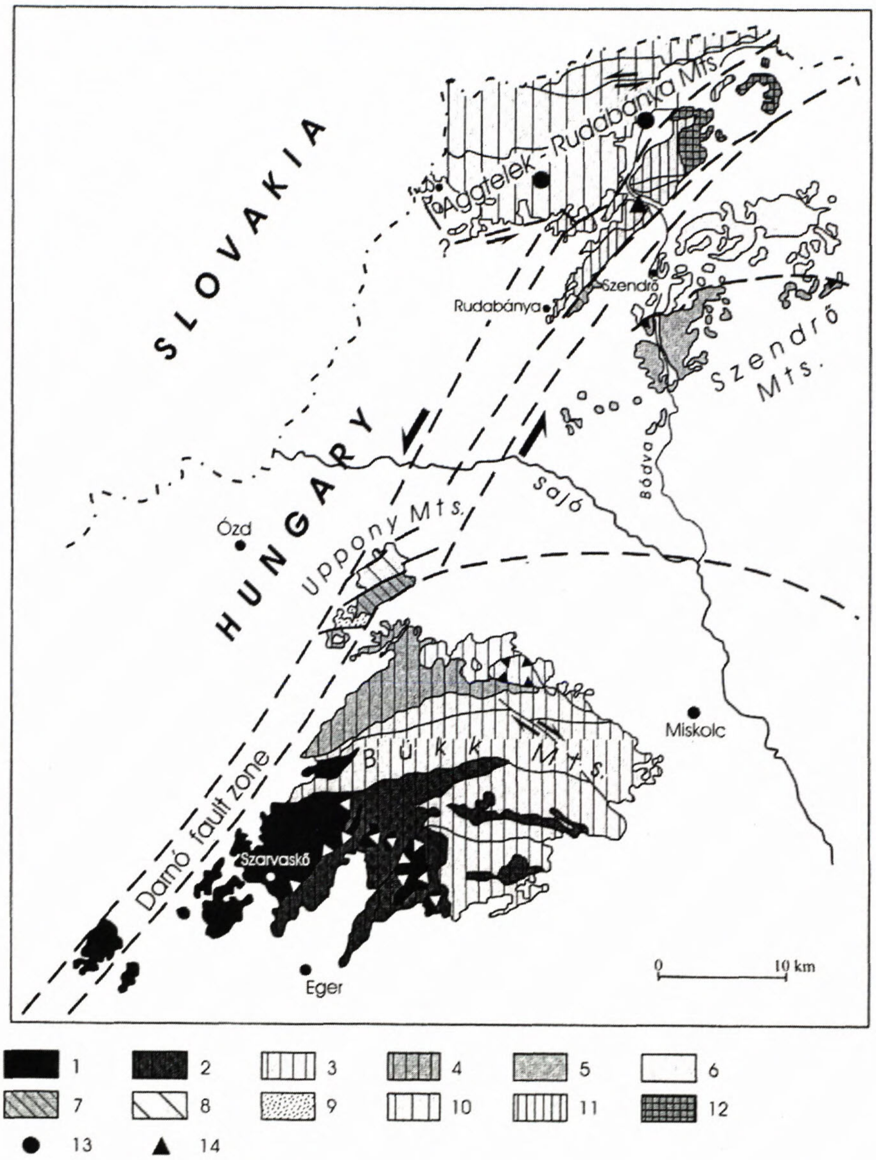

Fig. 3 Geological sketch map of NE Hungary.
Legend. 1-4: Units of the Bükk Mts.: 1: Neotethyan Szarvaskő and Darnó Ophiolite Complexes; 2: Jurassic of the Bükk Parautochthon (PA); 3: Triassic of the Bükk PA; 4: Upper Paleozoic of the Bükk PA; 5-8: Units of the Szendrő and Uppony Paleozoic:5: Abod Subunit; 6: Rakaca Subunit; 7: Tapolcsány Subunit; 8: Lázbérc Subunit; 9: Upper Cretaceous Gosau-type conglomerates in the Uppony Mts.; 10-14: Units of the Aggtelek-Rudabánya Mts.: 10: Aggtelek s.s., Alsóhegy and Derenk Subunits (undifferentiated); 11:Bódva and Szőlösardó Subunits;12: Martonyi (or Torna s.s.) subunit; 13: most important borehole occurrences of the Bódva Valley Ophiolite Complex (=Tornakápolna Subunit); 14: Upper Jurassic (?) rhyolites of the Telekesoldal Subunit of Bódva Unit.

Spilites are not frequent, occurring mostly as pillows, and melaphyres are present as small blocks only. It is interesting that leucocratic alkali granitoids appear as small masses and veins in gabbro and peridotite bodies.
The floor of the mélange is represented with the uppermost Jurassic limestones and the lowermost Cretaceous basal clastics.

In the northwestern segment, the continuation of the Zvornik suture should be expected between the Dinaridic Ophiolite Belt mélange and the "tectonized mélange", regarded as part of the Vardar Zone (presently in Croatia). Along the best part of this segment Upper Cretaceous mélange has not been found, and the "tectonized mélange" is reported to be covered (depositionally? tectonically?) by the Upper Cretaceous (Upper Turonian?) clastics and limestones. This is rather perplexing, contravening the Senonian results further southeast. To make the story more complicated, at the westernmost part of the zone, at Banija near Karlovac, the Senonian clasts were found in the mélange.

The Senonian mélange has been regarded either as an original Jurassic complex, reworked posteriorly by a kind of resedimentation (Dimitrijević & Dimitrijević, 1979, "recycled ophiolitic mélange") or as an original issue of the ultimate closing of the Vardar ocean in the Senonian. The latter opinion prevails recently, opening new problems of the history of the Vardar Zone. According to Karamata et al. (1994) this area represented a back-arc oceanic basin with (immature) island arcs up to the Upper Cretaceous. The closing age of different parts of the suture seems to be slightly different. The same authors envisage the domain west of the Kopaonik-Željin antiform as the closure area of the back-arc basin, and the Central Vardar Subzone (east of the antiform) as the suture of the main, Vardar = Tethys ocean. This ocean played the role of the main link between the southern part of the Tethys and the northern, ALCAPA regions.

In comparison with the OM in the Dinaridic Ophiolite Belt, the Jurassic mélange in the Vardar zone shows the following specific features:

- Inclusions of limestones, highly characteristic for the Dinaridic Ophiolite Belt, are very rare. In the Jadar block Middle Jurassic oolites, unknown from the adjacent areas, occur as clasts and olistoliths, and in the Kopaonik block only infrequent inclusions of dark limestone are found in places, mostly devoid of fauna.
- Blocks of sandstone are very frequent, showing splendid turbiditic features in places.
- Matrix is sparse, intensely tectonized, usually showing traces of transcurrent movements.
- Tectonic mixing with adjacent rocks of all ages (even Cretaceous) is conspicuous in regional zones.

- Ocean-derived magmatics are profuse, mostly predominating, with diapiric movements along the tectonic zones (Milovanović & Karamata, 1957), but with pillow-lavas less frequent than in the Dinaridic Ophiolite Belt.
- Large peridotite masses (e.g. the Ibar mass) are most conspicuous in the western part of the Kopaonik block. Their original position is regarded to be along the western boundary of the Central Vardar Subzone, with a cold overthrusting toward West, over the whole Kopaonik block up to its boundary toward the Dinarides, during the Upper Jurassic. They generally do not show a metamorphic floor. According to this model, the uplift of the complex Željin-Kopaonik dome, caused by the granite intrusion, formed a large erosional window which disconnected a formerly unique ultramafic cover.
- Large olistoplakae of sedimentary rocks are absent in the mélange.
- Some mélange masses exerted a regional (suprasubduction?) metamorphism of the greenschist facies, others being not influenced by it.

3. Olistostrome/mélanges in NE Hungary

Olistostromal deposits in NE Hungary (Darnó, Szarvaskő and Telekesoldal Complexes in the Bükk and Rudabánya Mts.) have been recognized much later, than in Yugoslavia. Till the end of the 1970-ies, they have been considered as "shales with limestone or sandstone lenses" (Balogh, 1964). Up to now no detailed sedimentological work on this topic has been published and only a general review on them, with a detailed terminological discussion, is available (Kovács, 1988). A specific type of "evaporite-ophiolite mélange" was recognized in the Aggtelek Mts. (Bódva Valley Ophiolite Complex; Réti, 1985; Grill et al., 1984). Traces of a further occurrence are known from boreholes near to the SW border of Hungary (Haas et al., 2000).

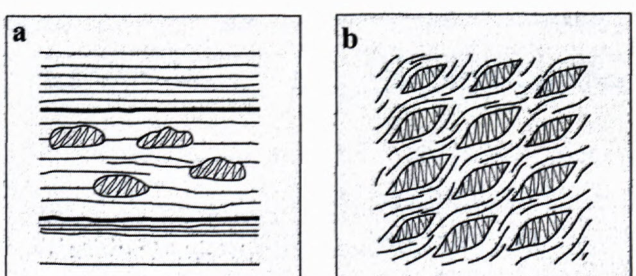

*Fig. 4 Ideal cases of sedimentary (A) and tectonic (B) mélanges. A: "slide bed" or debris flow horizon (=**olistostrome**) with exotic blocks in a normal succession; B: **autoclastic** mélange with pervasively sheared matrix*

It should be mentioned, that purely on facial reasons, ophiolite mélanges of the Austroalpine Gemeric nappe system and of the Dinaridic Bükkian nappe system had been recognized up to the last few years as belonging to the same tectonostratigraphic unit ("Meliaticum s.l."; Kovács, 1984) – a concept, which, first of all on structural geological grounds, should be completely abandoned.

3.1. Szarvaskő Complex

The Szarvaskő Complex (= Szarvaskő–Mónosbél nappes in sense of Csontos, 1988) is built up by the lower Mónosbél Unit composed of shales, olistostromes and carbonate turbidites and by the upper Szarvaskő Unit s.s. formed of mafic extrusive and intrusive rocks and associated shales–sandstones.

The "floor" (e.g. the footwall) of the Mónosbél Unit is constituted by the top part of Bükk Parautochton Unit: Bathonian–Callovian variageted radiolarites overlying Upper Triassic limestones of either platform or basinal facies (without evidences of Liassic and lower Dogger formations) and followed by Upper Jurassic distal turbiditic shales. Opinions about the contact between the two units are controversial: Csontos (1988) and Gulácsi (unpubl.) considers the Mónosbél Unit as a nappe on top of the Bükk PA, whereas Pelikán & Dosztály (2000) consider the two as a basically continuous succession.

Dark gray shales constitute the matrix of olistostromes in part of the outcrops, whereas in others they alternate with carbonate turbidites (as proven also by drill core evidences; Pelikán & Dosztály, 2000). The olistostrome horizons contain dm to meter sized olistoliths from the below described carbonate turbidites, bluish gray limestones of basinal facies (with some evidences of Norian conodonts), black and gray Jurassic (Bajocian to Oxfordian) radiolarites and sometimes basalts. Rarely basalt-breccia, radiolaritebreccia, as well as quartzconglomerate olistoliths also occur.

Carbonate turbidites belong to two types:

1. Ooidal limestone (Bükkzsérc Limestone) with the characteristic foraminifer species *Protopeneroplis striata* (Bérczi-Makk & Pelikán, 1984). These turbidites, deriving from a carbonate platform margin, indicate on the example of the Hellenides, the approaching of the continental margin to the subduction trench (Papanikolaou, pers. comm. on the field in 1993).

2. Basinal limestone (Oldalvölgy Limestone): homogenous microsparite, rarely with microbioclasts, without ooids.

As recognized recently in the Oldal Valley section, olistostromes with olistoliths of these two limestone types represent debris flow horizons within the shale-carbonate turbidite sequence, developed due to renewed gravity flow processes on the unstable slope. The rare exotic blocks can be slide blocks (olistothrymmata). Specific is from these the Triassic basalt–red chert–Hallstatt Limestone block at the eastern part of the complex (Pl. II, fig. 4), similar to those in the explored by the Darnó deep drillings (see below).

The several hundred meters thick Mónosbél sequence represents a proximal, slope facies in respect to the distal turbiditic facies of the top part of the Bükk PA (the latter lacking carbonate turbidites).

Sediments and extrusive mafic rocks of the Szarvaskő Unit seem to constitute a stratigraphic succession (Balla et al., 1983; Gulácsi, unpubl.). Mafic rocks of the Szarvaskő Unit refer to an incomplete ophiolite complex of back-arc basin or marginal-sea setting (Balla et al., 1983; Józsa in Dosztály & Józsa, 1992 and pers. comm.; Harangi et al., 1996). An olistostrome horizon of a few tens of meters thickness occurs near to the basalt lava flows, containing red radiolarite, red mudstone, gray radiolarite and gray limestone olistoliths of meter size. The red radiolarites yielded Ladinian-Carnian radiolarians, whereas the gray ones proved to be of Callovian-Oxfordian age (Dosztály & Józsa, 1992).

3.2. Darnó Complex

The Darnó Complex has been explored on the Darnó Hill area by the deep drillings Rm-131, -135 and 136, each of them 1200 m deep with continuous coring. Its separation from the Szarvaskő Complex is under discussion: according to the unpublished mapping by Gulácsi, it is thrust onto the Szarvaskő Complex (referring only to the upper, magmatic units) in the area SE of Egerbakta–Bátor. It is built up by two complexes:

- An upper magmatic unit, with subordinate amount of intercalated/intersliced abyssal sediments.
- A lower sedimentary unit, composed of toe-of slope (or apron?) sediments, with exotic slide blocks.

The upper unit consists of several 100 m thick slices/blocks of greenish and reddish, often amygdaloidal basalts of MOR-type (Harangi et al.,1996; Józsa, 1999), as well as intrusive rocks (gabbros, dolerites). The intercalated/intersliced sediments of a few meters to 10-20 m thickness, are represented by red radiolarites, red mudstones and bluish gray or dark gray siliceous shales. The radiolarites yielded alternatively Triassic (Ladinian–Carnian) and Jurassic (Bajocian–Callovian) radiolarians (Dosztály, 1994), whereas the siliceous shales are identical to those forming a significant part of the lower sedimentary unit.

The lower unit is built up of sedimentary rocks showing typical features of distal-type turbidites, and contains slide blocks (olistothrymmata) of exotic type. Two main types of sediments alternating with each other can be distinguished: 1) dark gray shales and bluish gray siliceous shales, deriving from a pelitic source area, showing partly "autochthonous", partly distal turbiditic character, and often shearing; 2) distal-type carbonate turbidites deriving from calcareous-marly source area. The previously settled turbidites were often again redeposited by slump and debris flow processes on the unstable slope. Debris flows with micaceous sandstone clasts indicate a third source area. Exotic slide blocks (olistothrymmata) are represented by Triassic (Ladinian–Carnian) Bódvalenke-type reddish cherty limestone and red chert, partly with amygdaloidal basalts. (A similar block is mentioned above at the Mónosbél Unit). A single block of Upper Permian Nagyvisnyó Limestone and Middle Permian evaporitic sequence was also penetrated by the borehole Rm-136.

The upper unit with subordinate amount of abyssal sediments and large blocks/slices of magmatic rocks, represent a typical accretionary prism, in which both Triassic and Jurassic elements piled up, probably both by gliding and imbrication. By no means, however, can it be an issue of tectonic (=autoclastic) or sedimentary (=olistostrome) mélange. The lower unit represents the lower, toe-of-slope part of a trench complex, and probably is identical with the Mónosbél Unit of the Szarvaskő Complex.

The Darnó and Szarvaskő Complexes were emplaced (according to present coordinates) onto the Bükk Parautochthon from the NW to the SE (Balla, 1987; Csontos, 1988, 1999); however, taking into account the large-scale (70-90°) anticlockwise rotation recognized in the Aggtelek–Rudabánya Unit of the Pelso Megaunit, it could be originally from the NE to SW.

3.3. Bódva Valley Complex

The Bódva Valley Ophiolite Complex occurs as slices/fragments of serpentinite, gabbro and basalt in Upper Permian evaporites (Perkupa Evaporite Fm.) at the base of the Aggtelek Unit of Aggtelek–Rudabánya Mts. Because of the autoclastic-mélange type occurrence in the Perkupa anhydrite mine, it has been generally believed, that there is an overall "evaporite mélange carpet" with incorporated ophiolite blocks in this position, formed during the overthrust of the Aggtelek Unit (Grill et al., 1984; Réti, 1985). Latest studies on drill-cores and in the open-pit Alsótelekes gypsum mine led, however, to the recognition, that true autoclastic mélanges with chaotic fabric occur only in intensively sheared horizons. Larger ophiolite blocks/slivers, on the other hand, occur as tectonic slices at the sole thrust (Csontos, pers. comm.) of the Aggtelek Unit, detached from its Variscan basement along its Perkupa Evaporite Fm.

3.4. Telekesoldal Complex

In the Telekesoldal Unit of the Rudabánya Mts. specific limestone-rhyolite olistostrome horizons lacking distinct matrix are intercalated within dark gray shales. Limestone clasts are mostly of irregular shape, gray, micritic, containing Ladinian to Norian conodonts. It is explained, that part of the lime mud was still unconsolidated during the movement of the debris flow and served as matrix, whereas rhyolite clasts were transported as hard rocks (Kovács, 1988). The latters are considered to derive from a Late Jurassic magmatic arc, which is also supported by the fact, that rhyolite subvolcanic bodies are present in the shales (Szakmány et al., 1989; Kubovics et al., 1990), whereas the olistostromes as representing a coeval trench complex.

It is to be added to this point, that in the sandstones of the Darnó and Szarvaskő Complexes abundant acidic effusive and plutonic lithic fragments are known (Árgyelán & Gulácsi, 1997), whereas in the Vardar Zone Upper Jurassic granitoids are known, but coeval rhyolites have not yet been recognized (Karamata, pers. comm.).

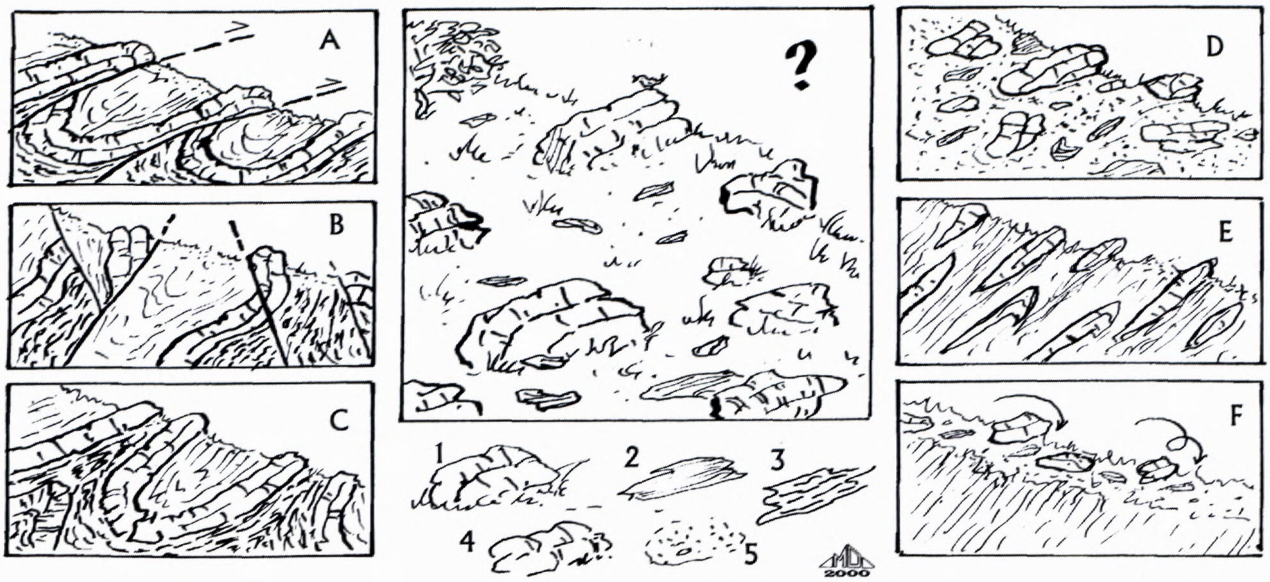

Fig. 5 Possibilities of interpretation/misinterpretation in the poorly exposed terraines of normal (A-C) and disrupted/distorted successions.
A. – overthrusts; B. – faulting; C. - folding; D. – sedimentary mélange (olistostrome); E. – autoclastic mélange sensu Greenly; F. – gravitationally transported blocks in the regolith. 1. – Triassic limestone; 2. – Jurassic shale; 3. – olistostrome matrix or regolith (difficult to distinguish in some cases of poor outcrops); 4. – gravitationally transported blocks in regolith; 5. – regolith. (Original drawing/sketch by M.D. Dimitrijević, 2000).

4. Conclusions

In the Yugoslavian-Hungarian area OM belts point to the presence of several Mesozoic oceanic realms: the Vardar Ocean as the main and highly complex Tethys part between the southern Tethys and the ALCAPA region (?Paleozoic to the Upper Jurassic, with a back-arc basin closed in the Upper Cretaceous), the Dinaridic Ophiolite Belt ocean (Middle Triassic to the uppermost Jurassic) with a possible branch between the present Dalmatian-Herzegovinan and East Bosnian-Durmitor terranes (up the Upper Jurassic). The continuation of these oceanic branches (probably that of DOB) have been displaced to the NE along the transcurrent zone between the ALCAPA and Tisia terranes during the (Late Cretaceous) – Tertiary time (Csontos & Nagymarosy, 1998). Mélanges of these oceanic realms differ significantly in composition, depending on the geotectonic setting and composition of the surrounding continental blocks and oceanic areas. As all oceans do, they had mutual connections during several times, but could not be regarded as one sole oceanic branch.

The few km^2 sized Darnó and Szarvaskő Complexes in NE Hungary can be regarded as small relicts of the Neotethyan accretionary mélange complexes (in the sense of Jones & Robertson, 1991), displaced along the Zagreb–Zemplín Lineament from the NW part of the Dinarides (Haas et al., 2000). In spite their relatively small extension, they are still considerably larger and available for detailed studies, than any other remnants of Neotethyan accretionary complexes in the ALCAPA region. On the other hand, identical/comparable elements are present as constituents in the huge Neotethyan accretionary mélanges of the Dinarides – Hellenides and Vardar Zone. Besides common elements of ophiolite mélanges (matrix composed of shales–siliceous shales, blocks of radiolarites, basalts), some specific constituents are:

- Triassic (Ladinian–Carnian) Bódvalenke-type slide-blocks (reddish, cherty limestones, red cherts) with basalts.
- Middle Jurassic ooidal-bioclastic carbonate turbidites deriving from a platform margin (upper part of the Grivska Fm. or a new formation, Bükkzsérc Lmst.).

Although ultramafic bodies are not known in the Darnó/Szarvaskő Complexes (except some ore-peridotitic differentiates in the latter), the presence of serpentinite detritus in Lower Miocene conglomerates and sandstones on the Darnó Hill (Sztanó & Józsa, 1996) seems to indicate an ultramafic sheet above the Darnó Complex, completely eroded since. The former presence of such a higher unit is made also probable by the intense shearing of its pelitic sedimentary rocks (see above).

5. Summarizing remarks – pitfalls of interpretation of poorly exposed terrains

The term "mélange" for itself, without a specific definition, means simply a mélange = a mixture. In the geological sense, this indicates a more or less chaotic mixture of lithologically and granulometrically differing ingredients; in the broadest sense even a disorganized rudite falls into this definition. Mélanges can be of highly various origin, but for the geotectonic thinking the most important is the ophiolitic mélange. It is considered a manifestation of former oceanic realms, marking thus the boundaries of formerly distant terranes.

Deep-water sedimentary (e.g. limestone-radiolarite-shale) successions occurring in poorly exposed terrains (like those in most part of the ALCAPA-region) can be attractively interpreted (and were and are often did like it) as some kind of mélange, representing a subduction-related complex, even if they are lacking ophiolitic rocks. In such terrains scarce, randomly outcropping cliffs of hard rocks surrounded by shale or marly debris (or even without debris of "matrix-suspected" soft rocks, being the soil completely covered by vegetation), even imbricated or folded, otherwise normal successions can be attractively misinterpreted either as tectonic (= autoclastic) or sedimentary (= olistostrome) mélange (Fig. 5). For pure cases of these often undistinguishable (Dimitrijević & Dimitrijević, 1973) two kinds of melanges see Fig. 4. A further possible misinterpretation, if just a regolith is interpreted as tectonic or sedimentary mélange. Naturally, the probability of a plate tectonic model, if that is based on such a falsely interpreted "subduction-related mélange", is highly questionable.

Consequently, for a correct interpretation of a given complex and to have a solid base for modeling, it is crucial to see the character of both the matrix and of the blocks and their relationship. And, if the complex is considered as representing deposits of an ancient ocean or part of that, it is likewise crucial to have evidences, whether it was really deposited on oceanic crust, e.g. whether it contains some pieces of ophiolites... (allowing its classification as a "true ophiolitic mélange").

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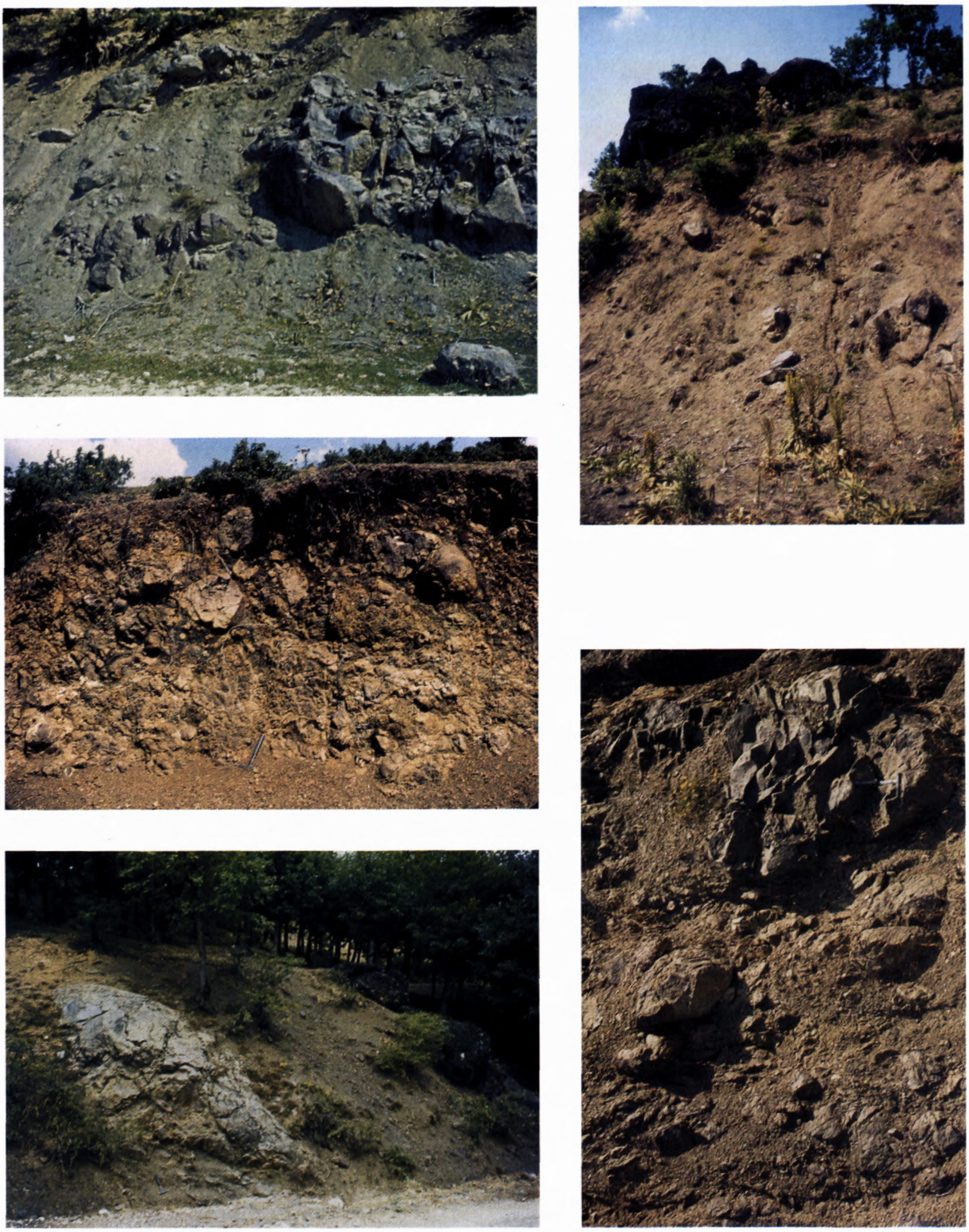

Plate I

Fig. 1 Blocks of characteristic reddish siliceous siltstones in the matrix; Dinaridic Ophiolite Belt, Mileševa.

Fig. 2 Olistolith of pillow-lawa, Dinaridic Ophiolite Belt, old road Mileševa-Sjenica.

Fig. 3 Blocks of limestone and dark gray sanstone in the matrix; Dinaridic Ophiolite Belt, Uvac valley.

Fig. 4 Ophiolitic blocks and clasts in matrix; some of them rounded; Dinaridic Ophiolite Belt, Mileševa.

Fig. 5 Olistoliths and blocks of arenites in matrix; Dinaridic Ophiolite Belt, Mileševa.

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Plate II

Fig. 1 Basalt olistolith (greenish) in dark gray shale matrix. Gorge of Almár Valley, south of Szarvaskő.

Fig. 2 Limestone olistolith in an olistostrome horizon of the Oldal Valley Formation, east of Felsőtárkány, SW Bükk Mts.

Fig. 3 Bódvalenke-type Triassic pelagic limestone with red chert and reddish amygdaloidal basalt. The dark gray siliceous shale matrix of Jurassic age can be seen in the upper right. Darnò Complex, borehole Rm-136, Box No. 81, 367,40–372,30 m.

Fig. 4 Olistothrymma of Triassic red chert, red basalt and light coloured Upper Carnian pelagic limestone in weathered shale matrix. Locality Kavicsos-Kilátó, central part of southern Bükk Mts., north from Bükkzsérc.

Plate III

Fig. 1 Basalt (greenish) associated with Carnian red radiolarite. Road-side outcrop in the valley of Katušnica Creek, Gostilje, Zlatibor Mt., Dinaric Ophiolite Belt.

Fig. 2 Triassic Bódvalenke-type limestone block (below the hammer) associated with basalt (greenish) and with red radiolarite and mudstone. Road-side outcrop in the valley of Katušnica Creek, Gostilje, Zlatibor Mt., Dinaric Ophiolite Belt.

Fig. 3 Triassic Bódvalenke-type red, bedded cherty limestone olistothrymma (right) in shale matrix (left) along the road from Bistrica to Priboj, Dinaridic Ophiolite Belt.

Plate IV

Fig. 1 Oldal Valley type olistostrome with limestone olistoliths. Exposure in the road curve about 500 m north of Tardos Quarry, between Szarvaskő and Mónosbél, Bükk Mts., NE Hungary. (Photo: courtesy of J. Vozár, Bratislava)

Fig. 2 Deformed bedded cherts (Callovian-Kimmeridgian). Dinaridic Ophiolite Belt, Road Nova Varoš-Bistrica.

Fig. 3 Detail of the deformed bedded cherts (Callovian-Kimmeridgian). Dinaridic Ophiolite Belt, Road Nova Varoš-Bistrica.

Plate V

Fig. 1 Folds in the Triassic limestone (Grivska Fm.); Dinaridic Ophiolite Belt, sharp road curve before Nova Varoš.

Fig. 2 Olistoplaka of Triassic limestone in the melange; Dinaridic Ophiolite Belt, Prijepolje.

Fig. 3 Blocks of Triassic limestone in the matrix; Dinaridic Ophiolite Belt, Uvac valley.

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Comparison of the Variscan – Early Alpine evolution of the Jadar Block (NW Serbia) and „Bükkium" (NE Hungary) terranes; some paleogeographic implications

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Abstract. The Variscan and Early Alpine evolution of the Jadar Block (NW Serbia) and „Bükkium" (NE Hungary) terranes are compared showing numerous obvious similarities such as marine development of Carboniferous and Permian (discovery of Paleotethyan fusulinids of Carboniferous age), presence of the Bobova Breccia (as equivalent of the Tarvis Breccia), identical development of Middle and Upper Permian and continual transition to Lower Triassic, Anisian dolomites with the unit of Sebesvíz-type conglomerate on top, early rift volcanism in Ladinian, etc. The Variscan and Early Alpine evolution of the both terranes is also comparable in part to that of the Carnic Alps (Austria, Italy).

Key words: Variscan-Early Alpine evolution, lithostratigraphy, Jadar Block (NW Serbia) and „Bükkium" (NE Hungary) terranes, Carnic Alps.

1. Introduction

The aim of the comparison of the Jadar Block (NW Serbia) and „Bükkium" (NE Hungary) terranes is to establish the similarities and the differences in their geologic development during Variscan and Early Alpine evolution and to show the similarities with coeval successions of the classic localities of Carnic Alps. The correlation of the „Bükkium" Terrane with the latter had already been previously published (Ebner et al., 1991, 1998).

The great similarity between the Jadar and Bükk Late Paleozoic successions was already recognized by Schréter (1948), who mentioned the presence of the „Jadar facies" in the Bükk Mts. Schréter (1959) correlated the Upper Permian, whereas Balogh (1964) both the fossiliferous Carboniferous and Permian sequences of the two areas, within the wider context of the comparison of the Bükk and the Dinarides.

The first Yugoslav geologists to mention similarities in the development of Upper Permian sediments of the Jadar region and Bükk Mts. were Ramovš et al., 1986. Later, in co-operation with Hungarian geologists, Pešić et al. (1988), considering the position of Upper Permian deposits of the Jadar region as part of Western Paleotethys, presented details on the development of the Upper Permian of the Jadar region and on the correlation with similar sediments of the Bükk Mts.

In this paper considerations of the relationships between the Jadar Block and the „Bükkium" terranes during the Variscan and Early Alpine evolution are analyzed in detail. The main characteristics were already given by Filipović et al., 1998.

The relative paleogeographic position of the compared units within the western Paleotethyan and Neotethyan domains is analyzed in a preliminary fashion.

2. General geological setting

Geographically the Jadar Block Terrane is located at the southern and the „Bükkium" Terrane at the northern margin of the Pannonian Basin. In spite of their present separation they both represent crustal fragments which had a very similar, i.e. equivalent geologic evolution during the Late Paleozoic and Early Mesozoic. Their present geologic position (as wedges stuck into geologically different surroundings) was achieved by (Late Cretaceous-) Tertiary strike-slip movements. Today they are isolated geotectonic units within the Vardar Zone Composite Terrane (Jadar Block) and the Pelsonia Composite Terrane („Bükkium") (Fig. 1).

The Jadar Block, as an exotic block terrane displaced into the Vardar Zone in the Upper Cretaceous, is surrounded on three sides by Vardar Zone Composite Terrane members. In the southwest it is thrusted over the Vardar Zone units, while in the southeast the relationships are opposite. Other margins are covered by Tertiary deposits and their contacts cannot be studied, except in the west, where a N-S stretching fault can be assumed as the block boundary (Filipović & Knežević, in Karamata et al., 1994). The differences with the Vardar Zone Composite Terrane are a lack of data on post-Liassic, as well as an absence of ultramafites, ophiolitic mélange, and of Cretaceous flysch development in the Jadar Block Terrane (Filipović, 1995).

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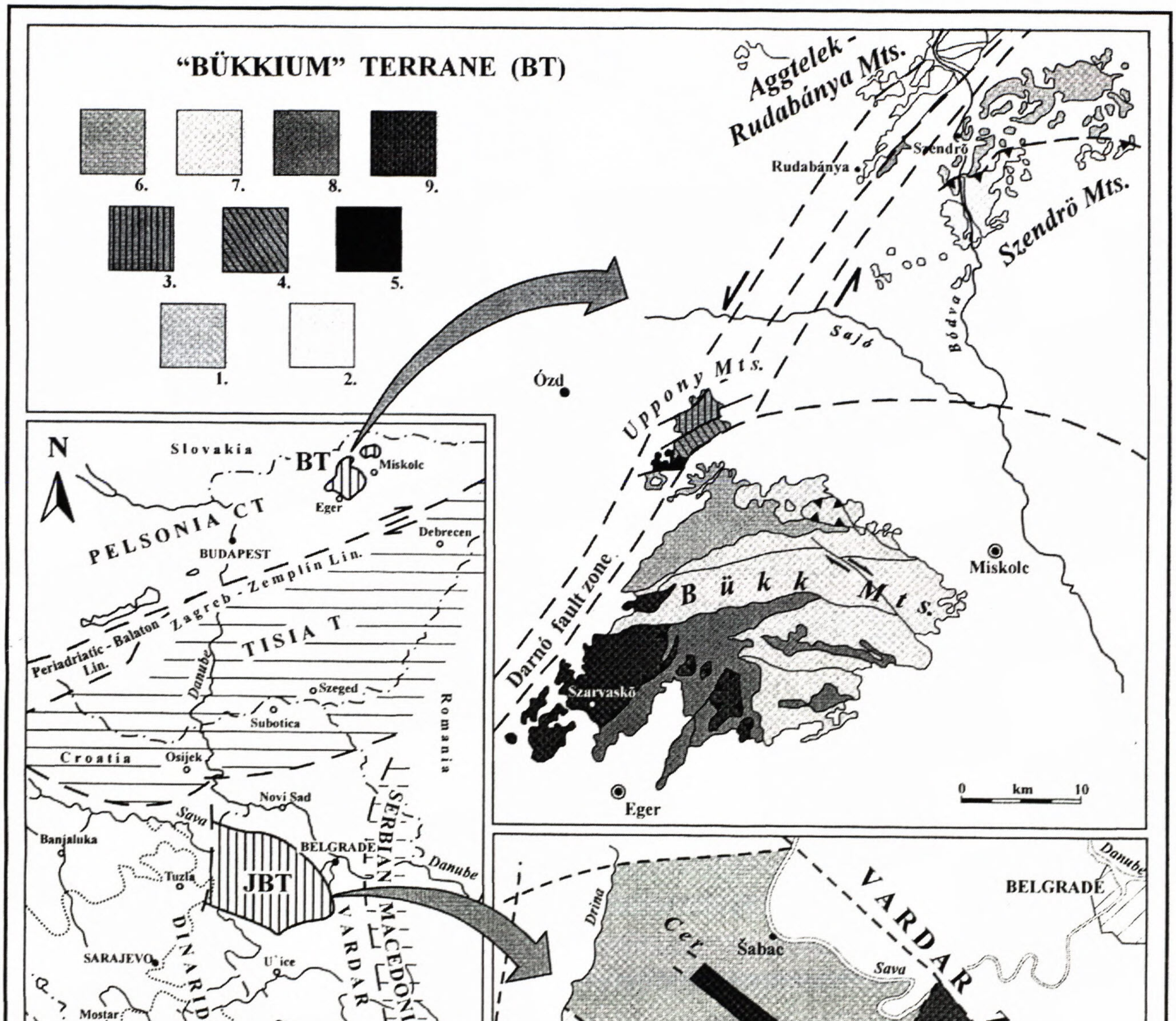

Fig. 1 Sketch of the geographic and present geologic position of the Jadar Block and „Bükkium" terranes within the Circum-Pannonian region and their simplified geologic maps.
Legend. Jadar Block Terrane, Units of the Jadar Autochthon: 1. KV – Krupanj-Valjevo, 2. V – Vlašić, 3. S – Slovac, 4. U – Ub; Jadar Allochthon: 5. LN – Likodra Nappe. „Bükkium" Terrane: 1, 2. Szendrő Unit: 1. Rakaca Subunit, 2. Abod Subunit; 3 – 5. Uppony Unit + Uppony – type Paleozoic in the Rudabánya Mts.: 3, 4. Uppony Paleozoic: 3. Lázbérc Subunit, 4. Tapolcsány Subunit, 5. Gosau-type Senonian conglomerate in the Uppony Mts.; 6 – 9. Bükk Mts.: 6 – 8. Bükk PA: 6. Upper Paleozoic, 7. Triassic, 8. Jurassic; 9. Szarvaskő-Mónosbél Nappe of the Bükk Mts.

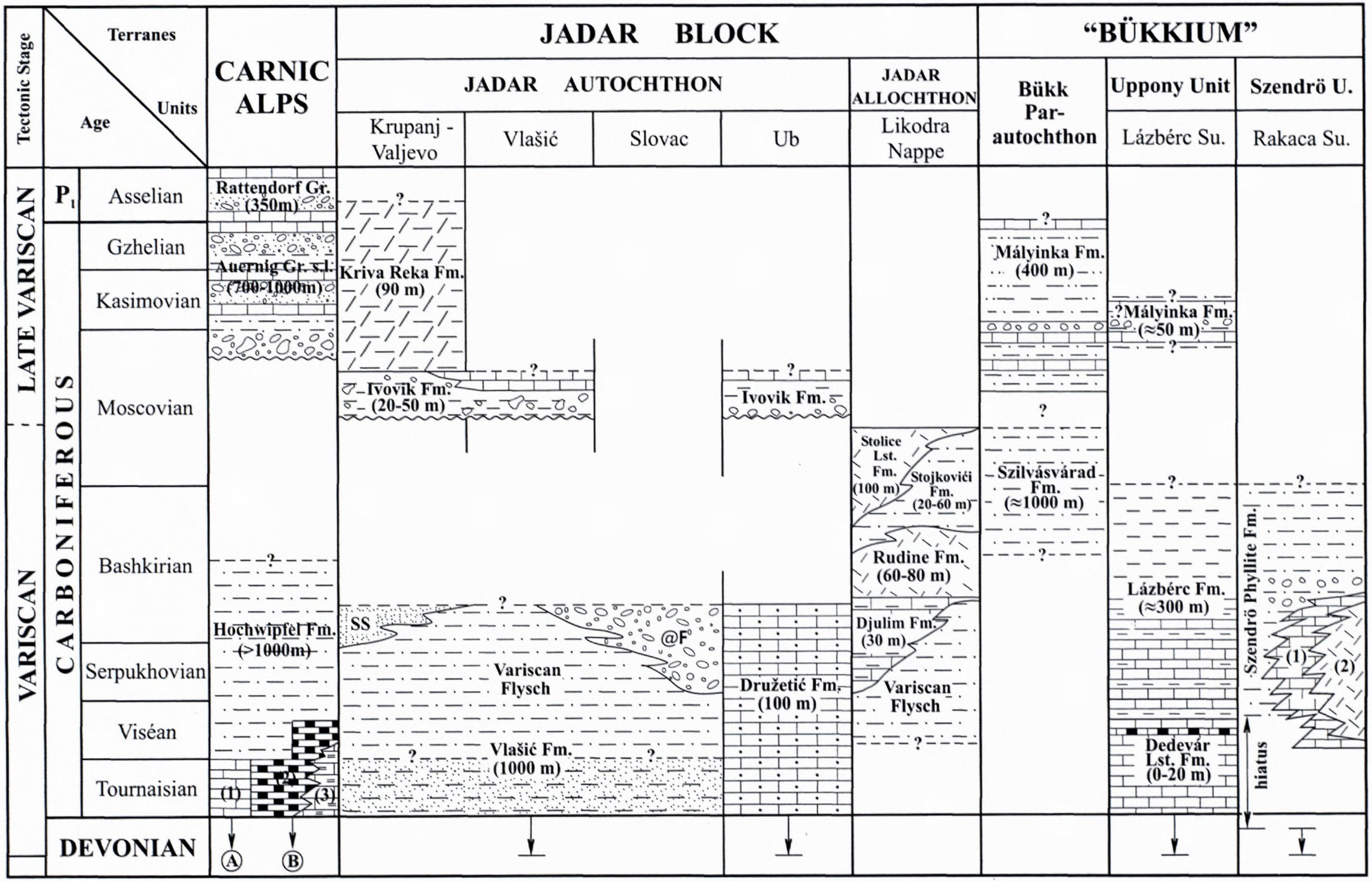

Fig. 2 Correlation of the Variscan (only Carboniferous part) and Late Variscan successions of the Carnic Alps, Jadar Block and „Bükkium" terranes. Abbreviations. Carnic Alps: Ⓐ after Schönlaub, 1985, (1) Kronhof Lst., 10m; Ⓑ after Vai & Venturini, 1995, 1997; Venturini & Spalletta, 1998: (2) lydite, radiolarian chert, shale etc., (Zollner Fm., >100 m), (3) clymenid and goniatitid pelagic limestone. Jadar Block Terrane: SS – Stupnica Sandstone Fm., ŽF – Županjac Fm.; „Bükkium" Terrane (Szendrő Unit, Rakaca Subunit): (1) Verebeshegy Lst. Mb., (2) Rakaca Marble Fm. (s.s).

Paleozoic rocks of the Jadar area belong to the anchimetamorphic zone, except for those from the southwestern marginal zone, which are metamorphosed in the low-grade part of the greenschist facies (Dobrić et al., 1981).

The „Bükkium" Terrane, in the sense of Kovács et al. (1997), on the basis of formerly prevailing geotectonic concepts, forms the southern section of the NE part of the Pelsonia Composite Terrane. Based on Carboniferous facies relations (Balogh, 1964; Kovács & Péró, 1983, Ebner et al., 1991), it was considered for a while to include the Bükk Parautochthon, Szendrő and Uppony Units. Despite the obvious facies links, however, they show opposite structural vergencies (Csontos, 1988, 1999; Koroknai, PhD thesis in preparation). This fact has received more emphasis in the latest terrane subdivision of Hungary (Kovács et al., 2000). Accordingly, the Bükkia Composite Terrane in the latter sense includes the structurally closely related (Csontos, op. cit.) Bükk Parautochthon, Szarvaskő and Darnó Terranes, whereas the Szendrő and Uppony Units are only tentatively included therein. It should be still mentioned that, among the present authors, P. Pelikán and Gy. Less even doubt the distinct nappe position of the Szarvaskő complex upon the Bükk „Parautochthon" and its distinction from the Darnó Complex. Whereas the Bükk PA and Darnó Units are overstepped by similar Upper Eocene marine formations, the Bükkia, Uppony, Szendrő and adjacent blocks of Pelsonia and Tisia are separated by young Tertiary faults overstepped by Middle Miocene sediments.

3. Lithostratigraphy

In the following review the main lithostratigraphic characteristics of the formations deposited during Variscan and Early Alpine evolution in both investigated terranes are described. The numerous similarities during the Variscan and Early Alpine evolution of the Jadar Block and „Bükkium" terranes confirm their mutual sedimentological and paleogeographic connection.

The Variscan succession began in the Middle Devonian in the Jadar Block Terrane (Filipović et al., 1975), but probably already in the Late Ordovician in the „Bükkium" Terrane (Ebner et al., 1998). Fig. 2 shows only the development of sediments during the Carboniferous and lowermost Permian, with arrows pointing to those formations which continue from the Middle and Upper Devonian (Vlašić and Družetić Fms. in the JBT), as well as to other formations of the same age (Abod Lst. and Uppony Lst. Fms. in the Lázbérc Subunit, Uppony Unit, and Bükkhegy Marble, Abod Lst. and Rakacaszend Marble Fms. in the Rakaca Subunit, Szendrő Unit).

The main characteristics of the Jadar Block Terrane during the Late Paleozoic and Early Mesozoic are the marine development of the Carboniferous and Permian, a continual transition of sedimentation from the Permian to the Triassic, the specific features of Triassic rocks with dolomite of Anisian age, „porphyrite" and pyroclastics of Ladinian age, platform-reefal limestone of Middle and Upper Triassic age and its gradual transition to Liassic limestone. Younger Jurassic formations are not known.

The „Bükkium" Terrane shows the same lithological characteristics up to the end of the Triassic. Lower Jurassic and Lower Middle Jurassic formations are not yet proven. The Upper Triassic platform and basinal carbonates are followed by Bathonian-Callovian variegated radiolarite, then by distal flysch-type sediments of the Eohellenic tectogenesis (Csontos et al., 1991).

3.1. Jadar Block Terrane

In the Jadar Block Terrane three sedimentary successions can be recognized: Variscan, Late Variscan and Early Alpine.

The **Variscan succession** (Middle Devonian – Early Moscovian) in the Jadar Block Terrane, according to the different development of sediments during Variscan evolution, includes the Jadar Autochthon and Jadar Allochthon (Fig. 2).

Jadar Autochthon

During the time of Variscan evolution in the Jadar Trough the clastics of the Vlašić Fm. (the Krupanj-Valjevo, Vlašić and Slovac Units) were deposited, but simultaneously on the Ub intrabasinal rise pelagic limestone of the Družetić Fm. was accumulated (Fig. 2).

The ***Vlašić Formation***, over 1000 m thick, is composed of alternating arenite and siltstone, with rare microconglomerate. There is no paleontological evidence in its lower part; palynomorphs of Upper Devonian and Tournaisian age were found only in the uppermost level. The great thickness of the lower part of the formation is the reason why we also suppose a Middle Devonian age for the Vlašić Fm. The upper part of Vlašić Fm. has characteristics of the ***Variscan*** („Kulm") ***Flysch,*** i.e. rapid vertical change of sandstone and siltstone, various types of lamination, gradation, sedimentary structures, remains of flooded floras of Viséan and Serpukhovian age, and trace fossils (*Phycosiphon, Dyctiodora liebeana* etc.). Only in the thin, cherty limestone intercalations in the Vlašić Fm. near the village of Tekeriš, are found conodont faunas of the uppermost Tournaisian and lowermost Viséan: *Gnathodus typicus, Scaliognathus anchoralis – Doliognathus latus,* and *G. texanus* Zones.

The ***Družetić Formation***, over 100 m thick, is made up of pelagic carbonate rocks of Middle-Upper Devonian and Lower Carboniferous age. In the Devonian parts of the formation numerous conodont zones are defined (Filipović et al., 1975). In the thinner, upper part of the formation (of a thickness of about 15 m), the following Lower Carboniferous conodont zones were identified, viz.: *Siphonodella sulcata, Siph. duplicata, Siph. sandbergi, Sc. anchoralis – Dol. latus, Gnathodus texanus, G. bilineatus bilineatus, Lochreia nodosa, G. bilineatus bollandensis* and *Kladognathus – G. girtyi* group.

At the beginning of the Serpukhovian the Variscan flysch was partially overlain by the ***Stupnica Sandstones* (SS)** in the western part of the area, and in eastern part by conglomerate of the ***Županjac Formation* (ŽF)**. The regressive tendency of the Serpukhovian ended in the early Bashkirian.

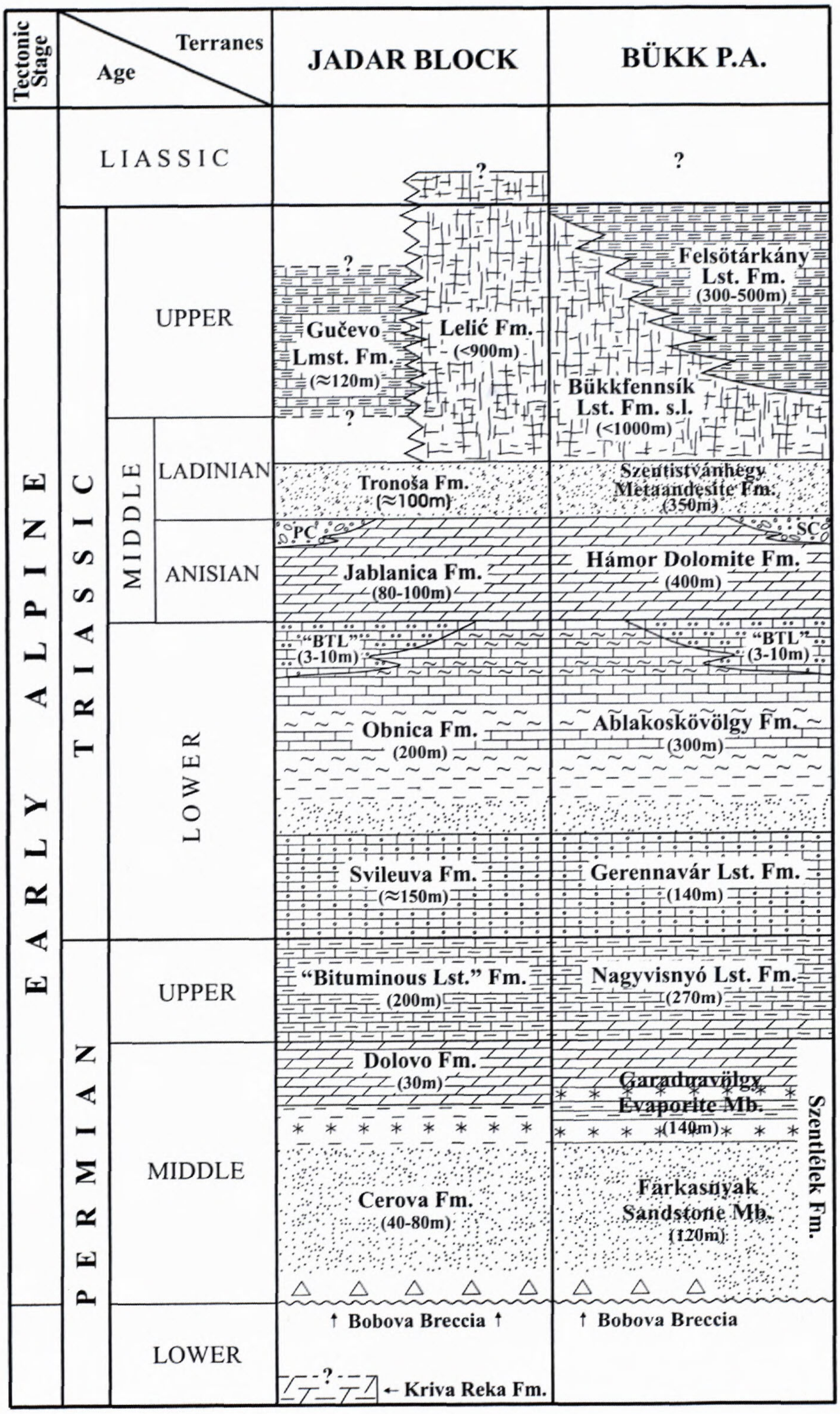

Fig. 3 Correlation of the Early Alpine succession of the Jadar Block and „Bükkium" terranes. Abbreviations. „BTL" – „Bioturbate Lst." Mb., PC – Podbukovi Conglomerate Mb., SC – Sebesvíz Conglomerate Mb.

Jadar Allochthon

The formations of the Likodra Nappe are quite different from the autochthonous Carboniferous ones (Fig. 2). At the same time they are equivalent to sediments of Carboniferous age of NW Bosnia (Sana-Una Terrane; Protić et al., 2000).

Within the Likodra Nappe the ***Variscan*** („Kulm") ***Flysch*** is overlain in variable thickness (up to 30 m) by the mostly bedded, bluish-gray limestone of the ***Đulim Formation,*** intercalated with marly shale and siltstone. Calcitic, mm-thick veinlets and stylolites within it are typical. The age of this formation is Serpuhkovian-Lower Bashkirian (conodont zones: *Gnathodus bilineatus bollandensis, Declinognathodus noduliferus inaequalis–D. lateralis* and *Idiognathoides corrugatus–Id. sulcatus*).

Above the Đulim Fm., and partly above the Variscan Flysch, lies the ***Rudine Formation***. Its thickness is 60–80 m. It consists of massive, subordinately stratified, gray to dark gray limestone, with frequent foraminifera (Lower Bashkirian, i. e. Severokeltenskian and Prikamskian in

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age), green algae (*Dvinella, Donezella*), brachiopods, corals, etc. At the locality of Rudine a bioherm with *Chaetetes* (probable coralline demosponge) is developed, with abundant solitary corals, pelecypods, crinoids, etc. (Jovanović, 1992).

The ***Stojkovići Formation*** overlies the Rudine Fm. It varies in thickness from 20–60 m and is built up of yellowish or brown siltstone, locally intercalated with shale and sandstone. It contains abundant, but poorly preserved brachiopods and crinoids, rarely bryozoans, bivalves and gastropods of Lower Bashkirian to Vereiskian age.

The youngest rock of the Likodra Allochthon is limestone of the ***Stolice Limestone Formation.*** It is more than 100 m thick, massive or thick-bedded, partially with abundant reef-building organisms. Rare foraminifera (*Archaediscus*) are of Vereiskian/Kashirskian age.

The **Late Variscan succession**, following the Carnic tectogenesis (Vai, 1975), is characterized by molasse development only in the Jadar Autochthon of the Jadar Block Terrane. In the western part of the area mountains were formed, and in other parts molasse depressions. Deposition of molasse began in the Podolskian and ended in the Asselian. At first sediments of the Ivovik Fm. were formed (Krupanj-Valjevo, Vlašić and Ub Units), and later carbonates of the Kriva Reka Fm. (Krupanj-Valjevo Unit).

Olistoliths and clasts of Devonian and Lower Carboniferous limestone in siltstone matrix are characteristic for the older part of the ***Ivovik Formation***. Here synorogenic products of sliding tectonics could be correlated with olistostromes of Prača, Vlasenica (SE Bosnia), Javorje Mt., SW Serbia (Filipović & Jovanović, 1994). The younger part of the formation shows facial changes. In the western part, in near-shore environments, siltstone with brachiopods (*Orthotetes, Neochonetes* and *Choristites* with fine branching costae, etc.) was deposited, intercalated with limestone with fusulinid associations of Podolskian age – *Fusulinella colloniae* Zone (Filipović, 1995). In the other parts of the Jadar Block Terrane (Vlašić and Ub Units) the upper part of this formation is made up of alternations of massive, bedded and thin-bedded silty limestone with woody plant remains.

The ***Kriva Reka Formation*** is developed only in the southern part of the Jadar Block Terrane (Valjevo-Krupanj Unit). It is built of gray, massive or stratified limestone with abundant fusulinids, and sporadically tiny foraminifera, algae, brachiopods, conodonts, pelecypods, bryozoans, crinoids, etc. The presence of stratigraphically important fusulinids and corresponding conodont associations are very characteristic. Four fusulinid associations (zones) were found: the first, of Myachkovskian age with *Fusulinella bocki* and *F. eopulchra*, the second of Kasimovian age with the zone fossils *Protricitites pseudomontiparus* and *Triticitites irregularis* (characteristic in the Russian platform for the uppermost part of the Kasimovian), and the third of Gzhelian age with *Rugosofusulina alpina* and *Quasifusulina longissima* (Filipović, 1995). According to Pantić (1969) in the fourth association of fusulinids consists of *Parafusulina pseudojaponica, P. freganica,* etc., corresponding to the Asselian. The presence of Lower Permian is confirmed by F. Kahler (unpublished data; personal notes given postmortem by courtesy of E. Flügel, 1993), who determined *Cuniculinella* cf. *fusiformis*, *Eosellina* ? sp. and *Pseudoschwagerina* sp., fusulinids characteristic of the Lower Permian.

The **Early Alpine succession** includes formations of the Middle and Upper Permian, Triassic and Lower Jurassic. The development of sedimentation was unique to the entire area of the Jadar Block Terrane and similar to that of the „Bükkium" Terrane (Fig. 3).

In the Permian the similarities are very obvious. They could also be correlated with many areas of the western Paleotethys. In the Jadar Block Terrane sediments of Permian age are represented by three formations: the Cerova Fm., the Dolovo Fm. and the „Bituminous Lst." Fm., the first and second being of Middle Permian, and the third of Upper Permian age.

Due to intensive tectonic events, tectogenetically different basement was formed. Therefore the transgressive sediments of Middle Permian age lie over different formations of the allochthon and autochthon: the Stolice Lst. Fm. in the western part, the Ivovik Fm. in the central part, the Kriva Reka Fm. in the southern part and the Županjac Fm. in the eastern part of the Jadar area.

The ***Cerova Formation***, Middle Permian in age, represented by white and yellow quartz sandstone with rare crinoid detritus, was deposited in a coastal plain environment. The sandstone is medium grained. The main component is angular, undulose quartz.

In the lowest part of this sandstone small lenses of ***Bobova Breccia*** are partially present, which could be correlated with the Tarvis Breccia of the Carnic Alps. Their thickness is of 0.5–3 m, rarely up to 10 m. The breccia consists of angular to medium-rounded fragments of limestone with fusulinids of the Kriva Reka Fm., which means that overthrusting of the Likodra Nappe took place before the Middle Permian.

The sandstone is overlain by purple, greenish and gray-yellowish shale and siltstone, rarely sandstone. Due to the very characteristic color and silky shine (large quantities of mica), these sediments are easily recognizable in the field. This white and yellow sandstone, together with purple and greenish siltstone, is very similar to the Szentélek Formation of the Bükk Mts. (Fülöp, 1994). The presence of gypsum is in connection with the evaporation of salt water in a lagoonal or sabkha environment, under arid conditions, which is characteristic for marine Middle Permian in many areas of the western Paleotethys (Southern Alps, Sana-Una Paleozoic in Bosnia, Nikšićka Župa in Montenegro, Bükk Mts. in Hungary, etc.).

The overlying ***Dolovo Formation*** is made up of thick to thin-bedded, yellow and gray-colored dolomitic limestone, intercalated with marly shale and siltstone. The average thickness is about 30 m. The scarce fossils encountered, *Gymnocodium, Agathammina, Earlandia, Geinitzina,* etc., from dolomitic limestone (dolomicrite, biomicrite, microsparite, etc.) and *Aviculopecten* sp. from marly intercalations, are not stratigraphic indicators. Therefore, according to the superpositional relationships, the formation is assigned to the Middle Permian in general. Very characteristic for the formation is rauhwacke, which, due to weathering has a net-like, cavernous, i.e. a „boxwork" texture (Leine, 1968). This rauhwacke is monomict and contains a higher content of strontium (965 ppm).

The ***„Bituminous Limestone" Formation*** of Upper Permian age lies over the Dolovo Fm. and passes continually into the overlying Lower Triassic limestone. It consists of limestone, which is gray to black-colored, very fossiliferous (presence of organic matter), bedded (thin-bedded to thick-bedded), rarely massive. In the lower and middle part of the formation intercalations of red and gray sandy shale occur (siliciclastic input).

Macrofauna and microfauna, distributed in a micritic to microsparitic matrix, are very abundant. Calcareous algae, small foraminifera and brachiopods predominate. Simić (1938) was the first to subdivide the Upper Permian, and later Pešić et al. (1988) and Pantić-Prodanović (1994, 1997) separated new horizons. Using all data from the „Bituminous Lst." Fm. the following eight horizons have been established: Horizon 1 with *Edmondia permiana*, Horizon 2 with *Mizzia* (*M. velebitana, M. yabei, M. cornuta*), Horizon 3 with brachiopods: *Tyloplectus, Spinomarginifera, Tschernyschewia, Leptodus,* etc., Bioherm 4 with *Richthofenia*, sponges and bryozoans, Horizon 5 with *Notothyris*, Horizon 6 with *Waagenophyllum indicum*, Horizon 7 with *Conodofusiella, Reichelina* and *Vermiporella*, and Horizon 8 with bellerophons, *Hemigordius* and *Gymnocodium.*

The „Bituminous Limestone" of Upper Permian age passes without interruption in sedimentation into ooidal Lower Triassic limestone (***Svileuva Formation***). As in the entire Tethys area, at the Permian-Triassic boundary living being almost disappeared. No indications of the „boundary clay" have been found as yet, but detailed investigations have not yet been carried out. The Lower Triassic begins with ooidal limestone. Apart from certain horizons of superficial ooids (Pantić-Prodanović, 1987, annual report) in bedded to thickly bedded limestone only rare ostracods and small foraminifera were found, such as *Earlandia tintiniformis* (horizon with ostracods and *E. tintiniformis*; Pantić-Prodanović, 1994).

The sequence continues with the carbonate-terrigenous ***Obnica Formation*** (in the surroundings of the town of Valjevo its thickness is about 200 m). Thin-bedded, yellow and brownish schisty sericitic sandstone, shale, marlstone, sandy and silty, dolomitic limestone, which are in mutual cm-dm alternation, were deposited on a shallow ramp/shelf. In these sediments an abundant mollusk fauna occurs: *Naticella, Turbo, Myophoria, Tirolites,* etc. According to the conodonts, the *Parachirognathodus–Furnishius* and *Neospathodus triangularis–Ns. homeri* Zones of Smithian and Lower Spathian (Budurov & Pantić, 1974, Sudar, 1986) age are determined.

The formation ends with thin-bedded dark gray limestone, rich in bioturbations, parallel laminated and nodular, which becomes massive in the uppermost part (***„Bioturbate Limestone" Mb***.). The limestone is sporadically dolomitic, siltose or clayey, with ooids in some beds.

These rocks pass gradually into gray-colored, brecciated or bedded, very weathered dolomite and dolomitic limestone of Anisian age (***Jablanica Formation***). They are mostly bedded and massive, but in the higher part they are brecciated and crushed. In the locality Podbukovi, as in the Bükk Mts., *Sebesvíz*-type conglomerate is visible, which indicates local uplift (***Podbukovi Conglomerate Mb***.). During the Lower Ladinian in many places in the Jadar Block Terrane, volcanic activity in connection with rift volcanism is manifested by effusions of metaandesite („porphyrite") and its pyroclastics (***Tronoša Formation***). These rocks alternate with thin-bedded, often silicified limestone with nodules and chert intercalations. The „porphyrites" are intensively altered (sericitization, carbonatization, rarely silicification).

In the Upper Triassic different developments occurred. Platform limestone of the ***Lelić Formation*** was gradually developed from the Ladinian, was karstified and transited into reefal, mostly gray, massive and brecciated limestone with megalodonts, corals, hydrozoans, bryozoans, brachiopods, pelecypods and microfauna (*Aulotortus, Endothyra, Trocholina,* etc.). Laterally the ***Gučevo Limestone Formation*** was deposited in basinal environments of the deep borderland or slope. This limestone is gray, thin to thick-bedded, with chert nodules, abundant in radiolarians, „filaments" and conodonts of Carnian and Norian age (*Paragondolella foliata, Pg. polygnathiformis, Pg. nodosa, Metapolygnathus abneptis,* and *Epigondolella postera* zones; Sudar, 1986).

The Upper Triassic rocks of the Lelić Fm. pass gradually into Liassic limestone. They are red and gray-colored, thick-bedded, of a thickness up to 10 m. In this limestone foraminifera of Lower Jurassic age were found: *Involutina liassica* and *Vidalina martana.*

3.2. „Bükkium" Terrane

3.2.1. Bükk Parautochthon Unit

Variscan succession. Late Paleozoic formations occur at surface only in the northern part of the mountains, in the so-called „North Bükk Anticline" of the Bükk Parautochthon Unit (hereafter Bükk PA) (Balogh, 1964; Fülöp, 1994). Only the end-member of the Variscan cycle is known, the flysch-like, distal turbiditic ***Szilvásvárad Formation***, consisting of an alternation of dark gray to black shale, siltstone and sandstone. It occurs in the core of the anticline with an estimated thickness exceeding 1000 m. Underlying formations are not known; it is overlain on the two limbs of the anticline by the marine molasse-type Mályinka Fm. In the absence of fossils, and based on the latter, its age is pre-Podolskian, probably higher Bashkirian and early part of Moscovian. An unconformity between the two formations could not yet be proven. In terms of its sedimentological character the Szilvásvárad Fm. can be compared with the distal turbiditic middle and upper members of the Szendrő Phyllite Fm., which are of post-Early Bashkirian age.

Fig. 4 Bobova Breccia at the base of the whitish sandstone of the Farkasnyak Sandstone Mb. of Szentlélek Fm., Middle Permian. Borehole Mályinka-13, (37,4-38,7 m), Csikorgó, NE Bükk Mts.

The **Late Variscan succession** is represented only by the marine molasse-type ***Mályinka Formation*** of 400 m thickness. It consists of fossiliferous shale, sandstone (mainly with brachiopods and crinoids), with three bluish-gray limestone horizons rich in calcareous algae, fusulinids and other fossils, each being 10 to 50 m thick. The age of the lower two is Late Moscovian (Myachkovskian; Berenás Member in Fülöp, 1994), as indicated by fusulinids: *Fusulinella* ex gr. *bocki, Fusulina* ex gr. *elegans, Pseudoendothyra pseudosphaeroidea,* etc. However, from the lowermost part of the formation *Hemifusulina moelleri* was reported from some limestone intercalations (Rozovskaya, 1963), pointing to a Podolskian age. The age of the third, uppermost limestone horizon (Csikorgó Member in Fülöp, 1994) is Gzhelian according to its fusulinds (*Quasifusulina longissima, Qu.* cf. *tenuissima, Qu. elongata; „Pseudofusulina" pseudojaponica,* etc.). Nevertheless, a partly Asselian age cannot be quite excluded; however, sure evidence is missing so far (Kozur, 1984).

In the Early Permian the region of the Bükk PA unit was uplifted and underwent erosion, which for the most part removed the higher (Kasimovian-Gzhelian) portions of the formation. Equivalents of the Rattendorf and Trogkofel Groups of the Carnic Alps are missing here, as well as in the Jadar Block Terrane.

The **Early Alpine succession** includes formations of Middle Permian to Upper Jurassic age, but there is no evidence for Lower and lower Middle Jurassic ones in this unit so far. The ***Szentlélek Formation*** disconformably overlies different levels (Moscovian to Gzhelian) of the Mályinka Fm. It begins with white, whitish gray to greenish quartz sandstone, then follows with red or reddish-brown sandstone and siltstone, representing a coastal plain environment (***Farkasnyak Sandstone Mb***., of 100–130 m thickness). In its basal part a limestone breccia horizon occurs, equivalent to the *Bobova Breccia* of the Jadar Block Terrane (Fig. 4). The 120–150 m-thick ***Garadnavölgy Evaporite Mb***. represents sabkha conditions and is built up by an alternation of purple or green siltstone-mudstone, subordinately sandstone, white gypsum and, in lesser amount, anhydrite, as well as gray dolomite. The formation, being in an underlying position to the Nagyvisnyó Lst. Fm., is regarded as of „Middle Permian" age in general, without age indicator fossils.

The ***Nagyvisnyó Limestone Formation*** (Bellerophon Fm. in the classical Alpine literature) of 270 m thickness develops with continuous transition from the Szentlélek Fm. The boundary is defined where the purple-green siltstone, resp. gypsum-anhydrite intercalations disappear from among the dolomite beds. The lower 30 m of the formation is dominated by dolomite, whereas the remaining part is formed by usually 20–30 cm thick, very fossiliferous (calcareous algae: *Mizzia velebitana, Vermiporella serbica, Gymnocodium bellerophontis,* etc., brachiopods: *Leptodus nobilis, Tschernyschewia, Tyloplecta,* etc.) black or dark gray limestone beds with 2–10 cm-thick, black, marly-silty intercalations. Ostracods (Kozur, 1985) and small foraminifera (Bérczi-Makk, 1992; Bérczi-Makk et al., 1995) are also very common. Small coral buildups with *Waagenophyllum indicum* are characteristic for the middle part of the formation, whereas the calcareous sponge *Peronidella baloghi* occurs in its upper part in the horizon with *Leptodus nobilis.* A faunal correlation with the Jadar Block Terrane and the other areas of the Dinarides was presented earlier by Pešić et al., 1988.

In the Bükk Mts. the ***„boundary clay"*** event at the Permian/Triassic boundary can be recognized in a few sections. The lowermost Triassic is represented by the light-colored, ooidal ***Gerennavár Limestone Formation*** of 120 m (or even more) thickness. At the formation boundary the very rich Permian fossil association disappears and only a few Permian small foraminifera and the calcareous algae *Gymnocodium* are still present just above it, followed by a thin horizon with the foraminifer *Earlandia tintinniformis*, which occurs somewhat higher (Bérczi-Makk, 1987).

The ***Ablakoskővölgy Formation*** of 300 m thickness, with four members, represents mixed carbonate-terrigenous sedimentation on a ramp environment. Its lower part consists of greenish-purplish sandstone and siltstone, with sandy-marly limestone intercalations, and higher up gray, bedded or platy limestone alternating with marl-shale horizons, containing *Naticella, Turbo, Tirolites*, etc. The uppermost member, not present in all sections, is formed of bioturbated limestone. The light colored, locally dark gray, peritidal ***Hámor Dolomite Formation*** of 300 m thickness seems to represent the entire Anisian. Locally in its top part emersional conglomerate, the ***Sebesvíz Conglomerate Mb.***, occurs (for details see Velledits, 1999).

The Lower Ladinian ***Szentistvánhegy Metaandesite („Porphyrite") Formation*** of 200–300 m thickness is composed of greenish or purplish lava and pyroclastics. Acidic (dacite, rhyolite) and slightly more basic (basalto-andesite) varieties also occur.

After this volcanic event, due to extensional movements, platform and basinal environments were differentiated. Platform carbonates are grouped herein together in Fig. 3 as the ***Bükkfennsík Limestone Formation***, which is the most widespread metamorphosed variety. Its age can be considered, based on the relationships with the conodont-dated basinal formations, as Late Ladinian to Norian/Rhaetian (Velledits, 2000). Rich Carnian reef biotas were published from non-metamorphosed varieties from several places (Velledits & Péró, 1987; Flügel et al., 1991/92) and a relatively poor Norian to Rhaetian one from one locality (Riedel et al., 1988). Gray, cherty limestone of basinal and partly slope facies is grouped together as the ***Felsőtárkány Limestone Formation***. Conodonts indicate its age from the Ladinian/Carnian boundary (*Metapolygnathus mungoensis, M. diebeli*) up to the Rhaetian (*Neospathodus posthernsteini*) (Kovács, in Velledits, 2000). In the underlier of the cherty limestone or at its base a second volcanic horizon occurs with intra-plate type basalts (Szoldán, 1990). Some partly siliciclastic formations (Vesszős Fm., Várhegy Fm.) of problematic age and of local occurrence, not recognized in the Jadar Block Terrane up to now, are not discussed herein.

3.2.2. Uppony Unit – Lázbérc Subunit

Variscan succession. The Upper Devonian pelagic, tuffitic Abod Lst. Fm. is followed by the very condensed (max. 10–20 m), similarly pelagic ***Dedevár Limestone Formation*** of flaser type, lacking tuffitic influence, but with a characteristic carbonatic lydite horizon in the Lower Viséan, indicated by *Gnathodus delicatus*. This formation is known only in a few outcrops. The ***Lázbérc Formation*** of much larger surface occurrence is built up by bluish-gray to dark bluish-gray basinal limestone, intercalated with dark shale, with conodonts from the Late Viséan *Paragnathodus nodosus* to the Early Bashkirian *Idiognathoides sinuatus* Zones. A thick (100–200 m) zone of shale and marly shale may be even younger than Lower Bashkirian. The entire formation, the thickness of which can be estimated at 300–400 m, lacks features of resedimentation, e.g. it is not a flysch-type sediment.

Late Variscan succession. The molasse stage can be represented by a zone of sandy limestone, sandstone, and pebbly sandstone, occurring in a narrow zone within the Lázbérc Fm. at the southern margin of the subunit. As the pebbly sandstone already contains small (up to 1–2 cm diameter), rounded white quartz and black lydite, it can be considered as a postorogenic sediment. It is tentatively referred to the ***Mályinka Fm.*** of the Bükk Parautochthon Unit by Kovács (1992), whereas Fülöp (1994) distinguishes it as the Derennek Mb. of the Lázbérc Fm.

3.2.3. Szendrő Unit –Rakaca Subunit

Variscan succession. Carboniferous pre-flysch sediments are fully developed beginning with the Lower Viséan in the southern subzone of the northern marble zone of the Szendrő Hills (Kovács, 1992, and in Ebner et al., 1991, 1998), whereas the Variscan flysch forms the middle, phyllite zone of the hills (Péró, in Fülöp, 1994).

The bluish-gray to white-banded ***Rakaca Marble Formation*** of about 200 m thickness in the locality of Kopaszhegy begins with an alternation of marble beds and brownish gray crinoidal limestone, the latter containing conodonts of the Early Viséan *Gnathodus texanus* Zone. This part represents a platform slope setting. In other sections the marble of platform facies is underlain, interfingering and overlain by the ***Verebeshegy Limestone Mb.*** of basinal facies. Its oldest part underlying the platform facies contains conodonts of the Late Viséan *Paragnathodus nodosus* Zone, whereas the youngest one on top of the platform those of the Early Bashkirian *Idiognathoides sinuatus* Zone. The zones in between are also represented in the basinal facies, laterally interfingering with the platform facies.

The ***Szendrő Phyllite Formation*** of about 600 m thickness represents the Variscan flysch stage and lies for the most part over the Verebeshegy Lst. Mb.-Rakaca Marble Fm. In its lower, olistostromal Meszes Member it already contains the clasts of the Early Bashkirian *Idiognathoides sinuatus* Zone. However, in the clast material of the olistostromes all ages down to the Middle Devonian are present. As opposed to this proximal type lower member, the middle and upper members of the formation are of distal flysch type.

4. Conclusions

The comparison of Late Variscan and Early Alpine succession of the presently distantly separated Jadar Block and „Bükkium" terranes revealed many more similarities than they show with the terranes presently surrounding them. An additional comparison with the classical Carboniferous-Permian succession of the Carnic Alps (Fig. 5) revealed their close paleogeographic affinities within the western Paleotethyan domain. In analyzing the successions the following main conclusions can be drawn:

1. During the Variscan synorogenic and postorogenic evolution, all the three compared units belonged to the southern European Variscan foreland, e. g. to the Noric-Bosnian Zone according to Flügel, 1990, and Neubauer & von Raumer, 1993, or Carnic-Dinaridic Block, according to Vai, 1995, 1998. All of them were parts the flysch basin (although with different age constraints) formed in

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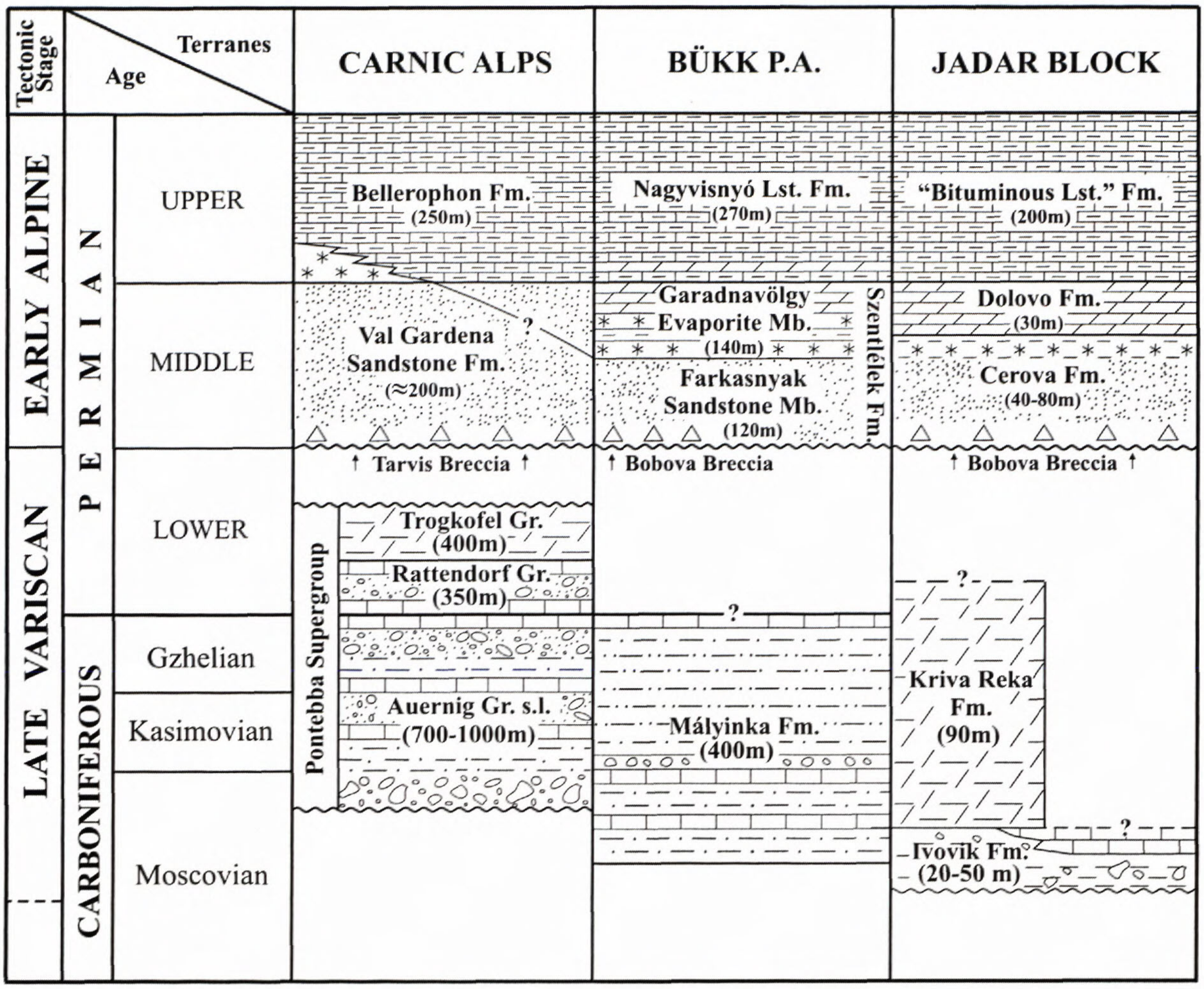

Fig. 5 Correlation of the Late Variscan – Early Alpine (upper Middle Carboniferous – Upper Permian) successions of the Carnic Alps (after Vai & Venturini, 1995; Venturini & Spalletta, 1998), „Bükkium" and Jadar Block terranes.

front of the advancing Variscan nappe system (Neubauer & von Raumer, 1993, Vozárová, 1998). This area was characterized by mostly marine Late Variscan and earliest Alpine (Late Carboniferous-Permian to the passage to the Triassic) development.

2. Whereas in the Jadar Allochthon the Variscan flysch deposition mostly preceded basinal and shallow marine carbonate sedimentation, or was partly contemporaneous with it (interfingering with the Đulim Fm.), in the Szendrő Unit it mostly succeeded the basinal and shallow marine carbonate deposition, or was partly contemporaneous with that (interfingering with the Vereshegy Lst. Mb.). It is important to note that basinal carbonate deposition in all of the Jadar Allochthon, Szendrő and Uppony Units persisted until the Early Bashkirian *Idiognathoides sinuatus* Zone, represented by similar lithologies (bluish gray to dark bluish gray limestone of the Đulim Fm., Lázbérc Fm. and Vereshegy Lst. Mb., correlatable also with the Dult Fm. of the Graz Paleozoic; Ebner et al., 1991, 1998), whereas in the Carnic Alps it came to end at the Tournaisian/Viséan boundary.

Although the shallow marine Rudine Fm. postdates the Variscan flysch sedimentation in the Jadar Allochthon, and the Rakaca Marble Fm. predates most of that in the Szendrő Unit, it may be a non-metamorphosed facial equivalent of the latter. The presence of a Carboniferous fossil-proven biohermal facies in one of the compared units is therefore important, as the Rakaca Marble has no in situ equivalents in the Carboniferous of the Carnic Alps and Graz Paleozoic, but occurs only in the form of clasts (Ebner et al., 1991, 1998).

3. As opposed to the S-vergent thrusting and folding during the Carnic phase in the Carnic Alps (Vai, 1975, 1998; Castellarin & Vai, 1981), no evidence for such a tectonic and corresponding metamorphic event could be proven in the compared Jadar Block and „Bükkium" terranes, e.g. between the Ivovik and Kriva Reka resp. Szilvásvárad and Mályinka Formations. Evidence for Variscan metamorphism is lacking in the „Bükkium" (Árkai, 1983).

4. The Auernig Group of the Carnic Alps represents the most nearshore depositional setting, with abundant quartz-conglomerate levels, whereas the Kriva Reka Fm. of the Jadar Block Terrane is in the most offshore setting with its 90 m-thick fusulinid limestone lacking siliciclastics. The up to 400 m shale-sandstone-limestone succession of the Mályinka Fm. of the Bükk PA Unit

represents a transitional setting between the two, also containing some quartz conglomerate.

5. A Variscan unconformity between the Kriva Reka Fm. and Middle Permian clastics (Cerova Fm.) can be clearly proven in the Jadar Block Terrane. In the Bükk PA Unit at least a disconformity can be proven, with the Szentlélek Fm. resting on different levels of the Mályinka Fm., indicating post-Carboniferous uplift and erosion. Equivalents of the 800 m-thick succession of the Rattendorf and Trogkofel Groups of the Carnic Alps are missing in both units.

6. The Middle Permian Neotethyan transgression, both in Jadar Block and „Bükkium" terranes began with whitish sandstone of a coastal plain environment. Limestone breccia (Bobova Breccia) at the basal part of these successions can be correlated with the Tarvis Breccia of the Carnic Alps. Following this transgression the two terranes showed a practically identical development until the end of the Triassic/beginning of the Jurassic. The main characteristics of this evolution are:

– Marine Late Permian deposition ("Bellerophon Fm." in general) with transition into the marine Early Triassic one (with the „boundary clay event" at the Permian/Triassic boundary, proven so far only in the Bükk PA Unit);

– Anisian carbonate ramp environment with peritidal dolomite, followed by partial uplifts of some blocks, indicated by Sebesvíz-type conglomerate;

– Early Ladinian andesite volcanism, succeeded by differentiation of carbonate platform and basin environments;

– From the earliest Jurassic onward (after the deposition of some cherty limestone), there is no sedimentological record for correlation.

7. The original place of the two terranes could have been at the Dinaridic/Adriatic margin of Neotethys, probably near to the Sana-Una Terrane, which is today in NW Bosnia (Protić et al., 2000). From this position the Jadar Block was displaced in the Late Cretaceous (Karamata et al., 1994), and the „Bükkium" Terrane in the course of the (Late Cretaceous-) Tertiary transpressional movements between the ALCAPA and Tisia Terranes (Csontos & Nagymarosy, 1998; Haas et al., 2000).

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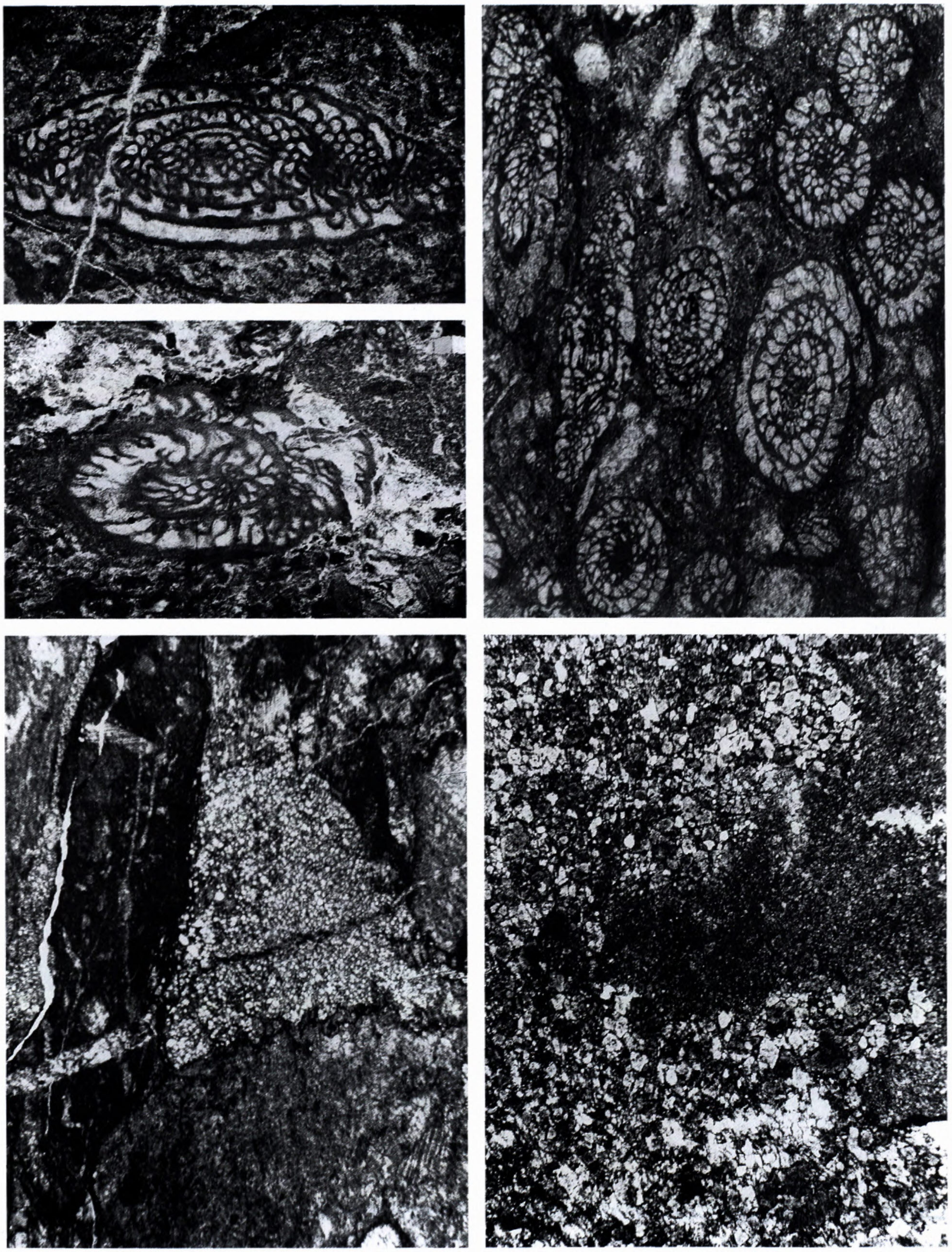

Plate I

Figs. 1–2 Biomicrosparite with fusulinids. Kriva Reka Fm., Upper Moscovian – Asselian. Kriva Reka Sklop near to Krupanj, NW Serbia. sample 116, N II, x 12.

Fig. 3 Fusulinid biomicrosparite, Mályinka Fm., Csikorgó Mb. Gzhelian (to Asselian?). Type section at Csikorgó, NE Bükk Mts., NE Hungary. N II, x25.

Fig. 4 Bobova Breccia, lowermost part of Cerova Fm., Middle Permian. Bobova, NW Serbia, sample 7381, N II, x30.

Fig. 5 Bobova Breccia with strongly recrystallized matrix. Middle Permian. Borehole Mályinka-13, (35,7 m), Csikorgó, NE Bükk Mts. N II, x12,5.

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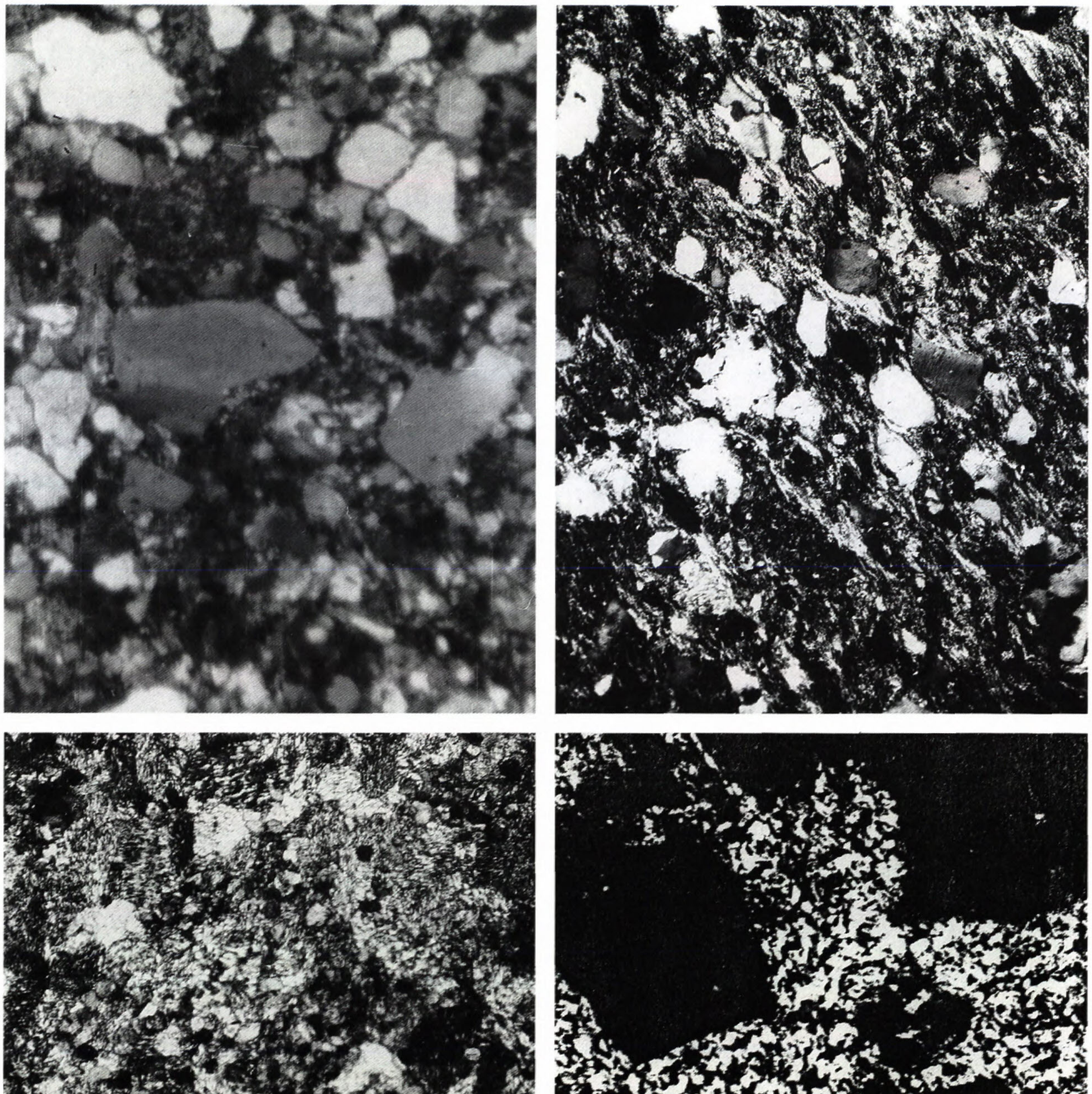

Plate II

Fig. 1 Whitish sandstone, Cerova Fm., Middle Permian. Obradovići, NW Serbia, sample 7225, N X, x30.

*Fig. 2 Whitish sandstone, Szentlélek Fm., Farkasnyak Sandstone Mb., Middle Permian. Borehole Mál
yinka-13, (13,5 m), Csikorgó, NE Bükk Mts., N X, x30.*

Fig. 3 Gypsum, Cerova Fm., Middle Permian. Sample from borehole on road Mojković -Bela Crkva, (20-80 m), NW Serbia, N II, x30.

Fig. 4 Gypsum (light) and dolomite (dark), Szentlélek Fm., Garadnavölgy Evaporite Mb., Middle Permian. Borehole Nagyvisnyó-21, (160,0 m), N X, x25

Plate III

Fig. 1 Rakaca Marble Fm., Kopaszhegy Mb.: epimetamorphosed platform-slope facies of Viséan age. Thick, light beds represent redeposited platform material, whereas brownish, thin bedded horizons are crinoidal limestone of slope facies. Rakacaszend, Kopaszhegy quarry, Szendrő Hills, NE Hungary.

Fig. 2 Bioclastic limestone, platform facies, with Chaetetes sp., bellerophons, brachiopods, etc. Rudine Fm, Bashkirian, Middle Carboniferous. Rudine near Krupanj, NW Serbia.

Fig. 3 Bobova Breccia at the basal part of the Cerova Fm. Middle Permian. Cerovaćka glavica near to Krupanj, NW Serbia.

Fig. 4 Whitish sandstone, Cerova Fm., Middle Permian. Road Stolice – Cerova, NW Serbia.

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Plate IV

Fig. 1 Whitish sandstone, Farkasnyak Sandstone Mb., Szentlélek Fm., Middle Permian. Borehole Mályinka-13, (≈12-21 m), Csikorgó, NE Bükk Mts.

Fig. 2 Alternation of green and purple argillite with gypsum. Garadnavölgy Evaporite Mb. of Szentlélek Fm., Middle Permian. Borehole Nagyvisnyó-18, (205,9–209,8 m).

Fig. 3 Gypsum alternating with black argillite and gray dolomite. Garadnavölgy Evaporite Mb. of Szentlélek Fm., Middle Permian. Borehole Nagyvisnyó-13, (≈ 220 m).

Fig. 4 Nagyvisnyó Lst. Fm., Upper Permian. Type section in Mihalovits quarry, Nagyvisnyó, northern foreland of Bükk Mts., NE Hungary.

Plate V

Fig. 1 Rauhwacke in the Dolovo Fm., Middle Permian. Mojković, NW Serbia.

Fig. 2 Organodetritic limestone, „Bituminous Lst." Fm., Upper Permian. Obnica river valley, NW Serbia. Horizon 7 with Codonofusiella, Reichelina and Vermiporella; Horizon 8 with bellerophons, Hemigordius, Permocalculus, Gymnocodium; Horizon 3 with brachiopods: Leptodus, Tschernyschewia, Tyloplectus, Spinomarginifera, etc.

Fig. 3 Podbukovi Conglomerate Mb. in the uppermost part of the Jablanica Fm., Upper Anisian, Middle Triassic. Road Valjevo-Kosjerić, NW Serbia.

Fig. 4 Sebesvíz Conglomerate Mb. in the uppermost part of the Hámor Dolomite Fm. and below Szentistvánhegy Metaandesite Fm. (overturned position), Upper Anisian, Middle Triassic. Forestry road, Sebesvíz Valley, NE Bükk Mts., NE Hungary.

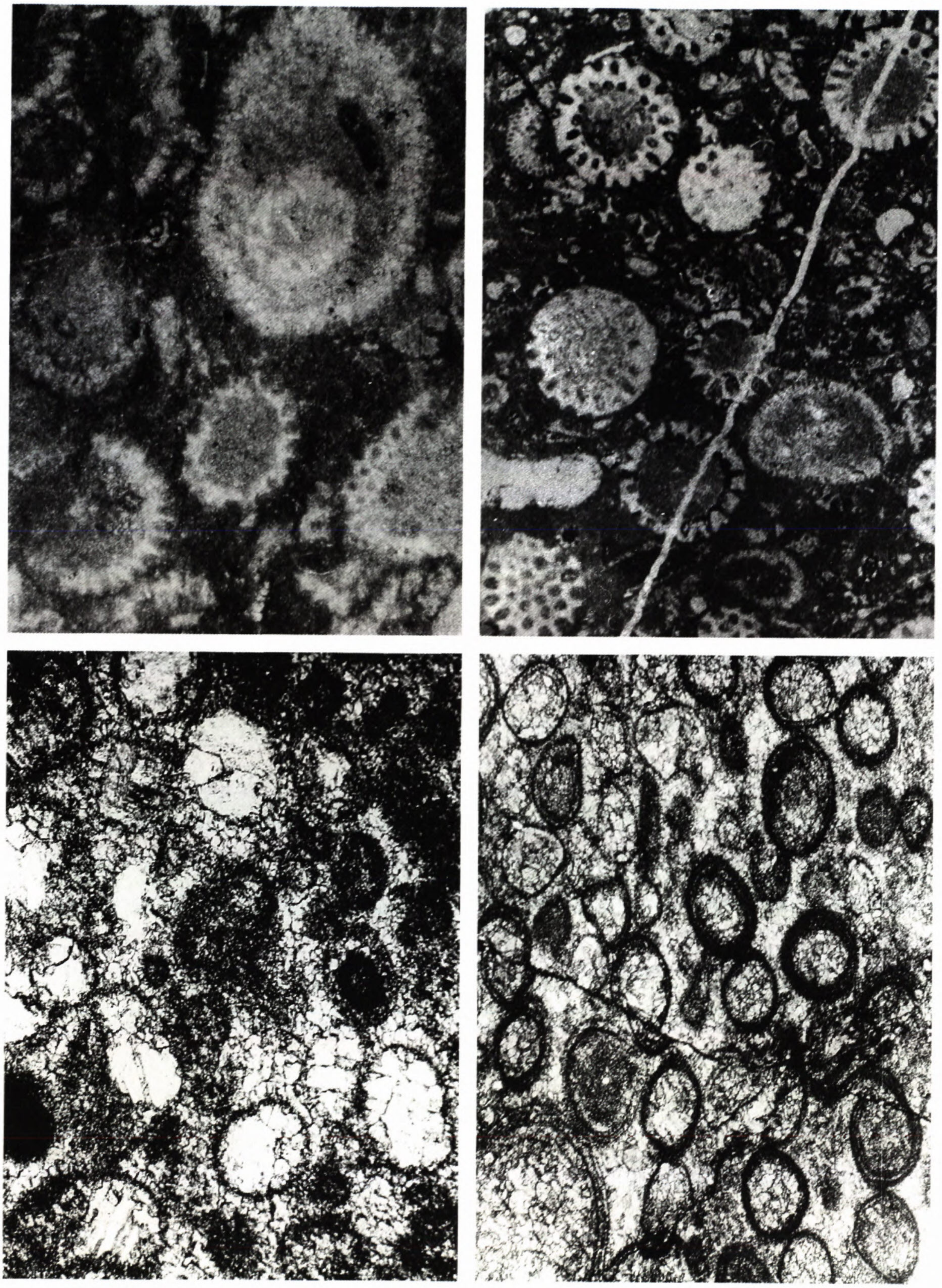

Plate VI

Fig. 1 Dolomitic biomicrosparite with dasycladacean algae (mainly Mizzia sp.). „Bituminous Lst." Fm., Upper Permian. Zeljići, NW Serbia, sample 962, N II, x17,5.

Fig. 2 Biomicrosparite with dasycladacean algae (mainly Mizzia sp.). Nagyvisnyó Lst. Fm., Upper Permian. Máloldal, W of Mihalovits quarry, Nagyvisnyó, NE Hungary, N II, x25.

Fig. 3 Oosparite. Svileuva Fm., lowermost Triassic. Svileuva-Lipovac, NW Serbia, sample from borehole Sv-3, (80 m), N II, x30.

Fig. 4 Oosparite. Gerennavár Lst. Fm., lowermost Triassic. Type section at Gerennavár, NE Hungary, sample G-2/1, N II, x25.

Anomalous paleomagnetic declinations of Karpatian and Badenian rocks, Southern Slovakia

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Abstract. The declination of the remanent magnetic polarization (RMP) of the Sečianky Member, Modrý Kameň Formation, Karpatian in age, and the Hrušov Member, Vinica Formation, Badenian in age, display clockwise (CW) rotation, which is an anomaly in the relation to the recent knowledge concerning the RMP of the contemporaneous rocks of Southern Slovakia and Northern Hungary. The volcano-tectonic activity of the Šahy-Lysec Zone would be the cause of the CW rotation. The biostratigraphic age of the studied rocks and the character of the RMP make it possible to correlate the Sečianky Member (Karpatian) with the chron C5Cr (17.7 - 17.2 Ma) and the Hrušov Member (Middle Badenian) with the older normal event of the chron C5Bn (15.15 - 15.03 Ma).

Key words: paleomagnetism, CW rotation, Karpatian, Badenian

Introduction

During the 90ties of the 20th century the paleomagnetic properties of the South-Slovakian and North-Hungarian Cenozoic rocks have been studied (Orlický et al., 1995; Márton et al., 1995, 1996; Márton and Márton, 1996). One of the most important results of that study was the finding that the declinations of the remanent magnetic polarisation (RMP) of the Lower Miocene rocks in the mentioned area display 80° counterclockwise (CCW) rotation. In the Northern Hungary two pulses of the rotation have been distinguished. The first rotation of about 50° CCW took place during the Ottnangian, while the latter and younger rotation of about 30° CCW took place during the Early Badenian (Márton and Fodor, 1995; Márton and Márton, 1996). Paleomagnetic measurements of Šiator Andesite and thermally altered sandstone of the Fiľakovo Formation, Eggenburgian in age, support such discrimination. The Šiator Andesite intrusion is evidently contemporaneous with neighbouring Karanč Andesite intrusion radiometrically dated to 15.1 Ma (Balog, 1984), the numeric age indicats the Middle Badenian. Declination of the Šiator Andesite is identical with that of recent Earth magnetic field, thus it was not rotated. The thermal effect of the andesite intrusion on the host rocks – the sandstone of Fiľakovo Formation caused the loss of original RMP and the acquisition of a new one, identical with RMP of the andesite intrusion (Orlický et al., 1995).

To specify the time and extent of the Miocene rotations of the Southern Slovakia, a paleomagnetic investigation of rocks coming from two sites has been performed (Fig. 1): the deposits of the Sečianky Member, Modrý Kameň Formation (Karpatian stage) and the tuffaceous claystones of the Hrušov Member, Vinica Formation (Middle Badenian).

Methodology

Paleomagnetic measurements were performed in the Paleomagnetic Laboratory of the Geophysical Institute SAS in Modra – Piesky. Thermal demagnetization was applied using a MAVACS demagnetization equipment. Magnetic polarization was measured with JR5 spinner magnetometer. Demagnetization was carried out in increment of 50°C starting at laboratory temperature up to 620°C. Magnetic volume susceptibility was measured after each step of demagnetization with Kappa bridge KLY3. All instruments are products of the AGICO comp. Brno, Czech Republic.

Demagnetization graphs were constructed for the analysis of results for each sample, namely normalized curves of thermal dependence of the remanent magnetic polarization and magnetic bulk susceptibility (KAPPA), as well as the Zijderveld diagrams of XY and XZ components of the RMP. The RMP directions were also plotted in double stereographic projections, one for RMP direction in situ, and the second one in position after bedding correction. This correction is necessary because original singenetic magnetic polarization was fixed in rock during sedimentation and clivage process, it means in a horizontal position.

Illustrations of the demagnetization graphs are in Figs. 2, 3 and 4. Fig 2 presents the demagnetization course of samples with work labels 1A and 3 from the locality Dolné Príbelce. It can be seen on the demagnetization curves of remanent magnetic polarization (marked as J) and magnetic volume susceptibility (marked as K) that magnetic cleaning is smooth up to 300°C. Mineralogical change which is indicated by rapid rising of magnetic volume susceptibility (curve K) occurs after this temperature. Also the value of RMP is rising after the same temperature (curve J). The rock, where the carrier

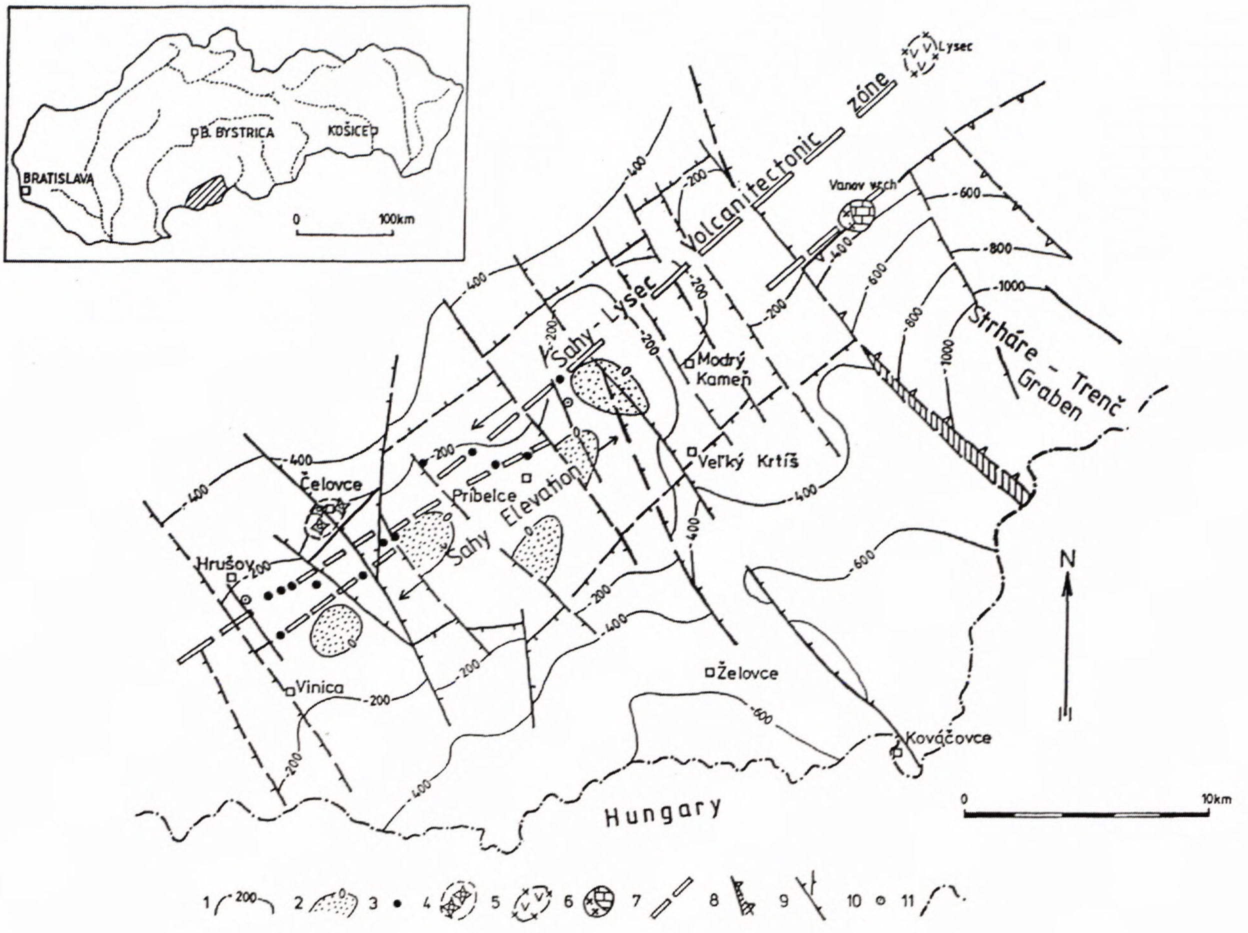

Fig. 1. Šahy-Lysec Volcanotectonic Zone with numerous andesite extrusions, Badenian in age, directed by perpendicular faults of NNW direction. The sampling sites are pointed.

of magnetism is a small amount of titanomagnetite (Curie temperature up to 300°C) with the admixture of some sulfide, has usually such behaviour (McElhinny and McFadden 2000). Stereographic projections of the paleodirections indicate, that magnetic polarization changes during the demagnetization from a normal direction in the natural state to the reversed one after 200°C. This reversed polarization is probably original in the rock. This is indicated also by the Zijderveld diagrams. Component analysis showed that there are three components of NRM in the rock (Fig. 3). The reversed paleodirections which remained in rock after demagnetization by the temperature of 250°C, were taken as a characteristic direction for the statistical processing of the Dolné Príbelce samples.

Similar analysis of demagnetization graphs was performed on samples from locality Hrušov. The characteristic course of demagnetization is presented in graphs of Fig. 4. Here the rock has only one carrier of magnetism, which is magnetite. Demagnetization is very smooth, there are no mineralogical changes (normal) and remaining after magnetic cleaning by heating to 300°C was taken for statistical processing.

The paleodirections for both localities were calculated using Fisher's statistics (McElhiny and McFadden 2000). The final paleodirections are presented in Figs. 5, 6 and Tab. 1.

Paleomagnetic sampling and results

The Dolné Príbelce site

The samples for measurements were taken in a gorge NE of the village Dolné Príbelce. The tin bedded calcareous friable siltstone – claystone of the Sečianky Member, Modrý Kameň Formation, was sampled. The Karpatian age of the Sečianky Member has been established mainly on the basis of the foraminiferal assemblage containing beside others the taxa typical for the Karpatian stage Uvigerina tarchanensis, G. bulloides, G. concina (Kantorová in Vass et a. 1979; in Vass and Elečko eds. 1992). The assemblage of the calcareous nanoplankton consists the taxa of NN4 zone including the index taxa Helicosphaera ampliaperta (Lehotayová in Vass et al., 1979).

The characteristic remanence of the sampled rock is reversed (partially overprinted?). The mean value of the declination (7 measurements) is of 184° and inclination of -29°. The dispersion of data is relatively large α_{95} = 17° (Fig. 5, Tab. 1). The declination indicates no rotation with respect to stable Europe.

The Hrušov site

The samples were taken from a deep gorge at the southern margin of Hrušov village. The site is a strato-

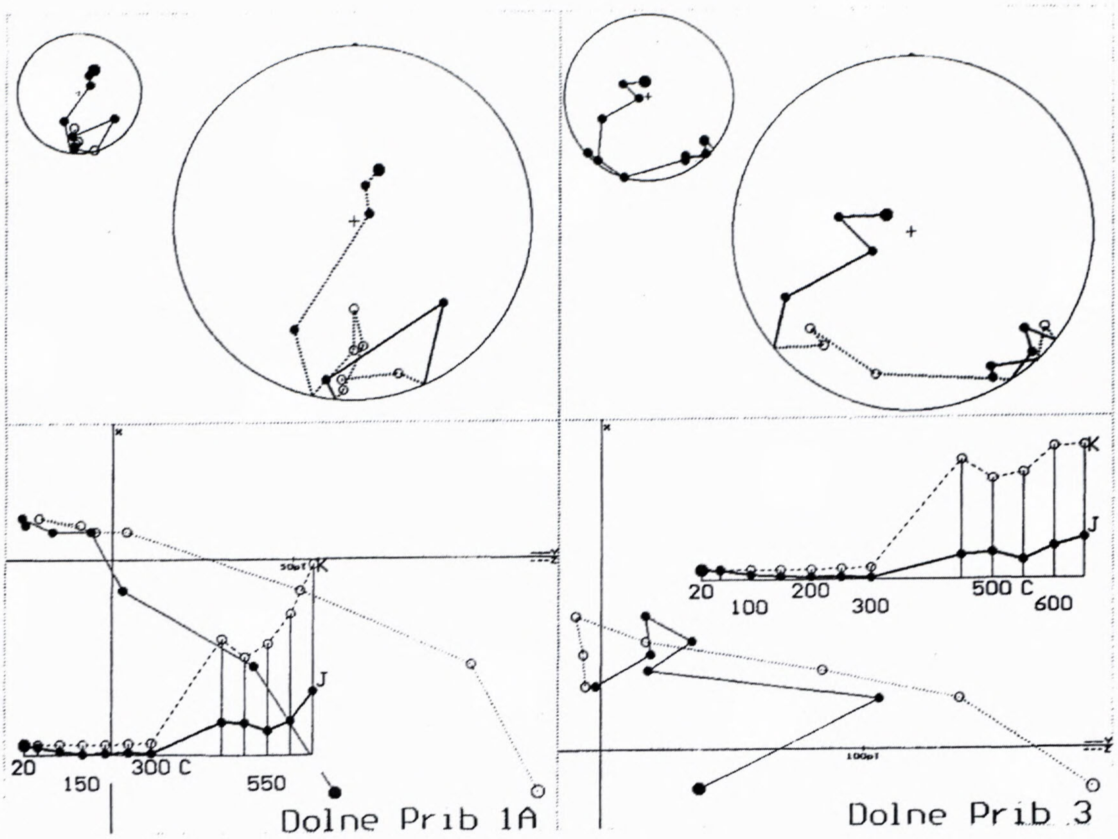

Fig. 2. Demagnetizing graphs of thermal demagnetization of sedimentary rocks from the locality Dolné Príbelce (Karpatian in age) samples 1A and 3. Upper part of picture – streoprojections of directions of remanent magnetic polarization (smaller circle – directions in situ, larger one – directions in position after bedding correction) after each demagnetizing step, the biggest point means start of demagnetization. The full dots – normal direction, open dots – reversed direction of magnetic polarization. Lower part of picture – thermal dependence of remanent magnetic polarization (curve J) and magnetic volume susceptibility (curve K); Zijderveld diagrams of the XY and XZ components of remanent magnetic polarization (Krs 1969).

type locality for the Hrušov Member (Vass et al. in press, Vass, 2002) occuring at the top the Vinica Formation. The sampled rocks are tuffitic andesite claystone and siltstone containing small non sculptured shells of *Amussium denudatum* (Vass in Vass et al., 1979), the foramaniferal assemblage including the planktonic taxa *Globigerinoides bulloides*, and calcareous nanoplankton including the taxa *Sphenolithus heteromorphus*. Its presence together with the absence of the taxa *Helicosphearea ampliaperta indicates* the nanoplanctonic zone NN5 (Lehotayová in Vass et al. 1979; Holcová in Vass et al. in press). The numeric age of the zone NN5 of 15.4 - 14.2 Ma (Berggren et al., 1995) corresponding in the numeric time-table of the Paratetys Neogene to the Middle-Late Badenian (Vass et al., 1987). Based on the biostratigraphically proven Early to Early Middle Badenian age we suppose that the Hrušov Member topping the Vinica Formation is Middle Badenian in age (Vass et al. in press). Because the RMP of the Member is normal it is possible to correlate the Hrušov Member with the oldest normal event of the chron C5Bn having numeric age of 15.15 - 15.03 Ma (Berggren et al., 1995).

The mean value of the declination (5 measurements) is 23° and mean inclination is 66°. The measured directions are consistent, the dispersion is small $\alpha_{95} = 3°$. The declination indicates a small CW rotation with respect to the stable Europe (Fig. 6, Tab. 1)

Discussion

As we have mentioned already in the introduction, in Northern Hungary and in Southern Slovakia the total Miocene rotation is about 80° CCW. Two pulses of rotation were discriminated. The younger one, of about 30°CCW, took place in Early Badenian. We had assumed to define a similar rotation by paleomagnetic measurements of the Sečianky Member, Karpatian in age in the Ipeľská kotlina .We also had assumed, that the declination of the Hrušov Member (Middle Badenian) would be a Stable European one as it is the case at the Middle Badenian Šiator Andesite (Orlický et al. 1995). The paleomagnetic measurements did not confirm our assumptions. So we shall try to explain the discrepancy between assumptions and results of measurements.

The investigated sites are situated either in the close neighbourhood of the Šahy – Lysec Volcanotectonic Zone (Dolné Príbelce) or directly inside the zone (Hrušov, see Fig. 1). The intensive volcanic activity of the zone took place during Badenian. The extrusive volcanic centers of Vinica, Opava and Lysec formations belong to the volcanotectonic zone. The volcanism was accompanied by tectonic activity manifested mostly in faults of NNW direction. The majority of those faults originated during the Badenian and their genetic connection with

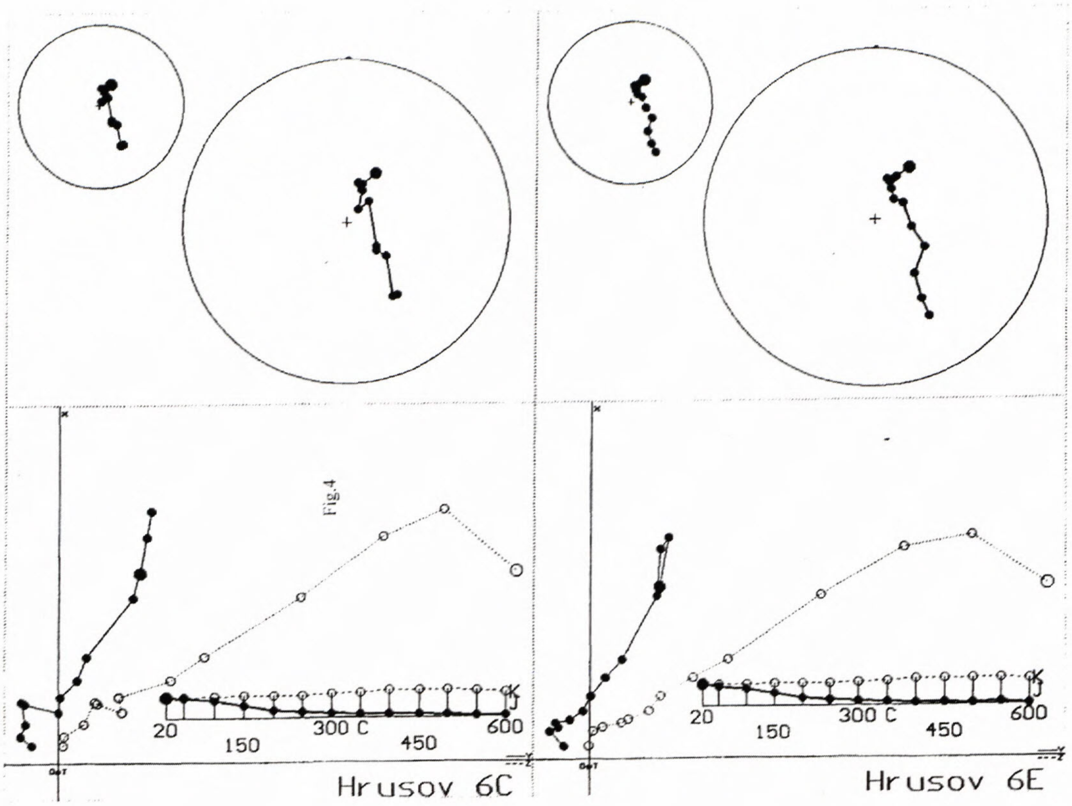

Fig. 3. Demagnetizing graphs of thermal demagnetization of tuffitic claystones from the locality Hrušov (Middle Badenian in age) samples 6C and 6E (for explanation see the Fig. 2).

volcanism is manifested in the fact, that volcanic centers are situated at the intersection of the NNW and NE trending faults. Several faults of NNW direction are strike – slip faults. One of them runs along the gorge where the stratotype profile of Hrušov Member is found – the paleomagnetically studied site (Fig.7). Another one runs along the eastern margin of Dolné Príbelce village, close to the sampled site (Fig. 8). Both faults are dextral strike-slips and may generate CW block rotation (Terres and Sylvester, 1981; Sengör in Allen and Allen, 1992 a.o.). So the dextral strike-slip on the NNW faults generated by volcanic activity could have been the cause of the local CW rotations in the area of the Šahy – Lysec Volcanotectonic Zone and in their close neighbourhood.

The angle of the CW rotation is determined by the vector of RMP declination of the Hrušov Member having the value of 23° (Fig. 8). Probably it is the rotation vector of a block rotated inside of the Šahy – Lysec Volcanotectonic Zone.

The local rotation connected with Badenian volcanic activity was preceded the regional CCW rotation of the Early Badenian. Present vector of the RMP declination 184° (= 4° CW) of the Sečianky Member deposits have got a backward rotation aprox. 23° (which is the rotation of Hrušov Member), so the regional CCW rotation during Early Badenian has had the vector aprox. 19° (Fig. 7, variant A). Is it not encluded, that the Early Badenian CCW rotation in the area studied was about 30° CCW (the same as the rotation measured by Márton and Márton, 1996 on the Karpathian rocks at the southern foothills of the Bükk Mts., Hungary) than the younger Badenian Badenian local CW rotation of the block at Dolné Príbelce was larger: about 34° CW (Fig. 7, variant B).

Another problem, that the paleomagnetic study of both sites helps to solve is the correlation of the studied rocks with the magnetostratigraphic Neogene scale and the precision of their numeric age. Coming from the Karpatian stage numeric age 17.5 - 16.5 Ma (Vass et al. 1987), then during the Karpatian the reversed polarisation was dominant. The chron of such polarisation C5Cr having numeric age 17.2 - 16.7 Ma (Berggren et al., 1995). During this chron the Sečianky Member came to existence because their RMP is reverse. The upper part of Karpatian stage corresponds to lower part of the chron C5Cn of normal magnetic polarity. The upper part of the Karpatian in Ipeľská kotlina Depression, but also in the whole Southern Slovakia and Northern Hungary area is missing being removed by a post – Karpatian and pre – Badenian erosion (Vass et al., 1979; Vass and Šucha, 1994).

The age of the Vinica Formation topped by the Hrušov Member is Early – Middle Badenian (Vass et al. in press). The Hrušov Member likely originated in late Middle Badenian. The late Middle Badenian and early Late Badenian correspond to the chron of normal magnetic polarity C5Bn having the numeric age 15.5 - 14.8 Ma (Berggren et al., 1995). The older normal event of the chron (15.15 - 15.03 Ma) is likely the time-period of the Hrušov Member coming to existence (Vass l. c.), (Fig. 9).

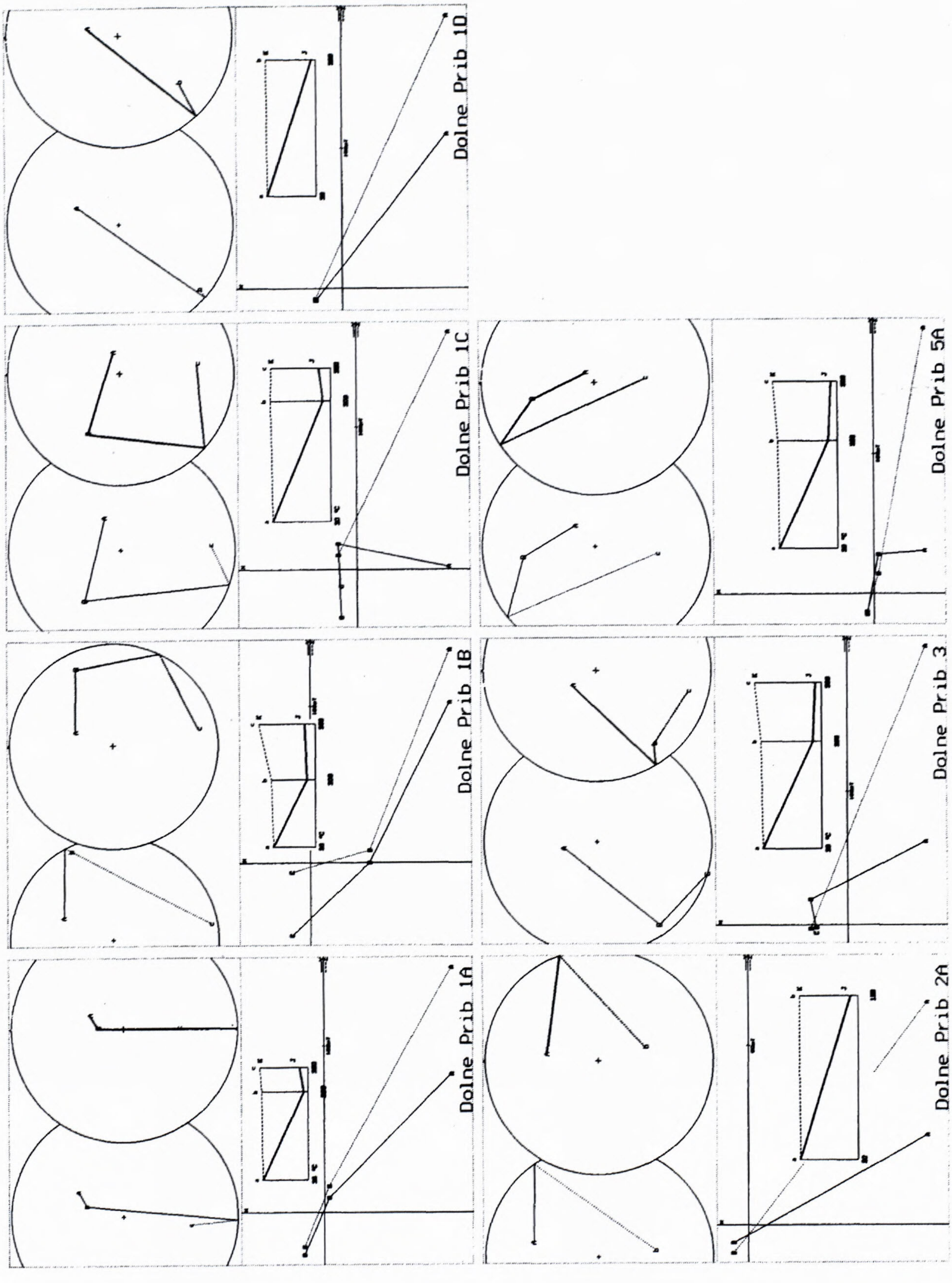

Fig. 4. Demagnetizing graphs of thermal demagnetization of 7 samples from sedimentary rocks from the locality Dolné Príbelce (Karpatian) – three components of remanence (for explanation see the Fig. 2).

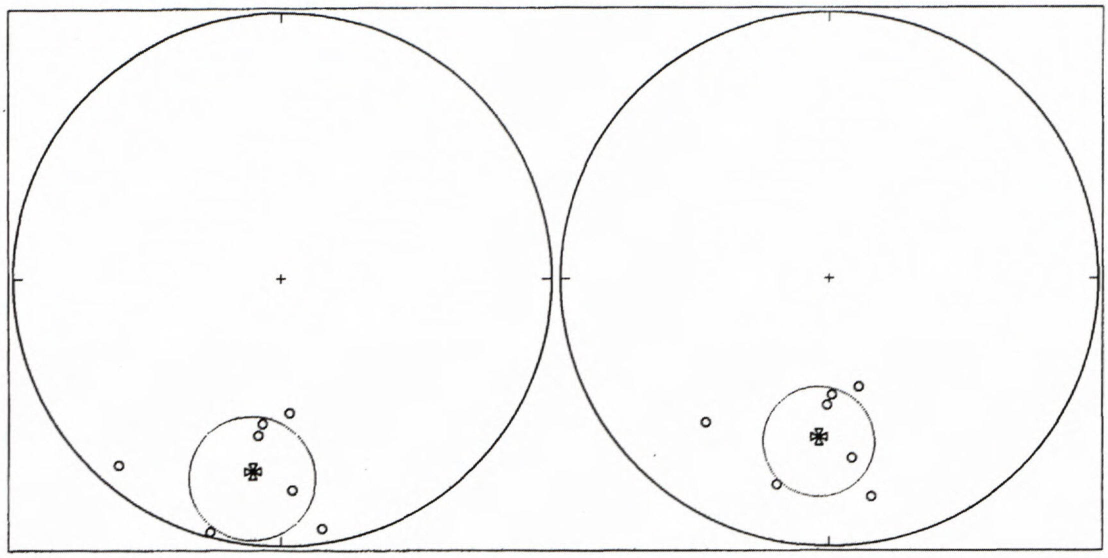

Fig. 5. Stereographic projection of the paleodirections and main direction of 7 samples from sedimentary rocks of the locality Dolné Príbelce. Left circle - paleodirections in situ, right circle – paleodirection in position after bedding correction. Main direction is marked by Malta cross (full for the normal, open for reversed paleodirection); circle around main direction marks cone of probability of 95%.

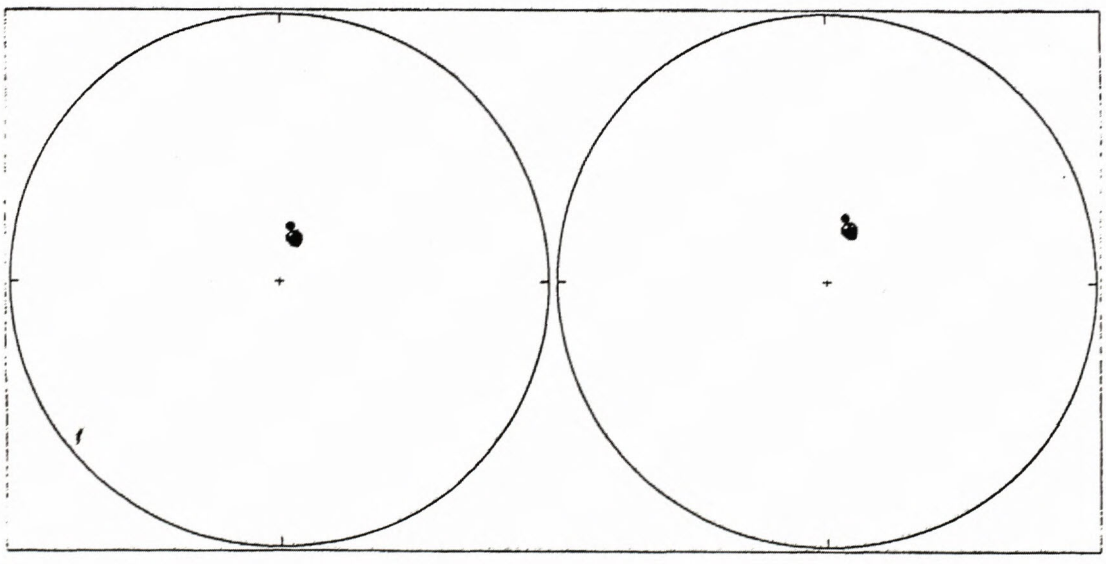

Fig. 6. Stereographic projections and main direction from 5 samples of tuttitic claystones from locality Hrušov (for explanation see the Fig. 5).

Table 1 Paleomagnetic results

Locality	Lithology	Age		BBC				ABC					
			N	D°	I°	k	α_{95}	D°	I°	k	α_{95}	J [nT]	K .10^{-6} uSI
Dolné Príbelce	calc. friable silstone-claystone	Karpatian	7	194	-18	9	21	184	-29	9	21	0.008	107
Hrušov	tuffitic andesite, claystone - silt-stone	Middle Badenian	5	17	71	660	3	23	66	66	3	17.8	6390

N – number of rock samples; D°, I° – paleomagnetic mean declination, inclination; BBC before bedding correction; ABC – after bedding correction; k – statistical precission parameter; α_{95} – half angel of confidence at the 95 % level (Fisher, 1953); J [nT] – mean value of remannent magnetic polarization; K.10^{-6} u.SI – mean value of magnetic volume susceptibility.

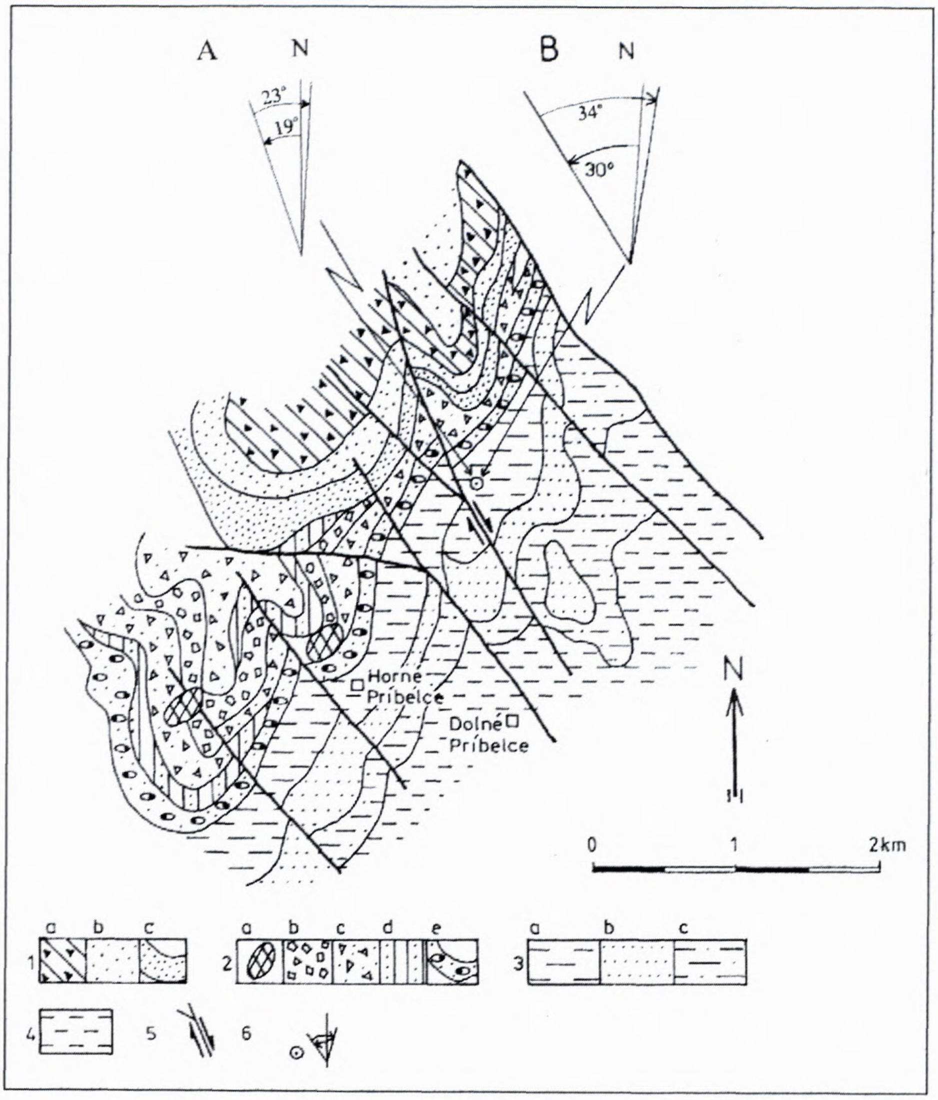

Fig. 7. Schematic geologic map of the village Dolné Príbelce surroundings with the sampling site of the Sečianky Member (Karpatian). See the dextral strike-slip and interpretation of CCW versus CW rotations

Conclusions

Paleomagnetic results of the Sečianky Member of the Modrý Kameň Formation, Karpatian in age, and the Hrušov Member of Vinica Formation, Middle Badenian in age, are not consistent with results of coeval rocks of Northern Hungary, as well as Southern Slovakia. While the declinations in Karpatian rocks in Northern Hungary display CCW rotation of 30° and Middle Badenian rocks in the same area have declination close to the recent geomagnetic field, the declinations of investigated rocks in the area of Šahy-Lysec Volcanotectonic Zone display no rotation or CW rotation with respect to stable Europe.

A probable cause of the CW rotation (with respect to the general, CCW rotated declinations) is the tectonic activity of the Šahy-Lysec Zone, where numerous faults of NNW direction had been generated. Some of them were strike-slips. One of such faults runs through village Hrušov and another runs close to eastern border of village Dolné Príbelce, thus not far from the sampled sites. The mentioned faults are dextral strike-slips and the dextral strike-slip has probably generated local CW rotation of some blocks. In the case of the Sečianky Member the first rotation must have been CCW taking place during Early Badenian. The second rotation was in opposite sense – clockwise.

Since the studied rocks are relative well dated biostratigraphically, we tried to correlate them with the Neogene magnetostratigraphic scale. The Sečianky Member, Karpatian in age, having reversed RHP, may be correlated with the chron C5Cr with numeric age 17.2 - 16.7 Ma.

Hrušov Member, Middle Badenian in age, having normal RMP, may be correlated with the older normal event of the chron C5Bn with numeric age of 15.15 - 15.03 Ma.

Acknowlegements

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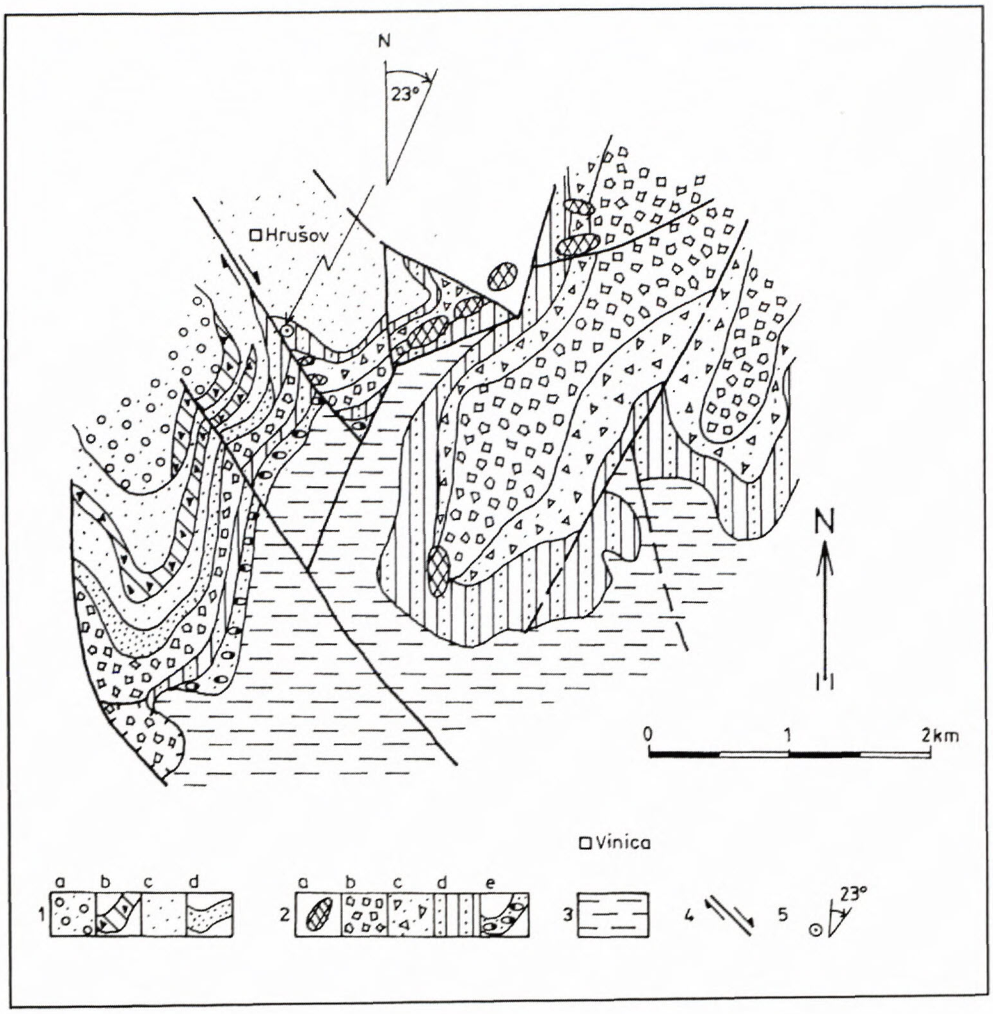

Fig. 8. Schematic geologic map of village Hrušov surrounding with the sampling site of the Hrušov Member (Middle Badenian). See the dextral strike-slip and imagination of CW rotation.

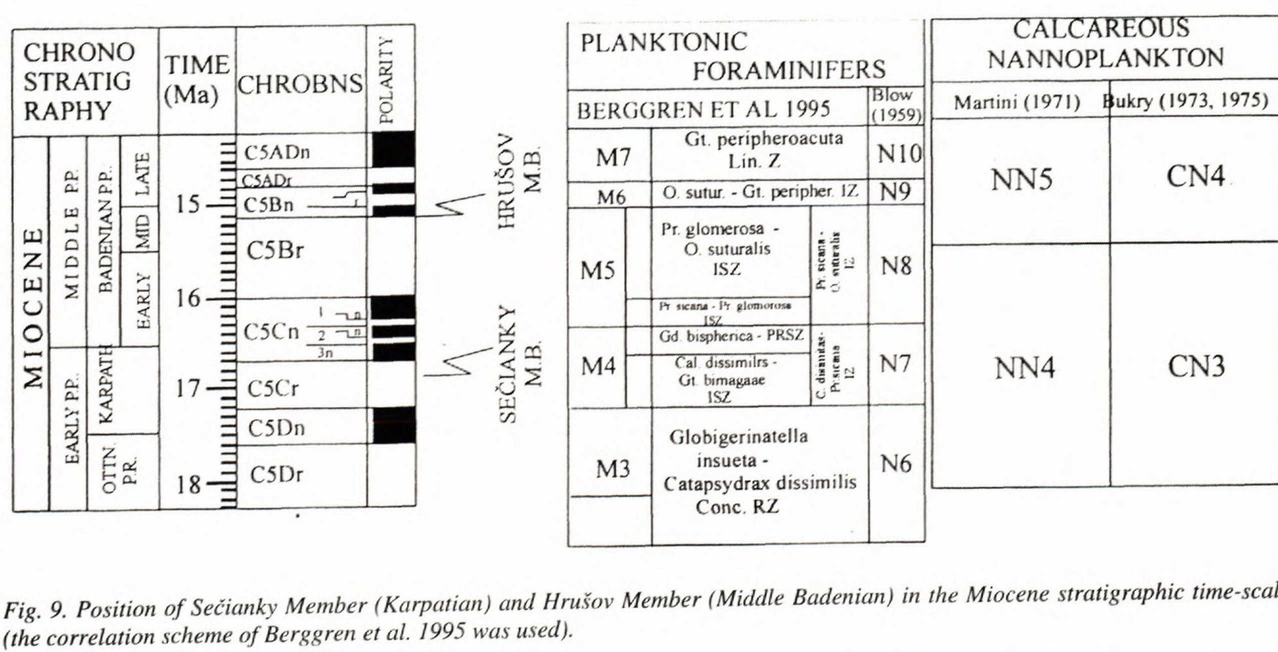

Fig. 9. Position of Sečianky Member (Karpatian) and Hrušov Member (Middle Badenian) in the Miocene stratigraphic time-scales (the correlation scheme of Berggren et al. 1995 was used).

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Manganese mineralization near Šarišské Jastrabie village, Pieniny Klippen Belt, Western Carpathians, Slovakia

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Abstract. Manganese mineralization is located in shale and radiolarite chert of Kysuca Formation of the Klippen Belt. Late Bathonian – Early Callovian (U.A.Z.7) shale is underlying in tectonic contact Middle Callovian- Early Kimmeridgian (U.A.Z. 8 – U.A.Z. 10) radiolarite chert. Layers with rhodochrosite (5 to 20 cm thick) are bound to shale. Manganese oxides and hydroxides form secondary crusts on layers with rhodochrosite and fill fissures in radiolarite chert. They are represented by pyrolusite, cryptomelane, romanèchite, todorokite and they are accompanied by goethite. Primary manganese carbonates were formed probably during diagenesis. Secondary manganese oxides and hydroxides were formed in shale and radiolarite chert during weathering processes.

Key words: Manganese minerals, radiolarians, Kysuca formation, Klippen Belt, Western Carpathians

Introduction

Several deposits of a manganese are known ore in the Jurassic radiolarite chert Late Jurassic up to Cretaceous chert in California contains lenses with manganese ore closely associated with basalt (Crerar et al., 1982). Jurassic chert with manganese ore overlying basalt occurs in Apennine peninsula (Bonatti et al., 1976). These deposits were formed in sea bottom by hydrothermal fluids related to volcanic activity.

Manganese ore occurs in the Middle to Upper Jurassic sequences of the Pieniny Klippen Belt of the Kysuca Succession in Eastern Slovakia near the eastern margin of Šarišské Jastrabie village (Fig. 1). The early prospecting for manganese started in the 19^{th} century. Later attempts to mine the ore followed during the First and the Second World War. New adit of NW direction was opened in 1941.

Manganese ore occurs according to Ilavský (1955) in bed 10 up to 40 cm thick bound to lower - most part of radiolarite chert overlying greyish green shale in the valley of Vesné brook. Lenticular nodules with dark manganese oxides were observed also near the contact (up to 30 cm) in the underlying shale. Farther from the contact the manganese oxides have not been observed.

Average chemical composition of ore according to Ilavský (1955) is: Mn 18,9 %, Fe 15,23 %, S 0,16 %, SiO_2 30,6 % and Al_2O_3 14,11 %. Primary ore is formed by manganese carbonate (rhodochrosite-dialogite) with crusts of psilomelane or wad and limonite stains. Chemical composition, microscopic observations and geological position led Ilavský (1955) to assumption of secondary origin of manganese mineralization by leaching from radiolarite chert and accumulation of manganese minerals on the base of radiolarite chert overlying the impermeable shale.

Geological setting

The Pieniny Klippen Belt is an extremely complicated tectonic zone of the Carpathians. It is a narrow belt spreading over 400 km in Slovakia from Záhorská nížina plain in the West to the border with Ukraine in the East. It is mostly several kilometres wide with maximum 15 km near the town Púchov. The Klippen Belt represents tectonic boundary between Outer Carpathians on the north and the Inner Carpathians on the south. It is formed by the Jurassic, Cretaceous and Paleogene sequences.

An investigated area belongs to the eastern part of the Pieniny Klippen Belt. Formations with manganese mineralization are bound to the klippes of the Kysuca Succession – equivalent of the Branisko Succession in Poland. These are surrounded by Paleocene to Eocene formations represented by red and green shale and sandstone (Nemčok 1990, Nemčok et al. 1990)

Birkenmajer (1977) introduced a term Sokolica Radiolarite Formation for Middle and Late Jurassic sequences with coatings of manganese mineralization in Pieniny, Branisko and Magura Successions. Birkenmajer (1977) supposed Upper Bajocian (?) to Callovian and Lower Oxfordian (?) for this formation. An original name of this formation was „manganese radiolarites" (Birkenmajer 1954, 1958). Rocks are represented by thin-bedded greyish green, greyish blue and black radiolarites alternating with similarly coloured siliceous shale. The lowermost part of this formation is represented by the shale and the limestone also bearing manganese mineralization. The Sokolica Radiolarite Formation was defined for the formation of radiolarite and shale with manganese mineralization without respect to a primary origin of the manganese mineralization.

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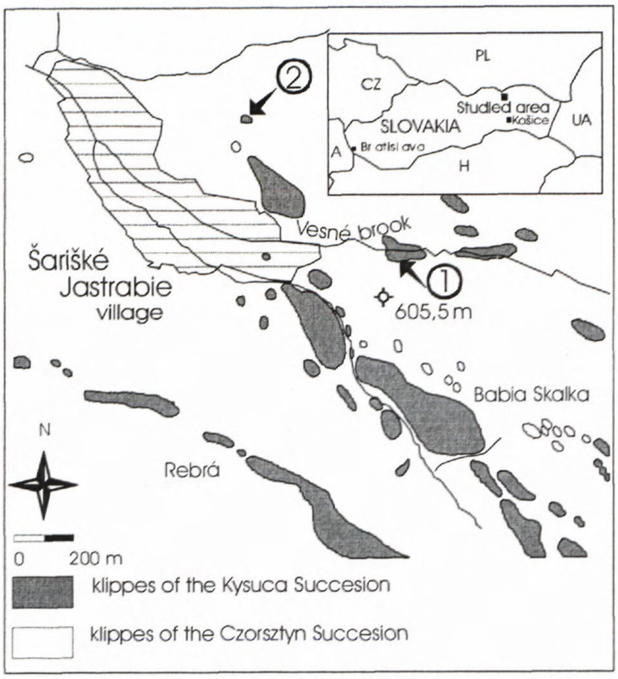

Fig. 1. Occurrences of manganese mineralization near Šarišské Jastrabie village. Localities: 1 – Vesné Brook, 2 – Quarry.

Overlying Czajakowa Radiolarite Formation of the Lower Oxfordian to Lower Kimmeridgian age (Birkenmajer 1977) is represented by green, grey or green-red stripped radiolarite chert in the lower part and by red radiolarite chert in the upper part. The manganese mineralization is absent in these rocks.

Position of outcrops

1. Vesné Brook

Klippe of a lenticular shape is situated in stream bed, 200 meters to the east from Šarišské Jastrabie village and 150 meters NNW from the elevation point 605,5 meters (Fig. 1). The klippe of Kysuca Succesion consists of Sokolica Radiolarite Formation and Czajakowa Radiolarite Formation (Birkenmajer 1977). The thickness of both formations in the outcrop is about 6 m. Strike of radiolarite chert beds is 340 – 350/10 – 20° to the west. Lower part of Sokolica Radiolarite Formation represented by shale is separated from radiolarite chert in upper part of formation by fault striking 60/25° to SSE (Fig. 2). Layers and boudinage of rhodochrosite can be seen in outcrop (Fig. 3). Dump of mined adit for Mn – ore from the first half of the 20th century is located nearby the outcrop, some 70 m NNW from the northern margin of the village.

2. Quarry

A small quarry in the same formation as in the first locality is situated 120 m NE from cemetery. The outcrop consists of sediments the Czajakowa Radiolarite Formation (Birkenmajer, 1977) 3 to 4 m in thickness striking 60/15° to SSE. Radiolarite chert of Sokolica Radiolarite Formation (Birkenmajer, 1977) with manganese coatings can be seen in small thickness only (less than 1 m). The same shale as in previous outcrop is separated from radiolarite chert by fault striking 20/55° to W (Fig. 4).

Lithologic characteristic

1. Vesné Brook:

Czajakowa Radiolarite Formation is composed of radiolarite chert layers (10 to 25 cm thick) with alternation of red and green strips. The upper part of radiolarite chert is dominantly of red colour. Spherical as well as three rayed tests of radiolarians (0,1 to 0,2 mm across) are frequent. Originally opal tests were transformed to quartz often with radial structure or they were dissolved and gradually filled up by calcite. Radiolarians represent up to 25 vol. % of rock in thin sections. Less distinct parallel lamination is hardly observed. Clastic quartz and mica are rare. Radiolarite chert of Sokolica Radiolarite Formation is mostly grey-green with coatings of manganese minerals. Radiolarite chert is near the tectonic contact with underlying shale brecciated and cemented by calcite.

Underlying shale of the Sokolica Radiolarite Formation is characterized by prevailing illite. There are also clastic anhedral quartz grains, micas, oval clasts of shale, altered clastic feldspars and fragments of plant tissue. Rare accessory zircon and rutile were also observed. Seldom tests of radiolarians, spores of pteridophyte ferns or fungi are also present. Cysts of dinoflagellates genus *Hystrichosphaeridium* in sample 17 were identified. Clastic minerals form less distinct lamination of shale (Fig. 5).

Shale alternates with layers or boudinage of pale brown carbonates (up to 20 cm thick) with dominant rhodochrosite (0,015 to 0,03 mm in size). Carbonates contain pseudomorphs after spherical radiolarians (Fig. 6). They are filled with rhombohedrons of rhodochrosite, fine-grained quartz and chlorite. Lithoclasts of siltstone (1 to 2 mm in size) with pelitic matrix were found also in carbonates. Manganese oxide and hydroxide coatings cover layers and boudinage of rhodochrosite. The other sediments of the Sokolica Radiolarite Formation as siliceous shales and grey-green spotted siliceous limestone described by Myczińki (1973) have not been found.

2. *Quarry*

The western part of quarry is mainly represented by the Czajakowa Radiolarite Formation with intercalation of siliceous shale (Ožvoldová & Frantová, 1997), which is overlaid by Tithonian to Lower Cretaceous light grey radiolarian limestone with rare silicified belemnites (Pieniny Limestone Formation). The fissures in underlying radiolarite chert of the Sokolica Radiolarite Formation are coated with manganese oxides and hydroxides.

Carbonate layers (5 to 10 cm thick) with manganese oxides and hydroxides can be observed in shale in the eastern part of the quarry. Shale consists of illite, chlorite and rare clastic quartz (0,02 to 0,05 mm in size). Shale

Fig. 2. Outcrop of radiolarite (in left) and shale (in right) in Vesné Brook, Šarišské Jastrabie. Symbols: radiolarite (circle), shale (square) and boudinage with rhodochrosite (star). Fault is marked with dashed line.

Fig. 3. Layer and boudinage (up) of carbonates in shale. Vesné brook, 5 m NW from tectonic contact on Fig. 2. Symbols: radiolarite (circle), shale (square) layer and boudinage with rhodochrosite (star).

contains disseminated coal plant fragments and rare fish teeth. Some samples show brecciated texture and cracks filled by polycrystalline quartz.

Radiolarian microfauna

Radiolarian microfauna was studied especially in shale and its tectonic contact with overlying radiolarite. The samples, taken from radiolarite were used to complement data to the established age by Ožvoldová & Frantová (1997). Shale samples were treated with 12 % acetic acid and 5 % HF (1-2 days), radiolarite samples using standard HF method as well. Dating of radiolarian microfauna is based on the biozonation of Baumgartner et al. (1995). The position of all samples is shown on the Fig. 2, 3 and 4. Distribution of radiolarians in the samples, containing radiolarian microfauna is demonstrated in Tab. 1. Illustration of important species is shown in Fig. 7, 8.

Vesné brook

Radiolarite of Czajakowa Radiolarite Formation, in the upper part of the sequence, of rusty red colour, without Mn coatings contains the assemblages, which represent U.A.Z. 9 – U.A.Z. 10 (Middle Oxfordian to Late Oxfordian - Early Kimmeridgian) (Ožvoldová & Frantová, 1997). This stratigraphical range was confirmed by our investigation (sample ŠJ 6), based on the occurrence of the species *Podocapsa amphitreptera* Foreman, *Fultacapsa sphaerica* (Ožvoldová), *Angulobracchia biordinalis* Ožvoldová and *Paronaella broennimanni* Pessagno.

Underlying layers of this formation, of greenish grey or greyish green colour contains assemblages, represent-

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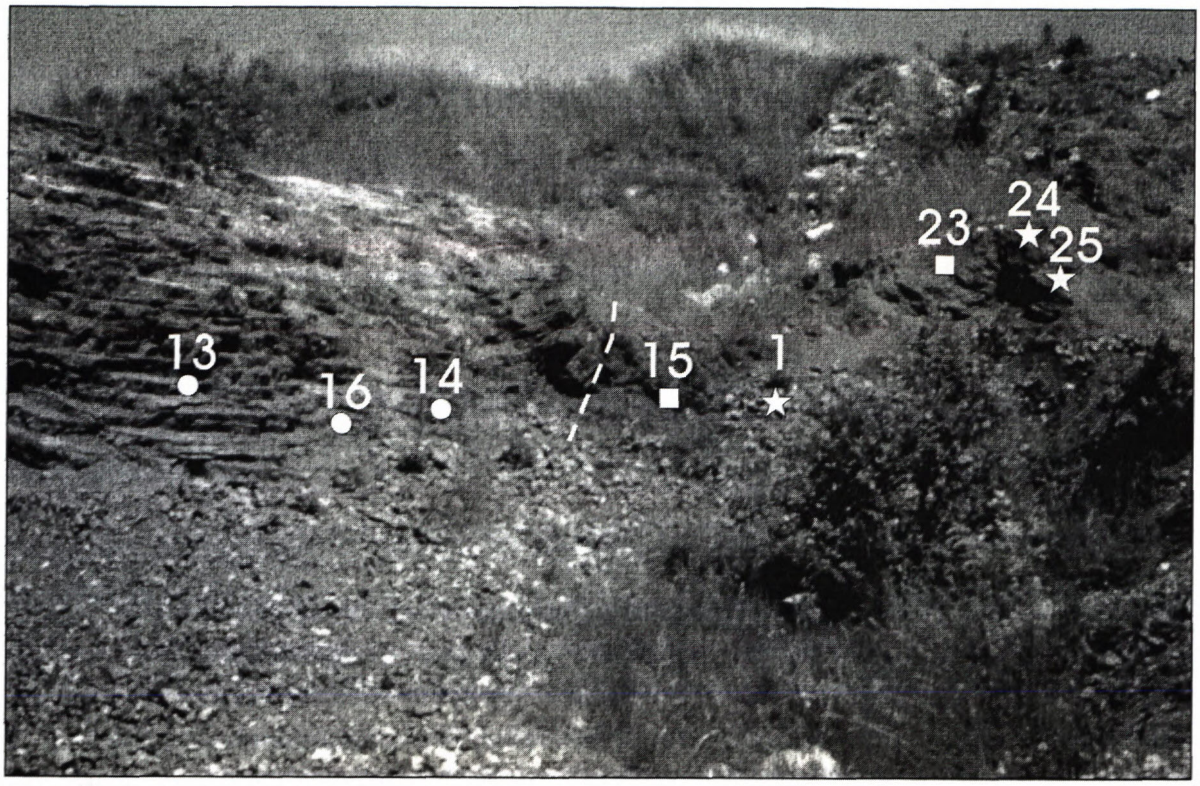

Fig. 4. Outcrop of radiolarite (in left) and shale (in right) in quarry NE from cemetery. Explanations: radiolarite (circle), shale (square) and layer with rhodochrosite (star). Fault is marked with dashed line.

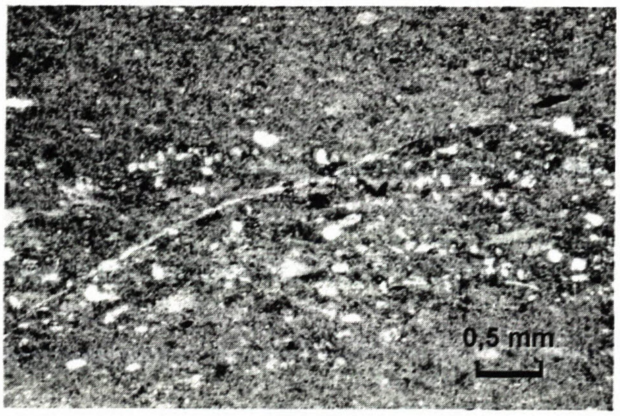

Fig. 5. Shale with band of clastic quartz (parallel to longer size of the figure). ŠJ 8, parallel nicols..

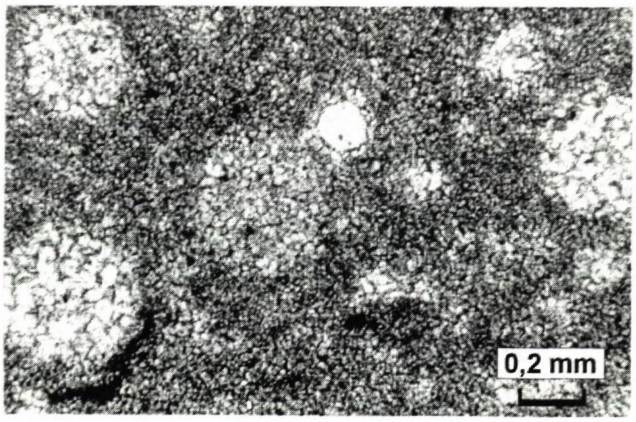

Fig. 6. Aggregates of rhodochrosite are dominant in rock. Carbonates and quartz (white) replace spherical radiolarians. ŠJ 2, transmitted light, parallel nicols.

ing Unitary Association Zone 8 (U.A.Z. 8) (l.c.), which stratigraphical range is Middle Callovian - Early Oxfordian.

Radiolarite with manganese coatings (Sokolica Radiolarite Formation) yields badly preserved assemblages. The presence of the species *Eucyrtidiellum ptyctum* Riedel et Sanfilippo, which, according recent research in the Pieniny Klippen Belt does not appear before Callovian, proves, that this part of sequence is not older than Callovian (Ožvoldová & Frantová, 1997).

Shale sequence, separated from overlying radiolarite by a tectonic contact, contained very poor microfauna, preserved mostly in phantoms (sample ŠJ 9). Determinable specimens were *Transhsuum brevicostatum* (Ožvoldová), *Paronaella* cf. *pristidentata* Baumgartner, *and Tricolocapsa* sp., *Paronella* sp. Its assemblage refers to Middle – Upper Jurassic age. The lower and upper boundary is restricted by the species *Transhsuum brevicostatum* (Ožvoldová), which appears in Bajocian and extincted in Tithonian.

The assemblage in the sample ŠJ 10 with the species *Kilinora spiralis* (Matsuoka), *Cingulotturis carpatica* Dumitrica, *Mirifusus dianae* (Karrer) and *Stichocapsa robusta* Matsuoka corresponds to U.A.Z. 7 and the stratigraphical range Late Bathonian to Early Callovian. In a comparison with the other analysed associations of this range in the Pieniny Klippen Belt (Ožvoldová, in preparation) it represents the upper part of this stratigraphical range.

Tab. 1. Distribution of radiolarians in the studied samples

Radiolarian fauna	Sample ŠJ 6	ŠJ 9	ŠJ 10	ŠJ16	ŠJ25
Angulobracchia biordinalis Ožvoldová	*				
Angulobracchia digitata Baumgartner			*		
Angulobracchia sp.					*
Archaeospongoprunum imlayi Pessagno	*			*	
Cinguloturris carpatica Dumitrică			*	*	*
Deviatus diamphidius hipposidericus (Foreman)				*	
Emiluvia ordinaria Ožvoldová	*			*	
Emiluvia pessagnoi Foreman	*				
Emiluvia premyogii Baumgartner	*				
Emiluvia salensis Pessagno	*		*		
Emiluvia sedecimporata (Rüst)	*				
Fultacapsa sphaerica (Ožvoldová)	*			*	
Eucyrtidiellum sp.					*
Haliodictya (?) antiqua (Rüst)			*		
Higumastra imbricata (Ožvoldová)			*		
Homoeoparonaella argolidensis Baumgartner	*				
Homoeparonaella sp.					*
Kilinora spiralis (Matsuoka)			*		
Mirifusus dianae (Karrer)	*		*	*	
Mirifusus guadalupensis Pessagno					*
Napora lospensis Pessagno	*				
Obesacapsula cf. morroensis Pessagno	*		*		*
Palinandromeda podbielensis (Ožvoldová)			*		
Paronaella broennimanni Pessagno	*			*	
Paronaella pristidentata Baumgartner				*	
Paronaella cf. pristidentata Baumgartner		*			
Paronaella sp.		*			
Parvicingula dhimenaensis Baumgartner	*				
Podobursa spinosa (Ožvoldová)					
Podobursa triacantha (Fischli)					
Podocapsa amphitreptera Foreman	*			*	
Protunuma japonicus Matsuoka et Yao					*
Pseudoctrucella sanfilippoae (Pessagno)					*
Sethocapsa funatoensis Aita					*
Spongocapsula palmerae Pessagno	*				
Stichocapsa robusta Matsuoka			*		
Tetraditryma corralitosensis (Pessagno)			*		
Tetraditryma pseudoplena Baumgartner			*		
Tetratrabs zealis (Ožvoldová)			*		
Transhsuum brevicostatum (Ožvoldová)		*	*	*	
Transhsuum maxwelli (Pessagno)			*		*
Triactoma blakei (Pessagno)	*			*	
Triactoma jonesi (Pessagno)			*		
Tricolocapsa sp.		*			
Tritrabs ewingi (Pessagno)			*		
Tritrabs rhododactylus Baumgartner			*	*	
Zhamoidellum ovum Dumitrică	*			*	

Quarry

Radiolarite sequence is predominantly formed by the radiolarite of Czajakowa Radiolarite Formation containing microfauna, which represents U.A.Z. 9 – U.A.Z. 10 - Middle Oxfordian to Late Oxfordian – Early Kimmeridgian (Ožvoldová & Frantová, 1997).

Radiolarite with Mn coatings of Sokolica Radiolarite Formation, which occurs in a small amount yields microfauna (ŠJ 16), in which the presence of the species *Paronaella pristidentata* Baumgartner and Paronaella *broennimanni* Pessagno indicates U.A.Z. 10 – Late Oxfordian – Early Kimmeridgian. This fact confirms the datum of Ožvoldová & Frantová (1997), that the manganese coatings in radiolarite extend somewhere up to Middle – Late Oxfordian.

Shale sequence contains badly preserved microfauna (ŠJ 25,) with the species of a relatively broad stratigraphical range. It can be assigned to the U.A. zones U.A.Z. 7 – U.A.Z. 10 – Late Bathonian - Early Callovian to Late Oxfordian-Early Kimmeridgian, based on the presence of the species *Protunuma japonicus* Matsuoka et Yao and Pseudocrucella *sanfilippoae* (Pessagno). However, it is likely, that the age is not different from the samples in the Vesné Brook (ŠJ 9, ŠJ 10).

The studied sections the shale sequence with Mn coatings, occurring in the lower part of the sections and belonging according to Birkenmajer (1977) to Sokolica Radiolarite Formation contained a radiolarian microfauna, representing U.A.Z. 7 - Late Bathonian – Early Callovian.

Radiolarite sequence overlying shale at the both outcrops yielded the assemblages corresponding to the U.A.Z.8 – U.A.Z. 10 with the stratigraphical range-Middle Callovian - Early Oxfordian to Late Oxfordian - Early Kimmeridgian. Radiolarite with Mn coatings, which formed according to Birkenmajer (1977) Sokolica Radiolarite Formation reaches somewhere up to Middle – Late Oxfordian.

Manganese mineralization

Manganese ore represented in both localities by rhodochrosite forms intercalations and boudinage in shale and it is not bound to basal part of the radiolarite chert as described by Ilavský (1955). Secondary manganese oxides and hydroxides form crusts on rhodochrosite layers (Fig. 9) and they also fill the fissure in the overlying radiolarite chert close to the tectonic contact (Fig. 10).

Methods

Identification of minerals, distribution o elements and chemical composition of minerals was analysed by wave-dispersion X-ray microanalysis (WDX), energy-dispersion X-ray microanalysis (EDX) and by X-ray diffraction analysis (XRD). WDS analyses were carried out on a JEOL-733 Superprobe equipped with KEVEX Delta IV+ energy disperse system (Geological Survey of Slovak Republic). Analysed elements were Al, Ba, Ca, Fe,

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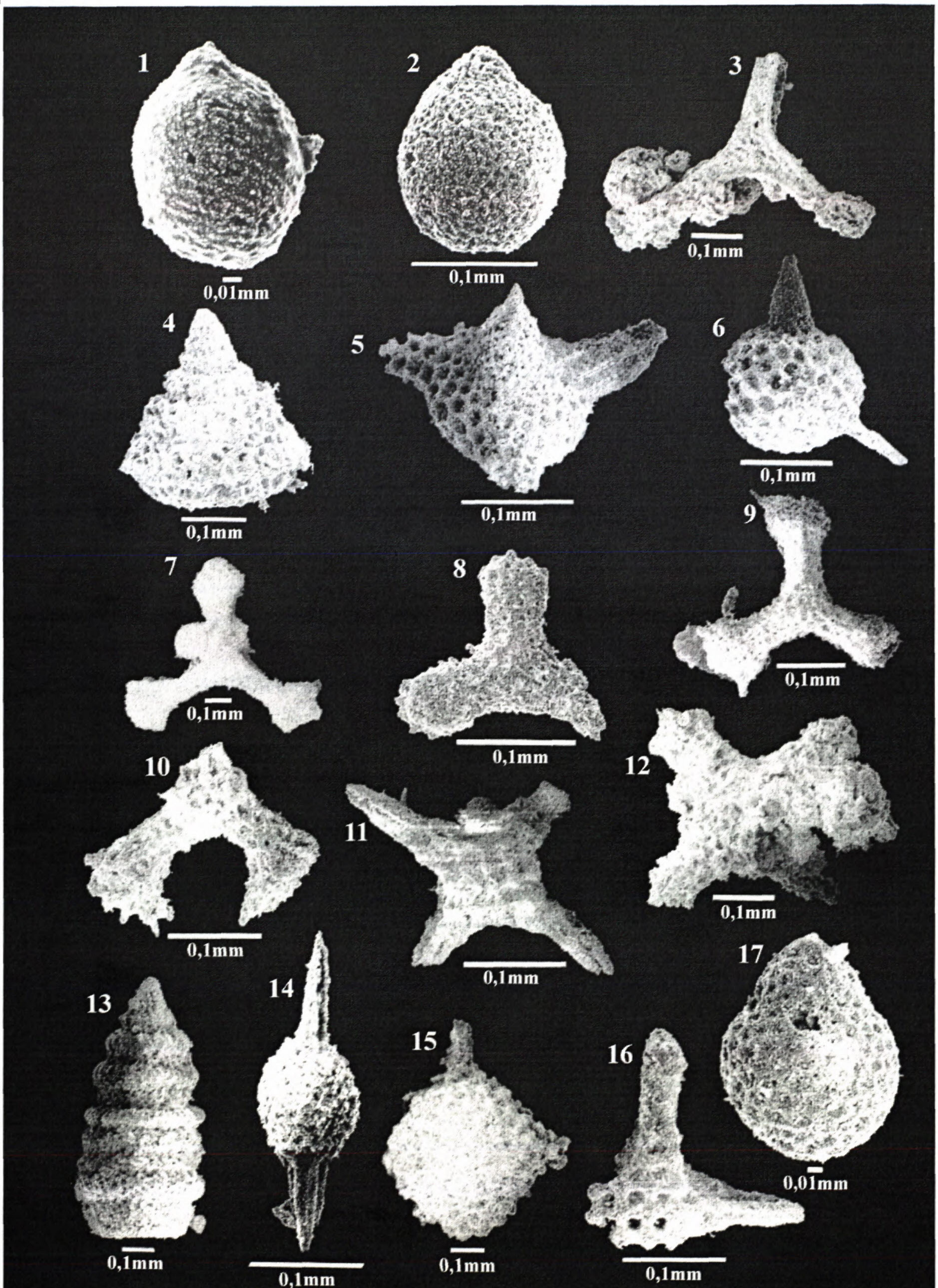

Fig. 7. 1 – Kilinora spiralis (Matsuoka) – 1309, ŠJ – 10, 2 – Stichocapsa robusta Matsuoka – 1306, ŠJ – 10, 3 – Angulobracchia digitata Baumgartner – 1312, ŠJ – 10, 4 – Palinandromeda podbielensis (Ožvoldová) – 1304, ŠJ – 10, 5 – Podocapsa amphitreptera Foreman – 1334, ŠJ – 16, 6 – Fultacapsa sphaerica (Ožvoldová) – 1339, ŠJ – 16, 7 – Angulobracchia biordinalis (Ožvoldová) – 7906, ŠJ – 6, 8 – Paronaella pristidentata Baumgartner – 1342, ŠJ – 16, 9 – Paronaella broennimanni Pessagno – 1326, ŠJ – 16, 10 – Deviatus diamphidius hipposidericus (Foreman) – 1340, ŠJ – 16 , 11 – Emiluvia sedecimporata (Rüst) – 1344, ŠJ – 6, 12 – Higumastra imbricata (Ožvoldová) – 1325, ŠJ – 10, 13 – Cinguloturris carpatica Dumitrică – 1346, ŠJ – 16, 14 – Archaeospongoprunum imlayi Pessagno – 1335, ŠJ – 16, 15 - Emiluvia pessagnoi Foreman – 7909, ŠJ – 6, 16 – Emiluvia ordinaria Ožvoldová - 1336, ŠJ – 16, 17 – Zhamoidellum ovum Dumitrică – 1345, ŠJ – 16.

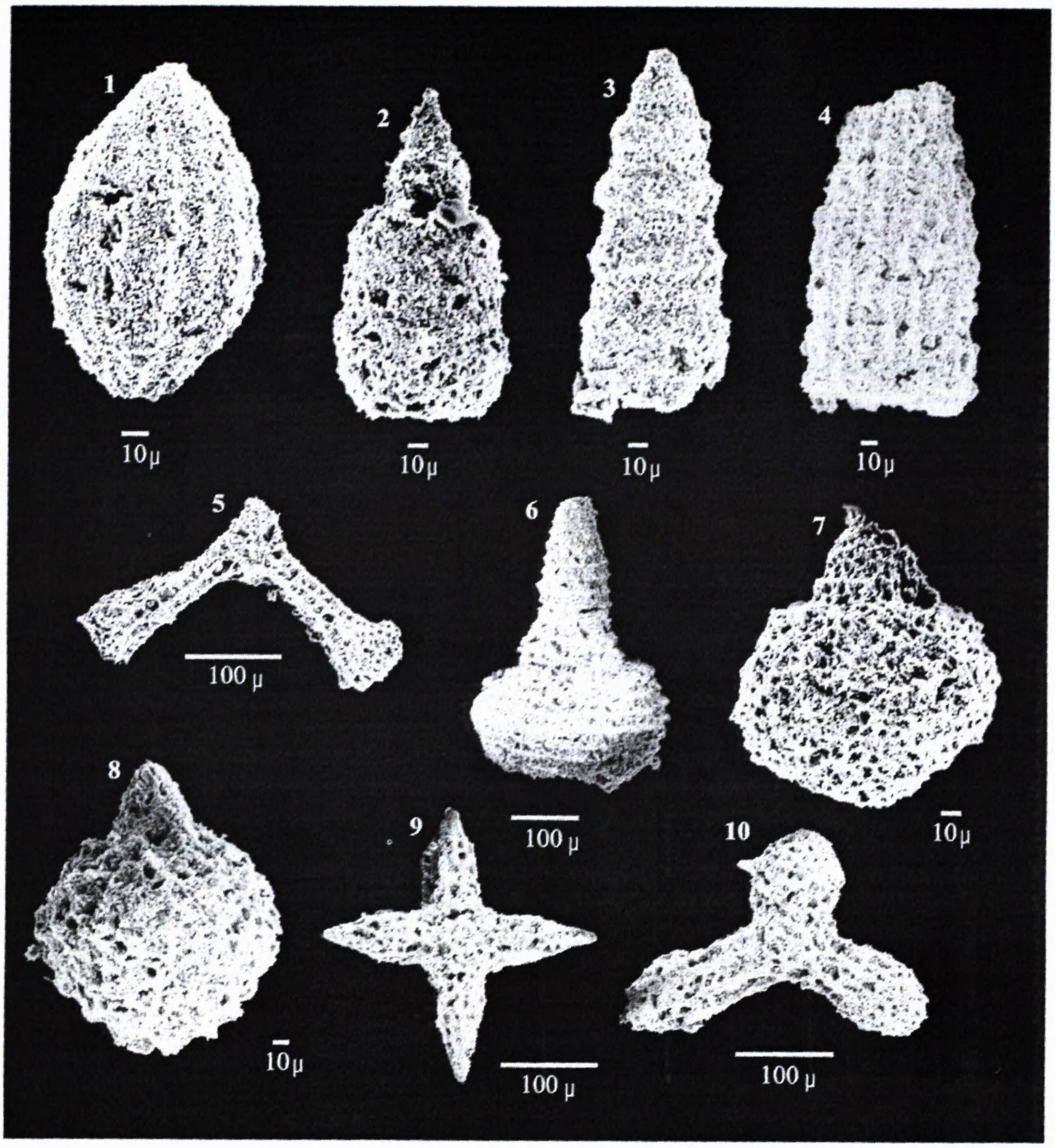

Fig. 8. (Sample ŠJ 25) 1– Protunuma japonicus Matsuoka et Yao – 8340, 2 – Eucyrtidiellum sp. –8339, 3 – Cingulotunris carpatica Dumitrică – 8336, 4 – Transhsuum maxwelli (Pessagno) – 8334, 5 – Angulobracchia sp. – 8337, 6 – Mirifusus guadalupensis Pessagno – 8331, 7 – Obesacapsula cf. morroensis (Pessagno) – 8338, 8 –- Sethocapsa funatoensis Aita – 8335, 9 – Pseudocrucella sanfilippoae (Pessagno) – 8333, 10 – Homoeoparonaella sp. – 8332.

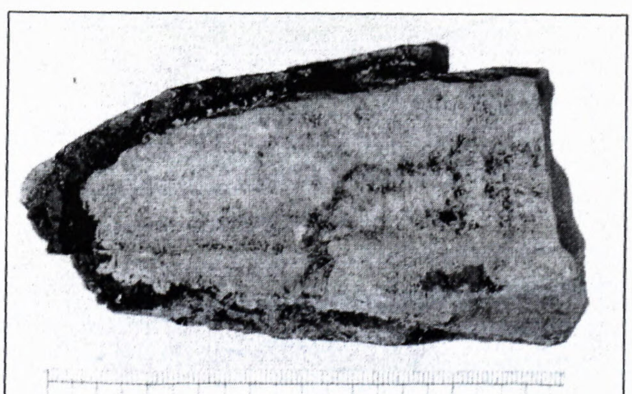

Fig. 9. Crust of manganese oxides (black) on carbonate rock with rhodochrosite. ŠJ 10.

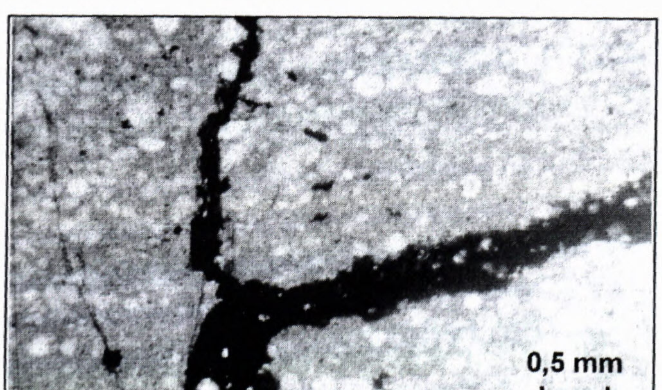

Fig. 10. Veinlet of manganese hydroxides (black). ŠJ 5, transmitted light, parallel nicols.

K, Mg, Mn, Na, Si and Sr. Natural and synthetic standards were applied on calibration of both systems: Al_2O_3, $BaSO_4$, Ca-wollastonite, Fe-hematite, K-orthoclase, MgO, Mn- rhodonite, Na-albite, SiO_2 and $SrTiO_3$. WDS analyses used 15 and 20 kV accelerating voltage, 15-18 nA beam current, and 10 to 20 seconds counting times according to total number of counts. Obtained counts were recalculated in oxides using PAP correction. Electron beam was focused on 2-5 micrometers. Chemical composition of minerals was calculated in the Minfile programme.

X-ray diffraction (XRD) analyses were made on a Philips PW 1710 diffractometer. Samples with high content of Fe were analysed by Co K_α radiation ($\lambda\alpha_1 = 1.78896$ m $^{-10}$, $\lambda\alpha_2 = 1.79285$ m^{-10}) and Cu K_α radiation ($\lambda\alpha_1 = 1.54060$ m^{-10} $\lambda\alpha_2 = 1.54439$ m^{-10}) was used in case of other samples. Accelerating voltage of 35 kV and beam current of 20 mA were used in the range 4 to 60 ° 2Θ with shift 0.02 ° 2Θ.

Minerals

Rhodochrosite is dominant mineral of the carbonate layers in shale. Euhedral grains (from 0,01 to 0,05 mm in size) are replaced by manganese oxides and hydroxides and by iron hydroxides (Fig. 11). Marginal part of grains is mostly replaced. XRD (Tab. 2) and WDS confirmed rhodochrosite. Chemical composition shows variable and significant iron content in rhodochrosite reflecting mostly replacement by manganese and iron hydroxides and oxides (Tab. 3, Fig. 12). Pseudomorphs of todorokite and cryptomelane after rhodochrosite can be observed in some places.

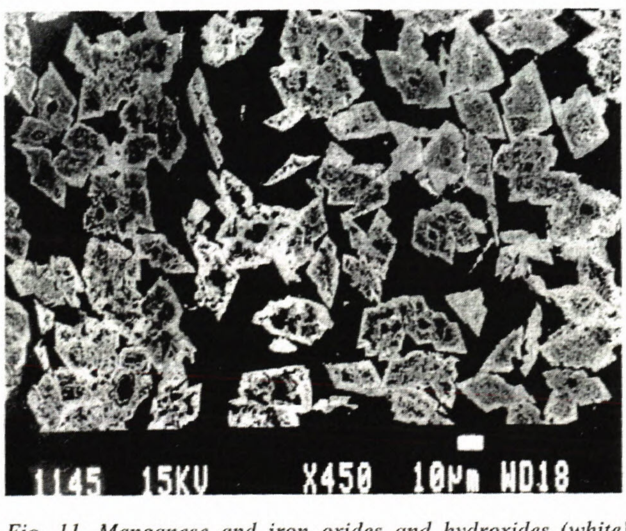

Fig. 11. Manganese and iron oxides and hydroxides (white) replace euhedral rhodochrosite (grey). ŠJ 9, scanning electron microscopy-back-scatter electron image (SEM-BEI).

Todorokite forms crusts (up to 1 mm thick) on rhodochrosite aggregates and fills fissures in them (up to 0.1 mm in thickness). Xenomorph distinctly anisotropic grains (10 to 50 μm in size) form darker core of concentric aggregates (0.02 to 0.03 mm in size) with rimming lighter romanèchite in reflected light (Fig. 13).

Tab. 2. X-ray diffraction of rhodochrosite

ŠJ 9		ŠJ 10		ŠJ 21		Rhodochrosite Mich 421		Quartz Mich 256	
d	I	d	I	d	I	d	I	d	I
4.255	2	4.271	1	4.255	1			4.24	5
3.628	1	3.644	1	3.649	3	3.65	7		
3.346	7	3.353	4	3.342	5			3.34	10
2.821	10	2.835	10	2.840	10	2.850	10		
2.458	1							2.45	5
2.373	1	2.375	1	2.375	1	2.389	4		
2.279	1							2.280	5
2.153	1	2.164	2	2.164	1	2.180	4		
1.983	1	1.984	2	1.988	2	1.990	5		
1.818	2	1.820	1	1.815	1	1.809	3		
				1.760	3	1.762	8		

Mich 421 and Mich 256 (XRD 421 and 256 in Michejev 1957)XRD

Tab.3 Chemical composition of carbonates

	Weight per cent					
Sample	CaO	MgO	FeO	MnO	CO_2	Total
ŠJ2	3.59	1.93	21.33	34.03	39.11	100.00
ŠJ9.1	0.57	2.09	34.15	24.40	38.79	100.00
ŠJ9.2	4.51	2.08	22.15	32.02	39.24	100.00
ŠJ9.3	3.30	2.01	23.31	32.29	39.09	100.00
ŠJ10.1	4.64	2.04	23.08	30.99	39.24	99.99
ŠJ10,2	3.50	1.97	22.42	32.99	39.11	99.99
ŠJ16.1	10.67	2.02	2.26	45.10	39.94	99.99
ŠJ16.2	3.03	2.00	29.95	25.99	39.03	100.00
ŠJ16.3	6.78	2.03	13.33	38.35	39.50	99.98
ŠJ16.4	2.31	2.08	32.02	24.62	38.97	100.00
ŠJ16.5	2.30	2.17	30.35	26.18	39.01	100.00
ŠJ20	1.63	1.47	27.47	30.69	38.75	100.00
ŠJ21.1	4.07	1.72	19.30	35.80	39.11	100.00
ŠJ21.2	4.80	2.04	19.10	34.77	39.27	100.00
ŠJ21.3	0.99	1.92	35.45	22.86	38.78	100.00
ŠJ21.4	4.50	2.08	19.66	34.51	39.25	100.00
ŠJ21.5	4.33	2.18	22.12	32.12	39.25	100.00
	Atomic proportion (to 3 oxygen)					
Sample	Ca	Mg	Fe	Mn	C	Total
ŠJ2	0.072	0.054	0.334	0.540	1.000	2.000
ŠJ9.1	0.012	0.059	0.539	0.390	1.000	2.000
ŠJ9.2	0.090	0.058	0.346	0.506	1.000	2.000
ŠJ9.3	0.066	0.056	0.365	0.512	1.000	2.000
ŠJ10.1	0.093	0.057	0.360	0.490	1.000	2.000
ŠJ10,2	0.070	0.055	0.351	0.523	1.000	2.000
ŠJ16.1	0.210	0.055	0.035	0.701	1.000	2.000
ŠJ16.2	0.061	0.056	0.470	0.413	1.000	2.000
ŠJ16.3	0.135	0.056	0.207	0.602	1.000	2.000
ŠJ16.4	0.046	0.058	0.503	0.392	1.000	2.000
ŠJ16.5	0.046	0.061	0.477	0.416	1.000	2.000
ŠJ20	0.033	0.041	0.434	0.491	1.000	2.000
ŠJ21.1	0.082	0.048	0.302	0.568	1.000	2.000
ŠJ21.2	0.096	0.057	0.298	0.549	1.000	2.000
ŠJ21.3	0.020	0.054	0.560	0.366	1.000	2.000
ŠJ21.4	0.090	0.058	0.307	0.545	1.000	2.000
ŠJ21.5	0.087	0.061	0.345	0.508	1.000	2.000

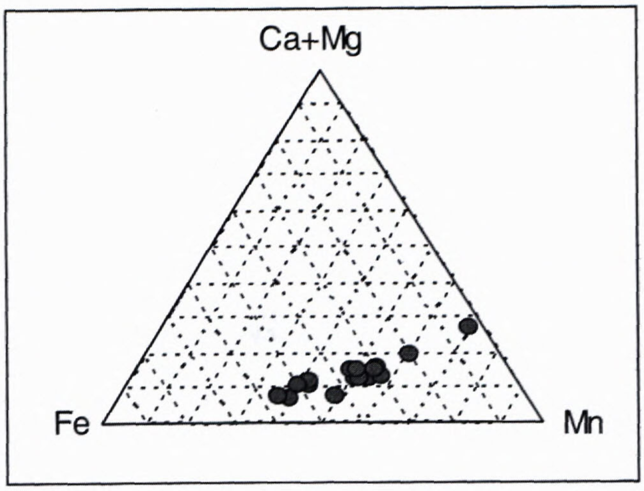

Fig. 12. Chemical composition of carbonates from Šarišské Jastrabie.

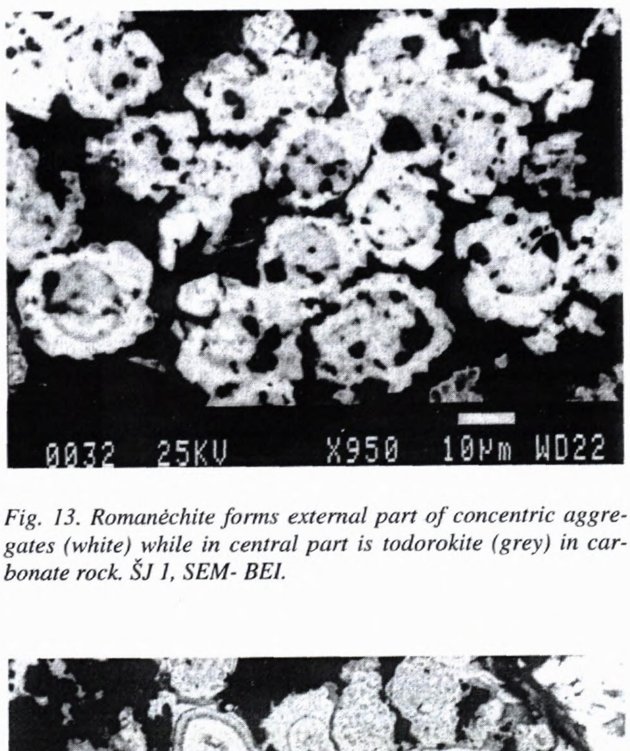

Fig. 13. Romanèchite forms external part of concentric aggregates (white) while in central part is todorokite (grey) in carbonate rock. ŠJ 1, SEM- BEI.

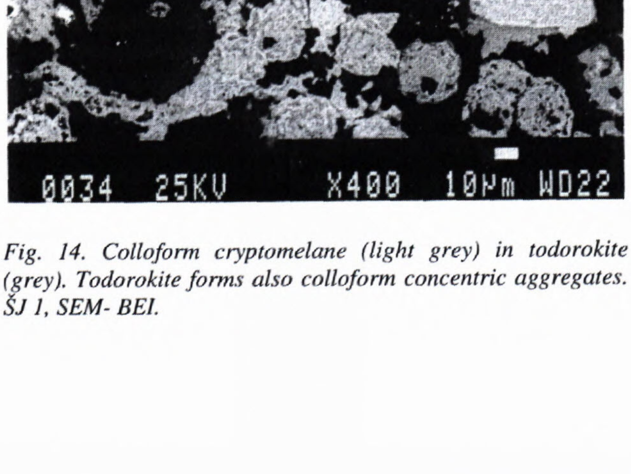

Fig. 14. Colloform cryptomelane (light grey) in todorokite (grey). Todorokite forms also colloform concentric aggregates. ŠJ 1, SEM- BEI.

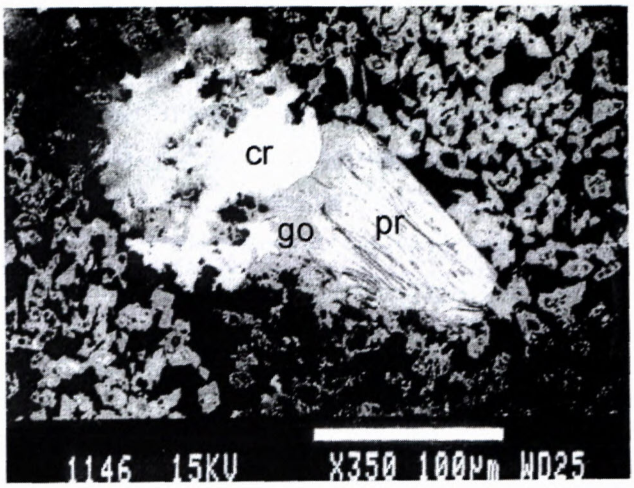

Fig. 15. Aggregate of pyrolusite (pr), cryptomelane (cr) and goethite (go) in radiolarite. ŠJ 16, SEM-BEI.

XRD with maximum at 9.6 d suggests todorokite. Presence of characteristic calcium with manganese is also typical for todorokite (Tab. 4).

Romanèchite forms rims of concentric aggregates of todorokite and veinlets (from 0.03 to 0.1 mm in thickness). Increase of the barium content in WDS analyses in external zones of aggregates helped to distinguish romanèchite (Tab. 5). Characteristic peaks of romanèchite were distinguished also by XRD in fissure fillings in radiolarite chert.

Cryptomelane represents the lighter phase with higher relief in the reflected light than todorokite. It forms botryoidal colloform aggregates up to 0,1 mm in size (Fig. 14). It fills fissures in todorokite aggregates or veinlets. Veinlets of cryptomelane cut rhodochrosite and todorokite. It is less frequent than todorokite. Chemical composition of cryptomelane is characterised by total close to 100 wt. % and K_2O content ≥ 3 wt. % (Tab. 6).

Pyrolusite is easily distinguished in reflected light among other manganese minerals by high reflectivity, strong anisotropy (yellow-dark brown) and yellow colour. Elongated grains (0,01 to 0,1 mm long) form aggregates (Fig. 15). They form 0,1 to 0,2 mm thick crusts of layers with rhodochrosite, where elongated grains are oriented perpendicularly to the surface of bedding. Zoned crusts are often alternating with goethite. WDS analyses confirmed only low content of Fe and Ca below 1 weight per cent (Tab. 7).

Pyrite is disseminated in radiolarite chert and shale as irregular grains or framboidal pyrite (to 0,01 mm in size). Euhedral grains (0.01 to 0.05 m in size) form aggregates (to 0,5 mm in size) and veinlets in rock or in quartz veinlets.

Goethite and iron hydroxides intergrow very often with manganese hydroxides or they rim them (Fig. 15). They replace and rim rhodochrosite and pyrite forming often pseudomorphs after these two minerals. Grains and aggregates (0,01 to 0,3 mm in size) show variable Mn and Fe contents due to intimate intergrowths of iron and manganese hydroxides (Tab. 8).

Tab. .4. Chemical composition of todorokite

	Weight per cent							
Sample	MnO_2	CaO	MgO	SiO_2	Fe_2O_3	K_2O	BaO	Total
ŠJ1.1	84.58	2.70	0.71	0.11	0.00	1.46	0.00	89.56
ŠJ1.2	84.63	2.66	0.88	0.34	0.00	1.63	0.52	90.66
ŠJ1.3	84.93	2.67	0.91	0.32	0.00	1.78	0.30	90.91
ŠJ21.1	84.34	3.23	1.00	0.40	4.97	1.14	0.00	95.08
ŠJ24.1	87.44	2.42	1.58	0.03	0.23	1.76	0.00	93.46
ŠJ24.2	88.89	4.83	0.66	0.52	0.38	0.82	0.00	96.10
ŠJ24.3	86.11	3.28	0.78	2.62	1.02	1.18	0.00	94.99
ŠJ24.4	87.90	4.20	0.56	0.55	0.38	0.85	0.01	94.45
	Atomic proportion (to 7 oxygen)							
Sample	Mn	Ca	Mg	Si	Fe	K	Ba	Total
ŠJ1.1	3.354	0.166	0.061	0.006	0.000	0.107	0.000	3.694
ŠJ1.2	3.327	0.162	0.075	0.019	0.000	0.118	0.012	3.713
ŠJ1.3	3.327	0.162	0.077	0.018	0.000	0.129	0.007	3.719
ŠJ21.1	3.171	0.188	0.081	0.022	0.204	0.079	0.000	3.745
ŠJ24.1	3.324	0.143	0.130	0.002	0.010	0.124	0.000	3.731
ŠJ24.2	3.282	0.277	0.053	0.028	0.015	0.056	0.000	3.710
ŠJ24.3	3.184	0.188	0.062	0.140	0.041	0.081	0.000	3.696
ŠJ24.4	3.299	0.244	0.045	0.030	0.016	0.059	0.000	3.693

Tab. 5. Chemical composition of romanèchite

Sample	Weight per cent							
No	MnO_2	Fe_2O_3	MgO	SiO_2	K_2O	CaO	BaO	Total
ŠJ 1.1	79.91	0.80	0.23	0.43	0.70	1.99	6.19	90.25
ŠJ 1.2	80.20	2.67	0.27	0.43	0.86	2.20	4.52	91.14
ŠJ 1.3	82.10	1.89	0.35	0.19	1.05	2.74	3.42	91.73
Sample	Atomic proportion (to 10 oxygen)							
No	Mn^{+4}	Fe^{+3}	Mg	Si	K	Ca	Ba	Total
ŠJ1	4.698	0.051	0.029	0.036	0.076	0.181	0.206	5.278
ŠJ1	4.627	0.168	0.033	0.036	0.091	0.197	0.148	5.299
ŠJ1	4.672	0.117	0.043	0.016	0.110	0.242	0.110	5.309

Chemical composition of rocks

Radiolarite chert, shale and rhodochrosite intercalations are characterised by the different content of major elements (Tab. 9). Radiolarite chert can be distinguished by distinctly high SiO_2 content (over 90 wt. %). High Si/(Al+Fe) ratio suggests organic origin of radiolarite chert (Rangin et al. 1981). Shale shows increased Al_2O_3 content (around 10 wt. %), MgO and K_2O (3 to 8 wt. %). Manganese content in radiolarite chert as well as in shale is low (below 0,5 weight per cent of Mn). Halamič et al. (2001) give MnO to 0.51 wt. % in radiolarite chert from Croatia. Distinctly increased is manganese content in carbonate layers and boudinage (14 to 23 wt. % of Mn). Iron content does not correlate with manganese (Mn/Fe ratio varies from 0.98 to 3.88), reflecting bonds to iron hydroxides and less to rhodochrosite. Ca is higher (19 wt. %) in manganese ore with rhodochrosite and todorokite, where low iron content was found (sample ŠJ 1), suggesting the presence of primary Ca rhodochrosite before replacement by iron hydroxides. Presence of kutnahorite or calcite was not confirmed by XRD. Part of Ca may be bound to apatite as was confirmed by XRD and increased $P2O_5$ content (2,5 weight per cent). Carbonate layers and boudinage are characterised by increased CO_2 content (over 17 weight per cent), inorganic carbon (TIC over 4 weight per cent) and loss of ignition (LOI over 10 weight per cent).

Manganese ore shows similarly as in other occurrences in the Jurassic shale very low content of Co, Cu and Ni especially comparing to the ores in Jurassic limestone (Rojkovič, 2002). Ni+Co+Cu contents are slightly higher in shale and carbonate layers comparing to radiolarite chert. Cu is distinctly higher not only to radiolarite chert but also to carbonate layers. Local increase of Co and Ni can be observed in samples with higher pyrite content. Ti, Mg, K, Cr, V, B, Pb and Zr contents are distinctly higher in shale and carbonate layers comparing to radiolarite chert. Mg, K, Cr and V are related to Al_2O_3 content mostly in clay minerals (illite and chlorite) similarly as in shale accompanying radiolarite chert in Mino-Tamba, Japan (Kakuwa, 1986). Ti, B and Zr contents in the stud-

Tab. 6. Chemical composition of cryptomelane

No	Weight per cent					
	K_2O	MnO_2	Fe_2O_3	SiO_2	CaO	Total
ŠJ 1.1	3.26	94.69		0.32	0.73	99.01
ŠJ 1.2	3.05	95.14		0.00	0.00	98.18
ŠJ 1.3	3.20	95.56		0.28	0.87	99.91
ŠJ16.1	2.51	96.59	0.59		0.32	100.01
ŠJ16.2	2.60	96.56	0.56		0.28	100.00
ŠJ16.3	2.46	96.55	0.70		0.29	100.00
ŠJ16.4	3.13	95.17	0.60		0.31	99.21
ŠJ16.5	2.54	95.99	0.66		0.27	99.46
ŠJ16.6	3.08	94.98	0.80		0.43	99.30
ŠJ 20.1	3.38	94.38	0.28	0.05	1.43	99.52
ŠJ 20.2	3.10	94.49	0.24	0.05	1.21	99.09
ŠJ 20.3	2.61	92.95	0.32	0.06	1.92	97.86
ŠJ 20.4	2.83	94.34	0.62	0.07	1.74	99.60
ŠJ 24.1	2.91	94.01	0.18	0.05	1.13	98.28
ŠJ 24.2	3.23	95.82	0.24	0.10	1.13	100.52
	Atomic proportion (to 16 oxygen)					
No	K	Mn	Fe	Si	Ca	Total
ŠJ 1.1	0.496	7.791		0.038	0.093	8.418
ŠJ 1.2	0.466	7.884		0.000	0.000	8.350
ŠJ 1.3	0.482	7.792		0.033	0.110	8.417
ŠJ16.1	0.376	7.847	0.052		0.041	8.315
ŠJ16.2	0.390	7.848	0.049		0.035	8.323
ŠJ16.3	0.369	7.843	0.062		0.037	8.310
ŠJ16.4	0.475	7.821	0.054		0.039	8.389
ŠJ16.5	0.383	7.843	0.059		0.034	8.319
ŠJ16.6	0.468	7.802	0.072		0.055	8.396
ŠJ 20.1	0.513	7.756	0.025	0.006	0.182	8.482
ŠJ 20.2	0.471	7.783	0.022	0.006	0.155	8.436
ŠJ 20.3	0.402	7.747	0.029	0.007	0.248	8.432
ŠJ 20.4	0.428	7.733	0.055	0.008	0.221	8.446
ŠJ 24.1	0.446	7.798	0.016	0.006	0.145	8.411
ŠJ 24.2	0.484	7.780	0.021	0.012	0.142	8.440

ied samples may reflect the presence of clastic minerals in sediments like rutile, tourmaline and zircon. Layers and boudinage with rhodochrosite show the highest Sr content bound to carbonates.

Distribution of the rare earth elements (REE) shows only slight positive Ce anomaly and REE contents similar to other occurrences in the Jurassic shale of the Western Carpathians (Borinka, Lednické Rovne and Zázrivá). Slight positive Ce anomaly suggest terrigenous and not hydrothermal source of manganese associated with volcanic activity (Fig. 16). La/Ce=0.28 is similar like in other Jurassic shale (0.26) and it is distinctly different from ratio La/Ce=2.8 of seawater characteristic for hydrothermal accumulation of manganese on the sea bottom (Toth, 1980). Small positive Eu anomaly reflects continental source of material and exclude hydrothermal manganese accumulation with typical negative Ce anomaly (Shimizu & Masuda, 1977, Matsumoto et al., 1985, Usui et al., 1997, Kuhn et al., 1998).

Tab. 7. Chemical composition of pyrolusite

No	Weight per cent			
	MnO_2	Fe_2O_3	CaO	Total
ŠJ 9.1	98.22	0.39	0.49	99.10
ŠJ 9.2	98.00	0.83	0.42	99.25
ŠJ 9.3	98.18	0.44	0.48	99.09
ŠJ 16.11	97.91	1.49	0.11	99.51
ŠJ 16.2	97.73	1.74	0.17	99.64
ŠJ 16.3	98.75	0.77	0.18	99.70
ŠJ 21.1	98.27	0.38	0.80	99.45
ŠJ 21.2	98.25	0.38	0.71	99.34
	Atomic proportion (to 2 oxygen)			
No	Mn	Fe	Ca	Total
ŠJ 9.1	0.993	0.004	0.008	1.005
ŠJ 9.2	0.990	0.009	0.007	1.006
ŠJ 9.3	0.993	0.005	0.008	1.005
ŠJ 16.11	0.987	0.016	0.002	1.005
ŠJ 16.2	0.984	0.019	0.003	1.006
ŠJ 16.3	0.992	0.008	0.003	1.004
ŠJ 21.1	0.991	0.004	0.013	1.007
ŠJ 21.2	0.991	0.004	0.011	1.007

Origin

Chemical composition, microscopic observation as well as geological position of manganese ore suggested according to Ilavský (1955) secondary origin of ore by mobilization of disseminated manganese mineralization from the radiolarite chert to the basal part of radiolarite overlying impermeable shale.

Primary manganese mineralization is bound to shale according to recent observations. We have similar situation as in other occurrences of manganese mineralization in the Pieniny Klippen Belt like Lednické Rovne and Zázrivá (Polák, 1955, Čillík, 1963). Microbial suboxic diagenesis and reduction of hydrogenous Mn^{+4} hydroxides by organic carbon was significant for origin of manganese carbonates (Roy, 1992, Öztürk & Hein, 1997, Gutzmer & Beukes, 1998). We assume formation of rhodochrosite layers by metasomatic replacement of marl during diagenesis. Reduction of sulphates was also important during the early diagenesis (Fan et al., 1999). Reduction of sulphates is dominant in sediments with lower Mn content (Veto et al., 1997). Pyrite formed most probably during diagenesis was found in radiolarite chert as well as in shale.

Supergene processes remobilized later manganese. Crusts of manganese oxides and hydroxides accompanied by iron hydroxides were formed in shale along bedding and perpendicular fissures. Pyrite was oxidized and sulphate solutions were formed. Important role of pyrite oxidation is known in Urkút deposit in Hungary where manganese and iron were leached from marl with radiolarite chert and mobilized by acid solutions (Szabó & Grasselly, 1980). Acid solutions could mobilize manganese also from shale with rhodochrosite in Šarišské

Tab. 8. Chemical composition of Fe-Mn hydroxides

No	Weight per cent						
No	Fe_2O_3	MnO_2	Al_2O_3	SiO_2	CaO	K_2O	Total
SJ 10.1	40.59	45.73	0.72	1.50	0.42	0.08	89.04
SJ 10.2	46.52	38.87	0.85	1.71	0.41	0.06	88.42
SJ 16	80.53	8.37			0.08	0.02	89.00
ŠJ 21.1	30.34	65.38		0.87	0.71	0.29	97.59
ŠJ 21.2	69.63	14.50		3.29	0.46	0.08	87.96
	Atomic proportion						
No	Fe	Mn	Al	Si	Ca	K	Total
SJ 10.1	0.470	0.486	0.013	0.023	0.007	0.002	1.000
SJ 10.2	0.538	0.413	0.015	0.026	0.007	0.001	1.000
SJ 16	0.912	0.087			0.001	0.000	1.000
ŠJ 21.1	0.326	0.645		0.012	0.011	0.005	1.000
ŠJ 21.2	0.790	0.151		0.050	0.007	0.002	1.000

Tab. 9. Chemical composition of manganese ore and rocks

Sample	ŠJ 1	ŠJ 5	ŠJ 8	ŠJ 9	ŠJ 10	ŠJ 14	ŠJ 15
SiO_2	33.12	93.47	65.14	27.94	32.87	91.36	69.92
TiO2	0.18	0.09	0.44	0.13	0.12	0.09	0.34
Al_2O_3	8.41	2.12	10.90	2.72	2.01	2.19	9.71
FeO	2.56						
Fe_2O_3	2.38	0.78	3.41	23.29	20.08	0.94	4.41
MnO	18.27	0.29	0.02	20.59	29.72	0.61	0.09
MgO	0.94	0.24	2.73	1.51	0.15	0.08	3.23
CaO	19.11	0.27	0.38	1.89	1.31	0.24	0.73
Na_2O	0.02	0.12	1.37	0.88	0.86	1.80	1.39
K_2O	0.03	0.48	8.29	0.81	0.80	0.39	3.41
P_2O_5	2.56	0.07	0.03	0.03	0.04	0.06	0.24
H_2O-	0.01	0.20	0.93	0.51	2.09	0.35	0.75
LOI	14.56	1.46	5.89	19.30	9.52	1.36	5.34
Total	102.15	99.59	99.52	99.62	99.57	99.46	99.55
B	2	46	136	357	41	47	94
Ba	15	213	215	127	42	324	206
Co	106	16	23	30	21	15	16
Cr	24	85	101	23	59	21	80
Cu	2	22	76	17	31	26	84
La	61	102	67				88
Mo	13	2	~1				~1
Ni	58	26	33	48	20	24	26
Pb	38	15	31	21	45	6	20
Sr	227	31	86	192	>500	65	84
V	50	12	88	17	20	13	58
Y	18	17	21	37	31	26	32
Zr	58	21	98	220	184	25	80
TC%	4.56	traces	0.2	5.11	0.12	0.1	0.28
TOC%	0.1	traces	0.16	0.2	0.12	st	0.2
TIC%	4.46	traces	0.04	4.91	traces	0.1	0.08
CO2 carb			0.146	17.97	traces	0.37	0.293
Fe tot	3.65	0.55	2.39	16.29	14.04	0.66	3.08
Mn	14.15	0.22	0.02	15.95	23.02	0.47	0.07
Mn/Fetot	3.88	0.40	0.01	0.98	1.64	0.72	0.02
NiCoCu	166	64	132	95	72	65	126
rock	Mn-ore	radio-larite	shale	Mn-ore	Mn-ore	radio-larite	shale

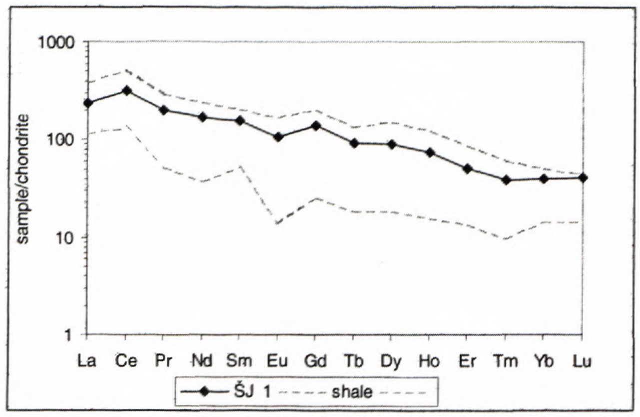

Fig. 16. Distribution of REE in sample ŠJ1. Field of manganese ores in Jurassic shale of the Western Carpathians is marked with dashed line.

Jastrabie. Their circulation facilitated tectonic contact of shale and radiolarite chert. Solutions could circulate from shale into sunken radiolarite chert close to the tectonic contact, where manganese hydroxides and oxides were formed.

The manganese mineralization in the radiolarite chert fills fissures along and across bedding and its origin is secondary. For this reason a dividing of radiolarite sequence to manganese radiolarite of the Sokolica Radiolarite Formation and to overlying radiolarite of the Czajakowa Radiolarite Formation by Birkenmajer (1977) is doubtful.

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Tourmaline-enriched horizons in the Lower Triassic quartzose sediments from the Tribeč Mts., Tatric Unit, Western Carpathians (Slovakia)

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Abstract. The tourmaline-rich laminae were found in the Lower Triassic Lúžna Fm. sediments of the Tatric Unit in the Tribeč Mts. Sedimentary features of the Lower Triassic sediments of the Tribeč Mts. Lúžná Fm. indicate the braided stream sedimentary model in semi-arid climatic conditions.

There were distinguished three varieties of tourmaline, two varieties of neomorphic tourmalines associated with clayey laminae, as well as clastic grains: 1. green/brown-green tourmaline with high degree of zonality, non-deformed by post-sedimentary tectonic deformation; 2. highly preferred aggregates of nearly unzonal green/green-bluish dravite-magnesiofoitite crystals, deformed by post-sedimentary foliation cleavage, together with primary clayey laminae; 3. well-rounded azonal clastic grains.

Chemical composition of the variety 1 tourmaline corresponds to alkali group with dravite-schorl-(foitite) end-member species. Generally, from the core toward to the rim is compositional zoning where Fe, Na, and Ti increase and Mg, Al decrease. Chemical composition of the variety 2 tourmaline corresponds generally to dravite species, rarely to magnesiofoitite. Mg^{2+} plays a dominant role at the Y-site occupancies in all the crystals. Slightly increasing of Mg/Fe ratio was found out within the scarce zonal tourmaline crystals of variety 2. Na is the dominant cation in the X-site on the both types of crystals and Ca, K concentration as well as Cr, Mn is very low or not detectable. Variety 3 tourmaline is compositionally monotonnous, corresponding to dravite species.

The following genesis for both neomorphic tourmaline varieties is supposed: A. variety 1: – fine-grained tourmaline detritus probably of several sources in the cores; – redistribution of boron as a result of post-depositional movement of boron-rich fluids in the rims; B. variety 2: – boron primarily attached to clay minerals and liberated during following process of diagenetic and low-grade metamorphic process. It is not excluded, that the primary clay laminae had been associated with presence of borates, genetically associated with small arid endorheic water reservoirs. C. variety 3: well-rounded clastic grains were derived from crystalline rocks complexes, mostly from mica schists and paragneisses coexisting with Al-saturating phase.

Key words: dravite, schorl, magnesiofoitite, Lower Triassic, quartzose sediments, Western Carpathians, braided alluvia

Introduction

Cropping out from the Tertiary sediments of the Danube Basin, the Tribeč Mts. represent the westernmost salient of the inner belt of the Western Carpathians Tatric Unit rock complexes. Generally, they consist of a crystalline core and their indigenous Late Paleozoic (mostly Permian) and Mesozoic envelope. The pre-Tertiary rock complexes of the Tribeč Mts. form a NE–SW striking horst divided by the Skýcov fault system into a northern Rázdiel part and a southern Zobor part (Fig. 1). Geological structure of the Tribeč Mts. comprises the crystalline basement of the Tatric and Veporic Unit and their Late Paleozoic-Mesozoic envelope sequences, the Late Paleozoic-Triassic assemblage of the Hronic Unit, as well as Tertiary and Quarternary sedimentary cover (Ivanička et al., 1998). The Tatricum crystalline rocks of the Zobor part are represented mainly by the granitoids of several petrographic types that make up a large, zonally structured Zobor pluton. The crystalline rocks of the Zobor part are direct unconformable overlapped by the Lower Triassic siliciclastic sequence. Generally, the Lower Triassic siliciclastic sequences were lithostratigraphically defined as the Lúžna Formation by Fejdiová (1980), formerly for the Tatric Unit, later also for the Fatric-Northern Veporic realm (Fejdiová, 1985; Vozárová and Fejdiová, 1996).

Lithological and depositional characteristics

The Lower Triassic of the Tribeč Mts. consists of sandstones (mainly coarse- to medium-grained) with intercalations of fine-grained conglomerates and inferior thin layers of silty/sandy shales. Generally, these sediments manifested their relatively high grade of structural and mineralogical maturity. In the Zobor part of the Tribeč Mts., as in prevalent part of the Tatric Unit, they occur in a new sedimentary cycle without direct connection to more polymictic (especially rich in feldspars) Permian deposits with synchronous acid volcanism. According to previous interpretation of Fejdiová (1980; 1985) sediments of the Lúžna Fm. correspond to marine litoral resp. barrier islands, deltas and shallow shelf depositional environment. Mišík & Jablonský (1978, 2000)

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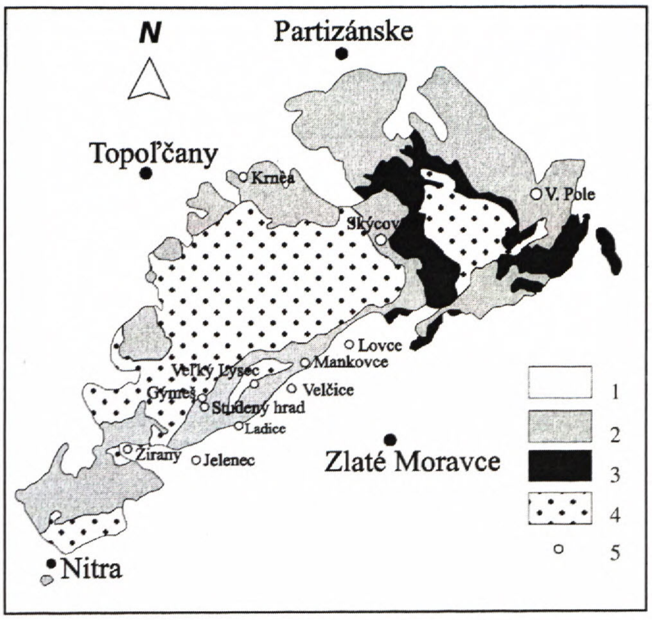

Fig. 1. Locations of investigated outcrops in the Tribeč Mts. Schematic geological map based on Ivanička et al (1998). Legend: 1 – Tertiary and Quarternary sediments; 2 – Mesozoic sedimentary rock complexes; 3 – Late Paleozoic sedimentary and volcanic rock complexes; 4 – Pre-Mesozoic crystalline rock complexes and magmatites; 5 – locations of investigated profiles of the Lower Triassic quartzose sediments.

interpreted the Lower Triassic of the Tatric Unit as continental sediments of ephemeral braided streams an a piedmont plain. Later, for the Lúžna Fm. sediments Fejdiová (in Ivanička et al., 1998) assumed a continental, fluvial sedimentary system. The eolian origin of the diagonal bedded sandstones from the Tribeč Mts. was postulated by Hók (1989). The braided stream depositional system is supposed for the Northern Veporic Lower Triassic sediments of the Čierťaž Mts. by Vozárová (2002).

The geometry of sedimentary bodies changes regionally and indicates the presence of laterally extensive drainage area. Single strata are very often lens- or wedge-shaped and tabular. The sedimentary complexes are represented predominantly by channel bars, consisting mostly of massive or horizontally bedded fine-grained conglomerates vertically replaced by coarse-grained sandstones with planar or trough cross-bedding (Fig. 2). In exposures sets of current bedding have apparent unimodal orientation (Pl. 1- Figs. 1, 2). Current planparallel horizontal lamination and cross-bedding is common in both type of these sediments. Contacts between individual bodies of channel bar sediments are often erosive, fringed with intraclasts of siltstones and claystones. The upper part of channel bars are represented by medium- to fine-grained sandstones, occasionally with ripple bedding (Pl.1- Fig. 3). The thickness of single channel sets is small, mostly not exceeding 2-2.5 m. These deposits correspond to migrating shallow channel bars in a river bed (longitudinal and transversal bars). Apart from these sediments, relics of channel fillings were identified. The filling consists of massive or horizontally bedded fine-grained conglomerates or coarse-grained sandstones with grain-supported structure. Transport directions derived from cross-bedding show a paleotransport from N. This data coincide well with those from the previous measurements of Hók (1989).

Sedimentary features of the Lower Triassic sediments of the Lúžná Fm. in the Tribeč Mts. indicate the braided stream sedimentary model in semi-arid climatic conditions. This sedimentary model is characterized by rivers with steep slope and relatively high speed of stream flow, that within a riverbed are split up into of shallow and broad channels, mutually divided by sandy or conglomerate accumulations and big floor dunes. The fluvial braidplain of ephemeral sandy-pebble streams was associated with intervals of strong aeolian activity. It was documented by occurrences of ventifacts (Pl. 1- Fig. 4) and layers of diagonally cross-bedded and structurally mature sandstones, with very good rounded grains.

Petrological characteristics

Conglomerates belong to oligomictic type, with absolute prevalence of quartz pebbles. Part of them have faceted clast shape (ventifact), attesting aeolian activity during the pauses of the stream transport (Mankovce; Pl. 1- Fig. 4). Quartz is dominant component among clasts: milky and pink varieties along with dark-pink, grey to black. It forms more than 90% of clasts, even in basal parts, while its concentration increases vertically and reaches more than 95% or up to 100% of all clasts. A substantial part of quartz pebbles is well roundned, suggesting mainly cyclic redeposition. However, entirely angular clasts of quartz occur too. Scarcely were identified pebbles of black tourmalinites and blastofelsitic acid volcanics. Besides them also clasts of graphitic metaquarzites were described by Mišík and Jablonský (2000) from Gýmeš.

Angular grains (4-5 mm in size) of pale-grey and beige K-feldspars represent a special detritic component in the basal conglomeratic layers of the Lower Triassic sequence. Intraclasts of violet, beige-red as well as green shales form a part of detritus, indicating processes of syndepositional erosion.

Sandstones predominantly belong to the group of quartzose arenites and subarcoses, with a high content of quartz grains (85–95 %), less K-feldspars (5–10%) and fragments of acid volcanites, clastic micas (muscovite and rarely secondary altered biotite) and heavy minerals. Small part of sandstones are compositionally with the affinity to sublitarenites, along with a relative higher felspars/acid volcanites ratio. Among heavy minerals were identified: zircon (2–30%), garnet (20–60%), ilmenite (7–18%), titanite (0–6%), rutile (1–5%), tourmaline (2–7%), magnetite (2–3), monazite-(Ce) (0.5–2.5%), rare epidote, goethite, anatase, allanite-(Ce) and gold (average of 3 analysis; bulk sample=15-20 kg).

Nearly all genetic types of quartz have been identified. Dominant are coarse-grained polycrystalline and monocrystalline as well as volcanogenic varieties, less occur fine-grained polycrystalline with preferred orientation and pressure-deformed cataclastic quartz grains. Occasionally, inclusions of muscovite, rarely rutile and

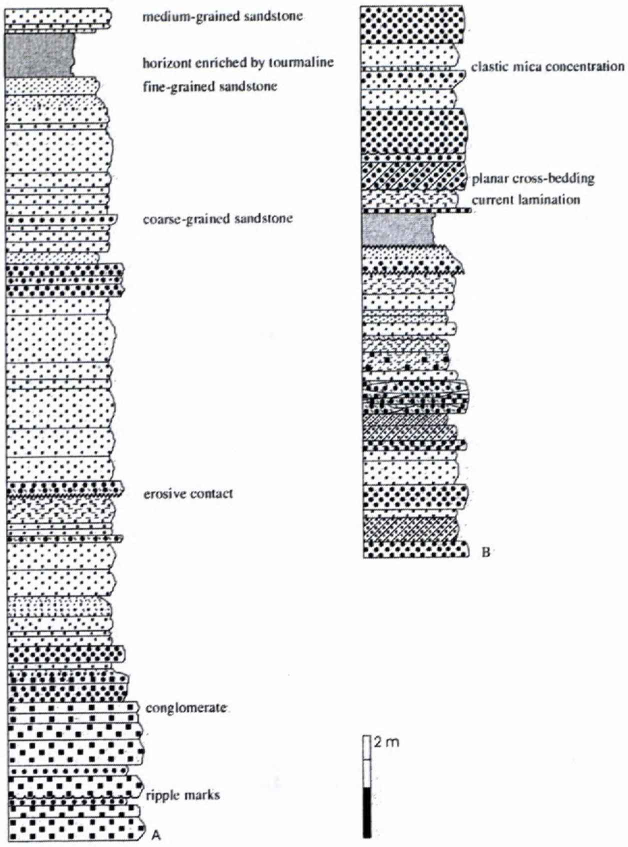

Fig. 2. Lithological log of Ladice (A) and Mankovce localities (B). Legend: 1 – conglomerate; 2 – coarse-grained sandstone; 3 – medium-grained sandstone; 4 – fine-grained sandstone; 5 – ripple marks; 6 – erosive contact; 7 – current lamination; 8 – planar cross-bedding; 9 – clastic mica concentration; 10 – horizons enriched by tourmaline.

zircon were detected in quartz grains. The surface of quartz grains is very often coated by Fe-oxides or very thin illite rim. Well roundned grains posses syntaxial quartz overgrowths (Pl. 1- Fig. 6).

Feldspars are almost exclusively orthoclase and more rarely microcline; perthite and plagioclase are very rare. K-feldspars are obviously clear, less of them cloudy due to different degree of kaolinization. They frequently preserved their tabular habitus as well as diagenetic syntaxial microcline overgrowths on older K-feldspars indented in quartz.

Besides of volcanic rocks small acid felsitic fragments with relics of spherulitic texture are common. They contain relics of beta-quartz type phenocrysts with magmatic corrosion.

The high grade of structural maturity is documented by a relatively low values of sorting, corresponding from well to moderate sorted sandstones (in the range of 0.35–0.7 *fí*, according to visual scale of Compton, 1962). The roudness of sandy grains reaches from 2.5 to 3.5 values, estimating subangular/subrounded and rounded grain shape (according to visual scale of Powers, 1953; Pl. 1- Fig. 6). Dominant are grains with spherical, subprismoidal and subdiscoidal shapes.

Primary clayey matrix is rare, only preserved as a recrystallized (quartzy-micaceous) partial filling of single pores. Very often are diagenetic coatings of micaceous or Fe-hydroxides minerals on the grain surfaces. Initially, clayey rim around quartz grains originated in the beginning of the early stage of diagenesis and it is older than the quartz cement that fills rest of pores between grains. The quartz cement occur in the forms of syntaxial cement or as a microcrystalline aggregate. Barite is very common among authigenic minerals in some localities.

The exceptionally phenomenon of the Lower Triassic sequence in the Tribeč Mts. are the tourmaline-bearing laminae. Besides of clastic tourmaline grains and tourmalinites clasts they were distinguished two type of neomorphic tourmalines: 1. green/brown-green tourmaline with high degree of zonality; single crystals have not been preferred oriented, but situated inside of primary clayey laminae; the individual crystals of tourmaline are not destructed by post-sedimentary tectonic deformation; 2. green/green-bluish tourmaline non-zonal, which forms high preferred aggregates of thin columnar crystals, parallel to sedimentary lamination; it is associated also with clayey laminae, but single crystals are deformed by post-sedimentary foliation cleavage together with primary clayey laminae (Pl. 1- Fig. 5). These two genetically different type of neomorphic tourmalines have also different chemical composition.

Chemical composition of tourmaline clasts as well as tourmaline crystals from clasts of tourmaline-rich rocks derived from the Lower Triassic sediments of the Tatric Unit was described by Uher (1999).

Analytical techniques

Electron microprobe analysis of tourmaline were performed on Cameca-SX 100 electron microprobe (operated with a beam current of 15 kV at 20 nA) at Slovak Geological Survey of Bratislava. The beam diameter is a 1-3 μm. The analytical data were reduced and corrected using the ZAF method. Anhydrous oxide and natural minerals were used as probe standards: wollastonite for Si Kα and Ca Kα , TiO_2 for Ti Kα, Al_2O_3 for Al Kα, hematite for Fe Kα, rhodonite for Mn Kα, MgO for Mg Kα, albite for Na Kα, orthoclase for K Kα, chromite for Cr Kα, BaF_2 for F Kα and NaCl for Cl Kα.

Characteristics of tourmaline

Based on available literature data (Henry and Guidotti, 1985; Hawthorne and Henry, 1999 and many others) tourmaline is shown to be a usefull petrogenetic indicator. Distinct composition field were defined within Al-Fe(tot)-Mg and Ca-Fe(tot)-Mg diagrams for tourmaline from three definied varieties. These tourmaline grains display three general styles of chemical zoning: 1. nearly/or lack of zoning; 2. core-to-rim zonation attributed to growth during progressive diagenesis and low-grade metamorphism; 3. detrital tourmaline grains non-zonal or sorrounded by a very thin metamorphic overgrowth.

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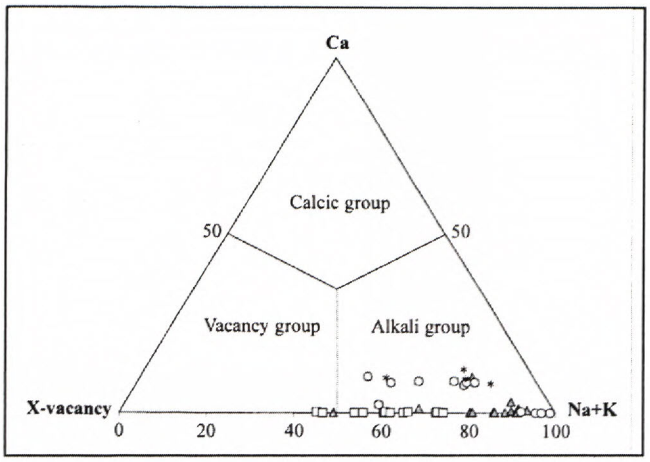

Fig. 3. Compositional diagram of tourmalines (after Hawthorne and Henry, 1999).
Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk.

All of the studied samples contain Si-, Al and Ti-saturating phases (quartz and muscovite, new-formed rutile respectively).

Variety 1: Tourmaline crystals have a distinct chemical and optical zonation. They are concentrate within white mica-rich laminae, but crystals have not preferential orientation and they are irregularly disseminated within the individual laminae. Optically strongly zoned tourmaline crystals coexist with less amount of optically unzoned tourmaline crystals. The colour change may be gradational or involve sharp optical discontinuities. Some tourmaline grains showing these optical discontinuities have irregular cores overgrown by euhedral rims, whereas others have both euhedral cores and rims. Well rounded detritic cores are very scarce.

Chemical composition of the variety 1 tourmaline grains corresponds to alkali group with dravite-schorl end-member species (Tab. 1, Fig. 3). Generally, from the core toward to the rim is compositional zoning such that Fe, Na, and Ti increase as Mg and slightly also Al decrease. Variation in tourmaline 1 rim and core composition is more evident in changes of Fe/(Fe+Mg) ratios, ranging from 0.12 to 0.74. Among the tourmaline 1 crystals were observed slight compositional differences.The main differences are in X-site vacancies. Within the 1a subvariety Na is the dominant cation in the X-site (0.51-0.77 apfu for core, 0.90-0.96 apfu for rim) and Ca concentrations are generally low-lying (up to 0.10 apfu), but with decreasing trend at the X-site to the rim (Fig. 4). K is near detection limit of microprobe. Mn, Cr are also present in limited quantities. The W-site is occupied by mainly OH^{1-}, in small quantities substituted by F^{1-}. This tourmaline subvariety shows a relative strong decreasing in Al and Mg towards the rim (core: Fe/(Fe+Mg)=0.32-0.42, Al=5.80-6.00; rim: Fe/(Fe+Mg) =0.74-0.79, Al= 5.22-5.31). This trend is confirmed by the strong decreasing of alkali-defect substitution to the rim (Fig. 5). Generally, the 1b subvariety tourmalines show core-rim variability only in Fe-Mg compositionally zoning with distinct Mg decreasing to the rim (core to rim: Fe/ (Fe+Mg)=0.12 to 0.70, sample t1, Fig. 4, 5, 6, 7). Substitution in 1b tourmaline can take place as homovalent cation exchanges on the Y-site (Fe^{2+} for Mg^{2+}).

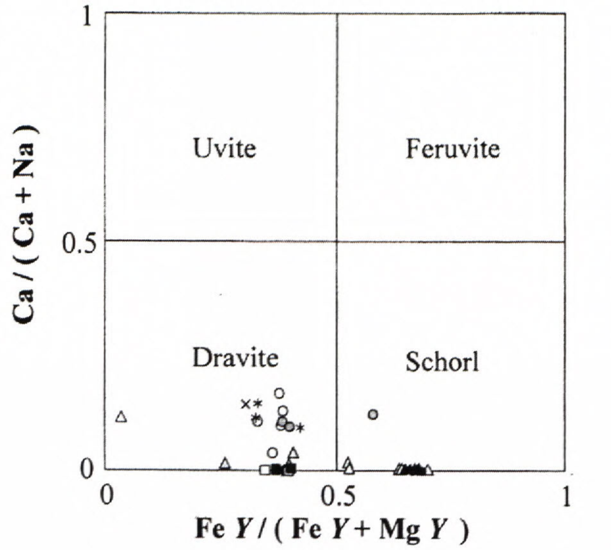

Fig. 4. Ca/(Ca+Na) vs. Fe/(Fe+Mg) diagram (atomic proportions) of varieties 1, 2 and 3 tourmalines.
Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk; core – rim = white - black.

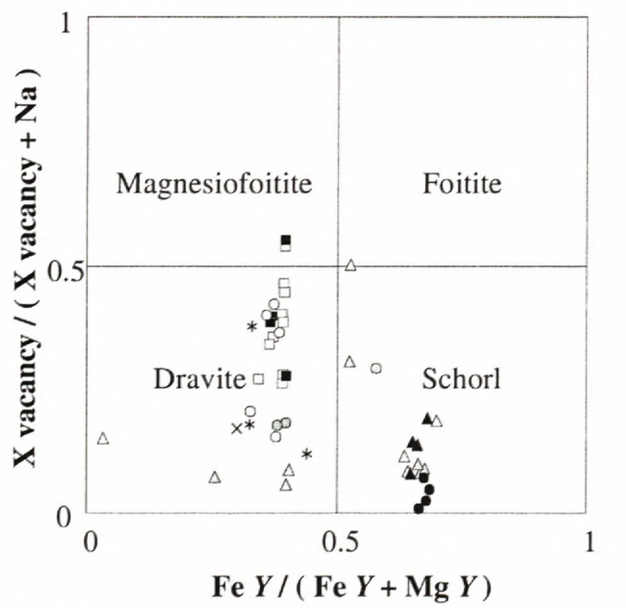

Fig. 5. X vacancy/(X vacancy+Na) vs. Fe/(Fe+Mg) diagram (atomic proportions) of varieties 1, 2 and 3 tourmalines. Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk; core – rim = white - black.

Variety 2: Tourmaline is found as an euhedral, thin-columnar crystals, that are disseminated in a white mica-rich thin layers. Tourmaline crystals are distinct preferential oriented, parallel to crystallization schistosity and deformed by crenulation cleavage (Pl. 1- Fig. 5). They form laminae up to 5 mm thick. These textural relations suggest that there have been some overgrowths on pre-existing boron-rich sedimentary laminae as well as nucleation

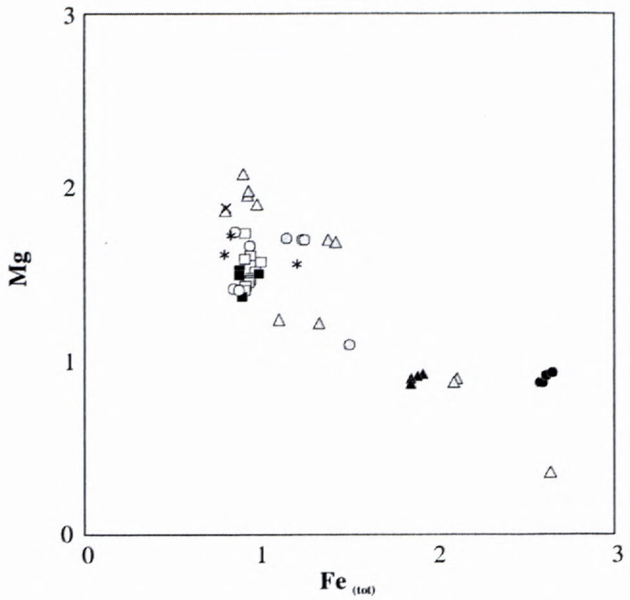

Fig. 6. Mg vs. Fe diagram (atomic proportions) of varieties 1, 2 and 3 tourmalines. Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk; core – rim = white - black.

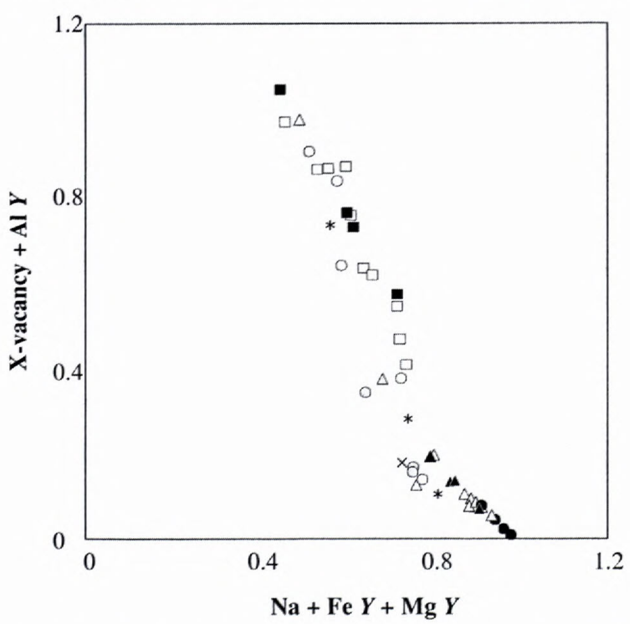

Fig. 7. X vacancy+^{Y}Al vs. ^{X}Na+^{Y}(Fe +Mg) diagram (atomic proportion) of varieties 1, 2 and 3 tourmalines. Legend: variety 1, subvariety b – triangle, variety 2 – square, variety 3 – asterisk, core – rim = white - black..

and growth of new tourmaline during process of authigenesis and following metamorphism.

Chemical composition of the variety 2 tourmaline corresponds generally to dravite (Figs. 3). Looking at the occupancies of Y-site, Mg^{2+} plays a dominant role in all the samples (Mg=1.37-1.73 apfu.). Mg/Fe ratio varies in of 1.55-1.90 (mean 1.67; n=6) in the unzonal tourmaline crystals. Representative microprobe analyses of the variety 2 are presented in Table 2.

Slightly increasing of Mg/Fe ratio was found out within the scarce zonal tourmaline crystals: ***core*** (range 1.53-1.56; mean 1.55; n=4), ***rim*** (range 1.52-1.72; mean 1.62; n=4). Na is the dominant cation in the X-site on the variety 2 tourmalines and Ca concentration is very low or not detectable (Fig. 4). Substitution in variety 2 tourmaline is heterovalent, coupled substitutions Mg-Fe in Y-site and alkali-defect substitution in X-site (Fig. 5, 6, 7). Some variety 2 tourmaline crystals have the end-member composition of magnesiofoitite. The end-member composition of magnesiofoitite was given with a variable cation occupancy at Y-site: Y-site is occupied by [Mg_2Al] (MacDonald et al. 1993; Hawthorne and Henry, 1999).

Variety 3: It is represented by clastic tourmaline grains within heavy mineral fraction. They are very good rounded, optical unzoned and/or with very thin metamorphic overgrowths on their surface. Compositionally are monotonnous, corresponding to dravite species with Fe/(Fe+Mg) in the range of 0.33-0.44, Al=5.91-6.00 and dominant Na on Y-site, with minor or not detectable amount of Ca and K (Tab. 2).

Discussion

Looking on the discrimination diagrams Al-Fe(tot)-Mg and Ca-Fe(tot)-Mg (Figs. 8, 9, 10, 11) of Henry and Guidotti (1985) two distinct core-rim trends can be recognized within the tourmaline of variety 1 (Figs. 8, 9). These zoned tourmalines have a complex history. They are differences in core and in rim compositions between subvarieties 1a and 1b. Samples nt 2 and nt 5 show distinct core-rim decreasing trend of Mg and Al, which indicates substitutions Mg-Fe in Y-site (Fig. 6, 10) and Na for vacancy in X-site (Fig. 5). The data of sample t1, within 1b tourmaline (Fig. 9) cluster along a line of nearly constant Al content and slightly Fe^{3+}- rich correlating with field (6). On the other hand, sample nt 2, nt 3 cores signalize increasing alkali-defect substitution, corresponding to the coexistence with Al-saturating phase (Fig. 8). As evidenced by the large variability of composition, both type of cores show considerably more compositional variation than corresponding rim composition. Instead of this, the tourmaline rims from both samples are compositionally equal. They are in chemical equilibrium with the matrix phases, which correspond to P-T condition of metamorphism. According to Henry and Guidotti (1985) discrimination diagrams (Fig. 10, 11) the core-rim compositions correspond from coexisting and/or not-coexisting Al-saturating phase to tourmaline from Li-poor granitoids and their associated pegmatites and aplites. A slight variability of core-Ca content between subvariety 1a and 1b can be caused by differences in primary matrix material (alternating of Ca enriched and Ca poor laminae of pelite). Different core-rim composition in variety 1 tourmalines is most probably effect of different source of boron: 1. fine-grained tourmaline detritus probably of several sources in the cores; 2. redistribution of boron as a result of post-sedimentary and pos-deformational movement of boron-rich fluids in the rims.

Tab.1. Representative microprobe analyses of variety 1a, b tourmalines from the Lower Triassic quartzites of Tribeč Mts.
** - B_2O_3 and H_2O contents of the minerals calculated by ideal stoichiometry (3 boron cations and OH+F+Cl = 4 anions). n.d. - non-detectable.*

	variety 1a						variety 1b					
sample	nt1a	nt1b	nt1c	nt5a	nt5b	nt5c	t1a	t1b	t1c	t1d	t1e	t1f
position	core	zone 1	rim	core	zone 1	rim	core	zone 1	zone 2	zone 3	zone 4	rim
SiO_2	36.83	36.47	35.32	37.96	36.59	35.39	38.29	36.71	37.11	36.64	35.99	36.35
TiO_2	1.19	1.24	1.18	0.06	0.50	1.39	0.90	0.68	0.36	0.06	1.13	1.20
Al_2O_3	29.98	29.72	25.77	32.98	30.73	25.92	30.49	29.37	29.56	29.12	28.64	29.19
B_2O_3 *	10.58	10.49	9.99	10.81	10.53	10.03	10.90	10.48	10.51	10.38	10.24	10.32
Cr_2O_3	0.01	0.02	0.02	0.00	0.04	0.01	0.00	0.02	0.03	0.05	0.01	0.01
MgO	6.92	6.84	3.51	6.89	6.90	3.38	11.05	6.83	7.99	6.74	3.44	3.61
FeO	8.98	8.96	17.93	6.95	8.45	17.74	2.75	9.93	7.69	10.20	14.65	13.34
CaO	0.49	0.48	0.02	0.13	0.45	0.00	0.57	0.05	0.06	0.17	0.00	0.01
MnO	0.03	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.03	0.03
Na_2O	2.42	2.34	2.68	1.88	2.34	2.86	2.55	2.89	2.83	2.73	2.72	2.76
K_2O	0.01	0.01	0.07	0.00	0.00	0.04	0.01	0.01	0.02	0.01	0.07	0.06
H_2O *	3.57	3.56	3.43	3.73	3.59	3.40	3.76	2.80	2.93	2.70	2.35	2.46
F	0.17	0.11	0.04	0.00	0.09	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CL	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
O=F	-0.07	-0.05	-0.02	0.00	-0.04	-0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
O=Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	101.10	100.20	99.95	101.38	100.17	100.29	101.27	99.98	99.11	99.88	99.27	99.34
Formulae based on the 31 anions												
Si	6.048	6.044	6.142	6.104	6.041	6.131	6.107	6.087	6.134	6.103	6.106	6.125
Al T	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total T	6.048	6.044	6.142	6.104	6.041	6.131	6.107	6.087	6.134	6.103	6.106	6.125
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al Z	5.803	5.804	5.282	6.000	5.979	5.292	5.731	5.740	5.759	5.716	5.726	5.797
Fe Z	0.197	0.196	0.718	0.000	0.021	0.708	0.269	0.260	0.241	0.284	0.274	0.203
Total Z	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Ti Y	0.147	0.155	0.154	0.007	0.062	0.181	0.108	0.085	0.044	0.071	0.144	0.152
Al Y	0.000	0.000	0.000	0.254	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.001	0.002	0.002	0.000	0.005	0.002	0.000	0.003	0.004	0.007	0.002	0.001
Fe Y	1.036	1.046	1.890	0.935	1.146	1.862	0.097	1.117	0.822	1.137	1.804	1.677
Mn	0.004	0.000	0.000	0.000	0.000	0.007	0.000	0.002	0.001	0.000	0.004	0.004
Mg	1.694	1.690	0.911	1.652	1.697	0.872	2.627	1.689	1.969	1.675	0.870	0.908
Total Y	2.882	2.893	2.957	2.848	2.910	2.924	2.832	2.896	2.840	2.890	2.824	2.742
Ca	0.086	0.085	0.004	0.023	0.079	0.000	0.097	0.008	0.010	0.031	0.000	0.002
Na	0.772	0.751	0.903	0.585	0.750	0.961	0.760	0.930	0.907	0.881	0.896	0.900
K	0.001	0.002	0.016	0.000	0.001	0.009	0.003	0.003	0.005	0.002	0.015	0.014
Total X	0.859	0.838	0.923	0.608	0.830	0.970	0.860	0.941	0.922	0.914	0.911	0.916
X - vacancy	0.141	0.162	0.077	0.392	0.170	0.030	0.140	0.059	0.078	0.086	0.089	0.084
OH	3.913	3.944	3.979	4.000	3.952	3.928	4.000	3.999	3.997	4.000	4.000	4.000
F	0.087	0.059	0.023	0.000	0.048	0.073	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cl	0.000	0.003	0.002	0.000	0.000	0.001	0.000	0.001	0.003	0.000	0.000	0.000
Total V+W	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Fe/Fe+Mg	0.421	0.424	0.741	0.361	0.407	0.747	0.122	0.449	0.351	0.459	0.705	0.674

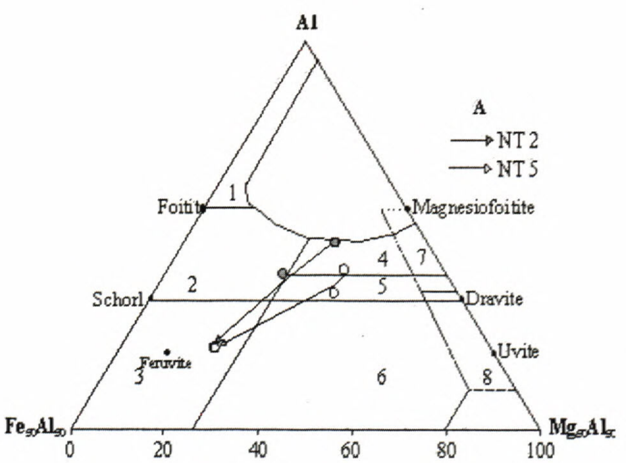

Fig. 8. Trend of zoning in the tourmaline of subvariety 1a. Arrows show changes from core to rim. Fields after Henry and Guidotti (1985): 1. Li-rich granitoid pegmatites and aplites; 2. Li-poor granitoids and their associated pegmatites and aplites; 3. Fe^{3+}-rich quartz-tourmaline rocks (hydrotermally altered granites); 4. Metapelites and metapsamites coexisting with an Al-saturating phase; 5. Metapelites and metapsamites not coexisting with Al-saturating phase; 6. Fe^{3+}-rich quartz-tourmaline rocks, calc-silicate rocks and metapelites; 7. Low-Ca metaultramafics and Cr, V-rich metasediments; 8. meta-carbonates and meta-pyroxenites. Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk.

*Tab. 2. Representative microprobe analyses of variety 2 and 3 tourmalines from the Lower Triassic quartzites of Tribeč Mts. * - B_2O_3 and H_2O contents of the minerals calculated by ideal stoichiometry (3 boron cations and OH+F+Cl = 4 anions).*

	variety 2				variety 3	
sample	JS1a	JS1b	JS3a	JS3b	tk3a	tk3b
position	core	rim	core	rim	core	rim
SiO_2	37.49	37.64	37.54	37.67	36.88	37.37
TiO_2	0.16	0.17	0.34	0.44	0.73	0.77
Al_2O_3	33.43	34.02	32.83	33.54	30.41	31.62
B_2O_3 *	10.64	10.72	10.72	10.77	10.52	10.74
Cr_2O_3	0.00	0.00	0.02	0.00	0.06	0.04
MgO	5.75	5.66	6.23	6.21	6.28	7.74
FeO	6.70	6.63	7.12	6.49	8.73	5.97
CaO	0.00	0.01	0.00	0.01	0.46	0.70
MnO	0.00	0.00	0.00	0.00	0.04	0.00
Na_2O	1.45	1.42	2.27	1.92	2.52	2.31
K_2O	0.03	0.04	0.06	0.05	0.02	0.03
H_2O *	3.63	3.61	3.56	3.66	2.90	3.26
F	0.08	0.19	0.28	0.13	n.d.	n.d.
CL	0.01	0.00	0.01	0.01	0.00	0.00
O=F	-0.03	-0.08	-0.12	-0.05	n.d.	n.d.
O=Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.34	100.03	100.86	100.84	99.55	100.55
Formulae based on the 31 anions						
Si	6.126	6.104	6.086	6.076	6.092	6.048
Al T	0.000	0.000	0.000	0.000	0.000	0.000
Total T	6.126	6.104	6.086	6.076	6.092	6.048
B	3.000	3.000	3.000	3.000	3.000	3.000
Al Z	6.000	6.000	5.914	5.924	5.920	6.000
Fe Z	0.000	0.000	0.000	0.000	0.080	0.000
Total Z	6.000	6.000	6.000	6.000	6.000	6.000
Ti Y	0.020	0.021	0.041	0.053	0.090	0.094
Al Y	0.438	0.502	0.359	0.452	0.000	0.031
Cr	0.000	0.000	0.002	0.000	0.008	0.005
Fe Y	0.916	0.899	0.965	0.876	1.125	0.809
Mn	0.000	0.001	0.000	0.000	0.005	0.000
Mg	1.401	1.369	1.506	1.493	1.547	1.868
Total Y	2.775	2.792	2.873	2.874	2.775	2.807
Ca	0.000	0.002	0.001	0.002	0.082	0.121
Na	0.460	0.446	0.714	0.599	0.806	0.724
K	0.007	0.008	0.012	0.011	0.004	0.007
Total X	0.467	0.456	0.727	0.612	0.892	0.852
X - vacancy	0.533	0.544	0.273	0.388	0.108	0.148
OH	3.959	3.901	3.860	3.939	4.000	3.999
F	0.043	0.099	0.143	0.064	n.d.	n.d.
Cl	0.002	0.000	0.003	0.003	0.000	0.001
Total V+W	4.000	4.000	4.000	4.000	4.000	4.000
Fe/Fe+Mg	0.395	0.396	0.391	0.370	0.438	0.302

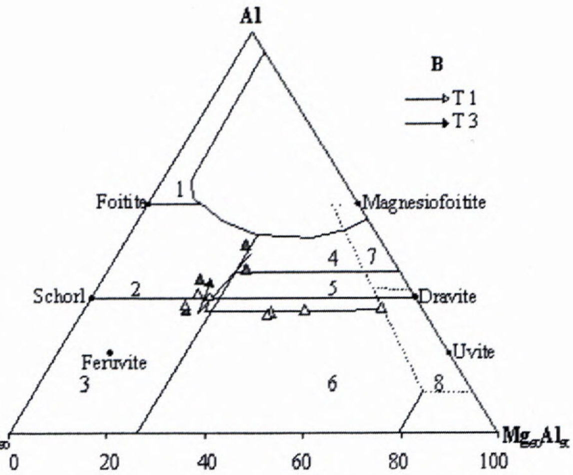

Fig. 9. Trend of zoning in the tourmaline of subvariety 1b. Arrows show changes from core to rim. Explanations as Fig. 8.

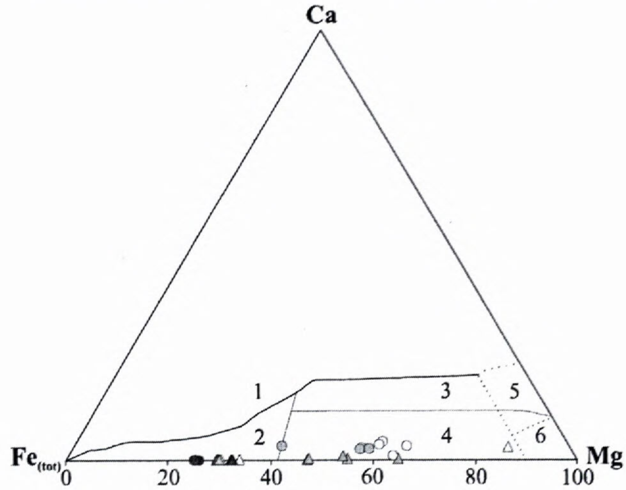

Fig. 10. Ca-Fe(tot)-Mg diagram (atomic proportions) tourmaline subvarieties 1a and 1b (core – rim = white – black). Fields after Henry and Guidotti (1985)): (1) Li-rich granitoid pegmatites and aplites; (2) Li-poor granitoids and associated pegmatites and aplites; (3) Ca-rich metapelites, metapsammites, and calc-silicate rocks; (4) Ca-poor metapelites, metapsammites, and quartz-tourmaline rocks; (5) Metacarbonates; (6) Metaultramafics. Legend: variety 1, subvariety a – circle; variety 1, subvariety b – triangle; variety 2 – square; variety 3 – asterisk; (+ - overgrowth on the clastic grain).

Comparing to the above mentioned, the tourmaline of variety 2 shows a relatively homogenous chemical composition (Figs. 4, 5, 12, 13), with high Mg/Fe ratios and negligible Ca content but relatively higher Al concentrations. This variety is corresponding to dravite species, rarely to magnesiofoitite. Dominant is alkali-vacant substitution in X-site (Fig. 5, 7). It corresponds to tourmaline associated with the compositional range of metapelites and metapsamites coexisting with an Al-saturating phase (Fig. 12, 13). The tourmaline-muscovite laminae indicates the primary clay-rich environment enriched in boron. The boron apparently was in solution within small areas of endorheic lake water in the semi-arid braided alluvial plain. It was held by adsorption onto the surface of clay minerals (substitution for silicon in the tetrahedral sites of the clay minerals). During prograding diagenetic process, the boron was released from the clays and made available to interstical fluids to react with the coexisting alumosilicate minerals in the sediments to form authigenic tourmaline. Further increase in temperature, causing boron releasing and forming of additional tourmaline zone on the preexisting core. The slight compositionally changes show minimal core-rim increasing in Al and Fe. Tourmaline of dravite composition, with most notable compositionally Fe-Al variations and less X-site vacancy was described from the cap rock of a salt dome (Gulf of Mexico) by Henry et al. (1999).

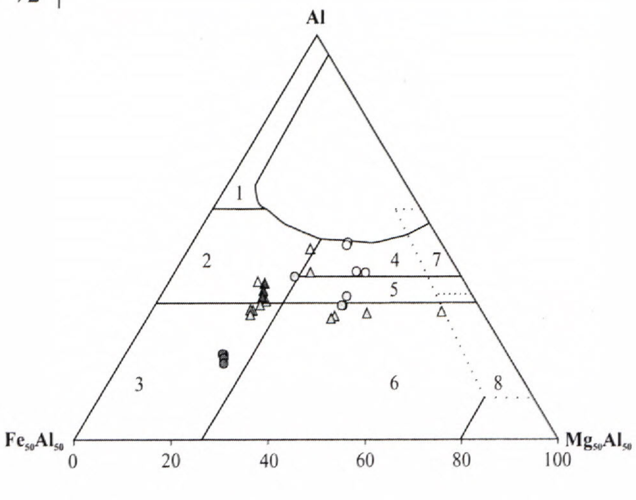

Fig. 11. Al-Fe(tot)-Mg diagram (atomic proportion) tourmaline subvarieties 1a and 1b (core–rim = white–black).
Explanations and symbols as Fig. 8 (× - overgrowth on the clastic grain).

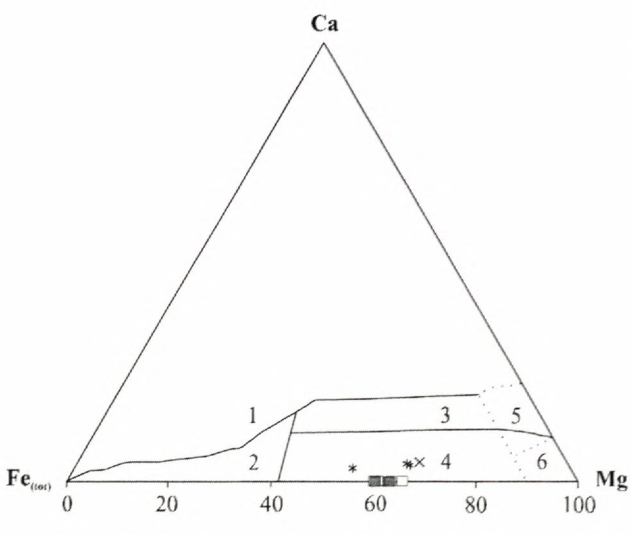

Fig. 12. Ca-Fe(tot)-Mg diagram (atomic proportions) tourmaline varieties 2 and 3 (core – rim = white – black).
Explanations and symbols as Fig. 10.

It could be also expected, that fluviatile concentration of water in separated small endorheic basins was associated with a strong evaporation during an arid climatic event. In this specific conditions the clays could have beeen altered in a concentrating brines. Boron was primarily attached to clay minerals and was liberated during following process of decomposition in concentrating brines. When the clays are altered in hypersaline bitterns to mixed-layer varieties rich in Mg, the original lattices are destroyed and boron is liberated (Sonnenfeld, 1984). The liberated boron could form also an independent laminae of primary borates associated with clay lamination. If this expectation is valid, then the genesis of the tourmaline laminae could be associated with primary borate-clay laminae.

Tourmaline of variety 3 is represented by very often clastic dravite grains. Compositionally has proximity to variety 2 but is more variably in Ca content. The variety 3 mainly correspond to tourmaline derived from metapelites and metapsamites with Al-saturating phase. Since the grains are non-zonal, the source area could be in crystalline rock complexes (mica schist/paragneisses terrane).

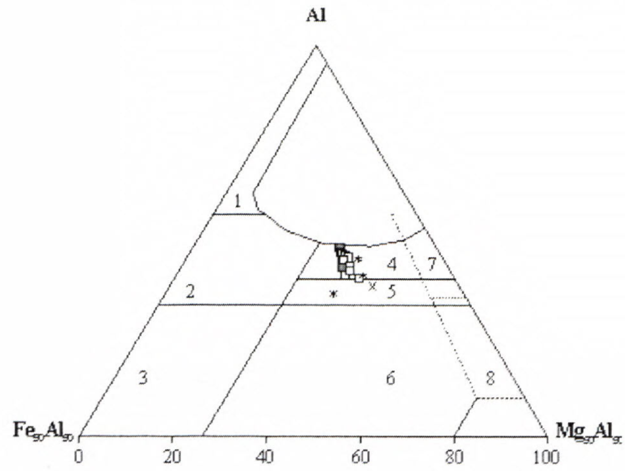

Fig. 13. Al-Fe(tot)-Mg diagram (atomic proportion) tourmaline varieties 2 and 3 (core–rim = white–black).
Explanations and symbols as Fig. 8 (× - overgrowth on the clastic grain).

Conclusions

The tourmaline-rich laminae were found in the Lower Triassic Lúžna Fm. sediments of the Tatric Unit in the Tribeč Mts. Sedimentary features of the Lower Triassic sediments of the Lúžna Fm. in the Tribeč Mts. indicate the braided stream sedimentary model in semi-arid climatic conditions. The fluvial braidplain of ephemeral sandy-pebble streams was associated with intervals of aridity with a strong aeolian activity.

There were distinguished three type, from which two varieties belong to neomorphic tourmaline: *variety 1:* green/brown-green tourmaline with high degree of zonality, associated with primary clayey laminae and non-deformed by post-sedimentary tectonic deformation; *variety 2:* high preferred agregates of nearly non-zonal green/green-bluish tourmaline crystals, deformed by post-sedimentary foliation cleavage together with primary clayey laminae; *variety 3:* well-rounded clastic dravite grains. These two genetically different type of neomorphic tourmaline have also different chemical composition.

Chemical composition of the variety 1 tourmaline corresponds to alkali group with dravite-schorl-(foitite) end-member species. Generally, from the core toward to the rim is compositional zoning such that Fe, Na, and Ti increase as Mg and slightly also Al decrease. This is signalizing substitutions Mg-Fe in Y-site and Na in X-site vacancy. Chemical composition of the variety 2 tourmaline corresponds generally to dravite, rarely to magnesiofoitite. Mg^{2+} plays a dominant role at the Y-site occupancies in all the samples. Slightly increasing of Mg/Fe ratio was found out within the scarce zonal tourmaline crystals of variety 2. Dominant is alkali-vacant substitution in X-site.

Na is the dominant cation in the X-site on the both types and Ca, K concentration as well as Cr, Mn is very low or not detectable.

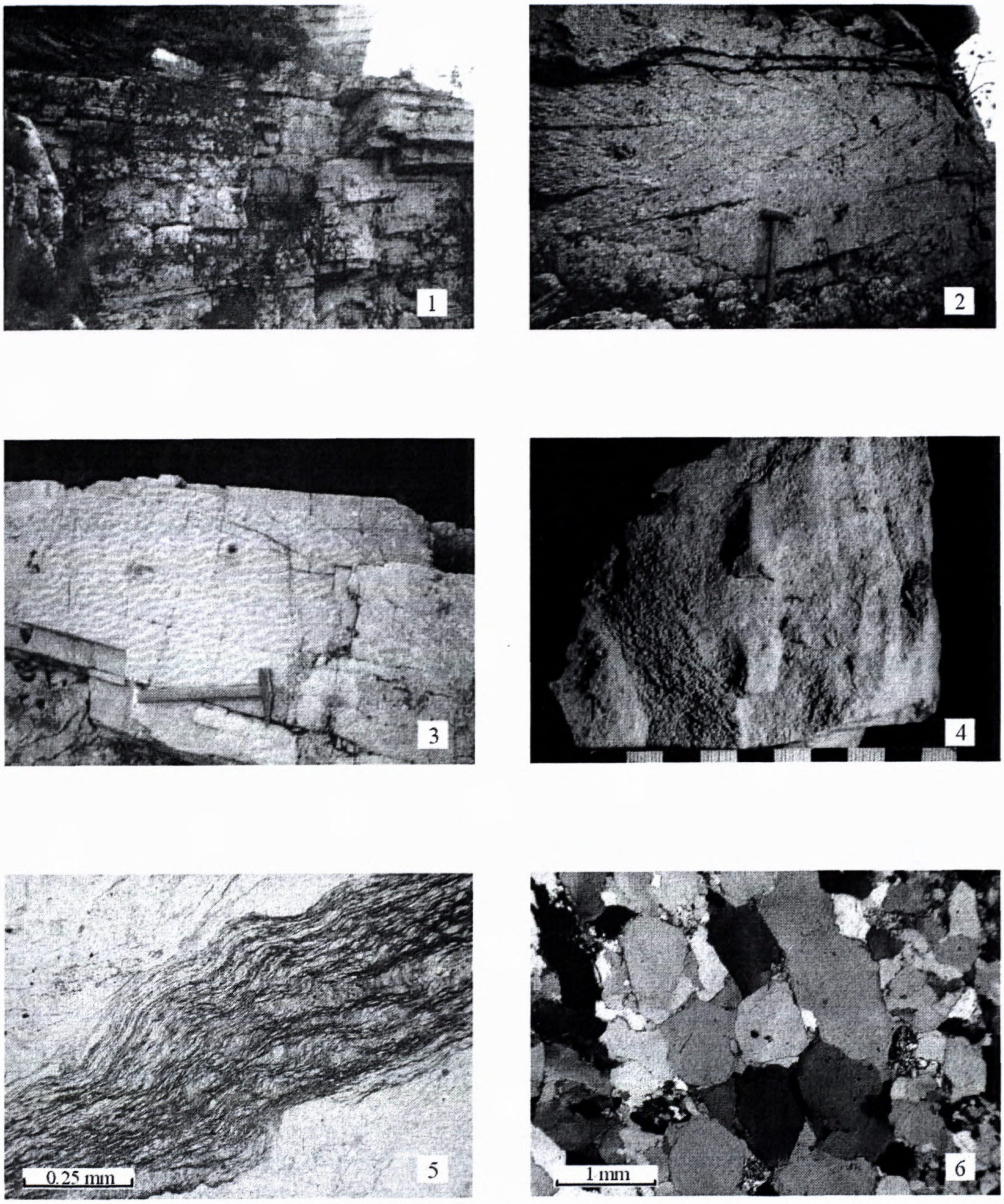

Plate 1.

Fig. 1. Planar angular cross-bedding (Studený vrch), Fig. 2. Planar tangential cross-bedding (Studený vrch), Fig. 3. Asymetric ripple marks on the bedding surface (Mankovce), Fig. 4. Faceted clast (venticlasts) indicates aeolian activity during the pauses of stream transport (Mankovce), Fig. 5. Laminae of tourmaline variety 2, Fig. 6. Well-rounded clastic quartz grains with syntaxial cement. X pollars

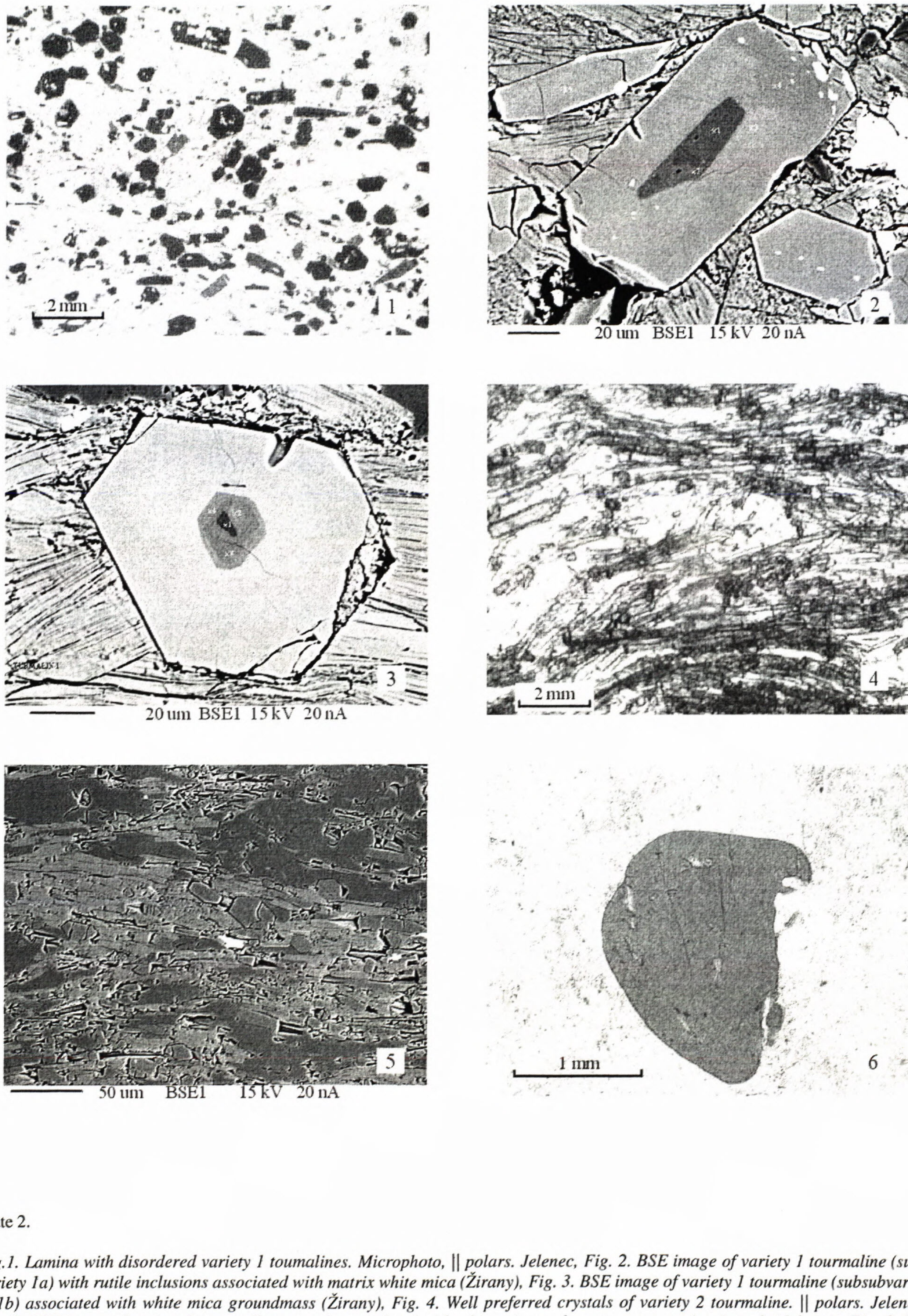

Plate 2.

Fig. 1. Lamina with disordered variety 1 toumalines. Microphoto, || polars. Jelenec, Fig. 2. BSE image of variety 1 tourmaline (subvariety 1a) with rutile inclusions associated with matrix white mica (Žirany), Fig. 3. BSE image of variety 1 tourmaline (subsubvariety 1b) associated with white mica groundmass (Žirany), Fig. 4. Well preferred crystals of variety 2 tourmaline. || polars. Jelenec, Fig. 5. BSE image of variety 2 tourmaline crystals associated with white mica and quartz as a matrix minerals (Jelenec), Fig. 6. Optical microphoto showing well rounded clastic grain of variety 3 tourmaline. || polars. Mankovce.

The following genesis for the both neomorphic tourmaline varieties is supposed: A. variety 1: - fine-grained tourmaline detritus probably of several sources in the cores; - redistribution of boron as a result of post-depositional movement of boron-rich fluids in the rims; B. variety 2: - boron primarily attached to clay minerals and liberated during following process of diagenetic and low-grade metamorphic process. It is not excluded, that the primary clay laminae had been associated with presence of borates, genetically associated with small arid endorheic water reservoirs.

Clastic grains of the variety 3 tourmaline represent dravite, derived probably from crystalline rocks complexes, mostly from mica schists and paragneisses coexisting with Al-saturating phase.

Acknowledgements

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Appendix

List of investigated localities:

Gýmeš	– natural outcrop; fine-grained oligomictic conglomerates; tourmaline: variety 3;
Jelenec	– abandoned quarry; cyclical quartzose sediments consist of coarse- to fine-grained sandstones, with less thin intercalations of fine-grained conglomerates in the basal part and siltstones and pelites in the upper part of the sequence; tourmaline: variety 1, 2 and 3;
Krnča	– quarry; cyclical quartzose sediments consist of coarse- to fine-grained sandstones, with less thin intercalations of fine-grained conglomerates in the basal part and siltstones and pelites in the upper part of the sequence; tourmaline: variety 1 and 3;
Ladice	– abandoned quarry; cyclical quartzose sediments consist of coarse- to fine-grained sandstones, with less thin intercalations of fine-grained conglomerates in the basal part and siltstones and pelites in the upper part of the sequence; tourmaline: variety 1 and 3;
Mankovce	– abandoned quarry; cyclical quartzose sediments consist of coarse- to fine-grained sandstones, with less thin intercalations of fine-grained conglomerates in the basal part and siltstones and pelites in the upper part of the sequence; tourmaline: variety 1 and 3;
Skýcov	– nature outcrop; cyclical alternation of fine-grained oligomictic conglomerates and coarse-grained quartzose sandstones; tourmaline: variety 3;
Studený hrad	– natural outcrop; coarse-grained quartzose sandstones; tourmaline: variety 3;
Veľký Lysec	– natural outcrop; coarse- to medium-grained quartzose sandstones; tourmaline: variety 3;
Velčice	– small quarry; medium-grained quartzose sandstones; tourmaline: variety 3;
Velčice	– large quarry; alternation medium- to fine grained quartzose sandstones; tourmaline: variety 1 and 3;
Žirany	– abandoned quarry; cyclical quartzose sediments consist of coarse- to fine-grained sandstones, with less thin intercalations of fine-grained conglomerates in the basal part and siltstones and pelites in the upper part of the sequence; tourmaline: variety 1 and 3.

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Relation of geological setting, soil-gas and indoor radon concentrations

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Abstract. Comparison of the results of soil-gas and indoor radon observations clearly show their dependence on geological-tectonic setting of the observation site. The paper presented deals with relations between the soil-gas and indoor radon concentrations and geological structure. It is evident that neotectonic faults are ideal pathways for movement and rising up radon emanations to the surface and, thus, to the dwellings. There, in case of permanent presence of high levels of the radon and its daughters´decay products may cause lung cancer of an inhabitants. The several cases abroad and in Slovakia are demonstrated.

Key words: geology, soil-gas, indoor, radon, concentrations

Introduction

The radioactive gas radon (^{222}Rn) and its daughters´decay products (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po and ^{210}Pb) represent 47 % of mean annual effective dose equivalent of radioactive irradiation of human being (UN, 1988). The ^{222}Rn is product of radioactive decay of ^{226}Ra. The source of the radon is uranium mineralisation in acide rocks-granites with pegmatite veins, acide volcanites-rhyolites, rhyodacites, dacites and their pyroclastics.

Due to its properties, the radon and its daughters´products may penetrate through geological medium from relatively great depths and on long distances from the source.

It is known from medical researches that high and long-term radon doses in dwellings have an impact on the excess incidence of lung cancer of their inhabitants. That is why radon problematics is widely studied all over the world.

Because indoor concentrations are dependent on the strength of the radon emanations source in geological basement, it is important to know the areas with the highest radon concentrations in soil gas, that is, those that have the potential for providing the greatest indoor radon concentrations that contribute directly to individual exposure. The geological data have to be used to estimate the relative emanation source strength, because soil types derived from underlying bedrock are a function of rock type and weathering. Follow-up soil-gas radon measurements provide a functional identity of the availability of radon and radon-movement potential. Both-geologic and soil-gas radon survey assessment-defines then areal boundary of the potential source of radon emanation. In simplest term, both the physical and chemical constitutions of the soil are important factors controlling local radon concentration. These parameters affect soil moisture, radium concentration, emanation and mobility.

The mobility is governed by permeability and the strength of the driving force, whether it is forced by flow or diffusion (Reimer, 1991).

Some case histories on geology-radon problem

Radon mapping in Luxembourg

The measurements of indoor concentrations in Luxembourg made before 1990 showed numerous dwillings with high values of „equivalent volume radon activity (EVRA)“, especially in the North. In order to detect houses with high radon levels, a campaign with long exposure-time solid state detectors started in 1990 and is still going on (Kies et al., 1994). About 110 800 houses were observed.

Despite of small surface of Grand-Duchy of Luxembourg, a great regional variability of indoor radon concentrations is noticed. The Eislek area in the North shows EVRA values substantially higher than in Gudland, in southern part of country. The reason of it is different geological structure of both regions. The Gudland is built by Mesozoic sequences with a thickness of some 1400 m which outcrop over 65 % of the country. Triassic and Lower to Middle Jurassic outcrop extensively where Tertiary has only small representations.

To the North the Eislek is a region of highly disturbed Paleozoic with extensive plateaus and deep, narrow valleys where metamorphic rocks of Eodevonian age are exposed. The Eislek is highly folded. In most lithologies rocks cleavage is developed. The faults are abundant here.

The results of 3-months indoor radon observations reflect different geological structure of both, Gudland and Eislek units. Gudland is characteristic by low radon levels (geometric mean 57 $Bq.m^{-3}$), while Eislek is typical by high levels (geometric mean 145 $Bq.m^{-3}$).

Percentage of houses with radon-gas concentrations above a fixed level is shown in Table 1.

These data show that the most important factor is the rock underlying the house. The local variability of indoor radon levels will be more detailed after survey based on radon-soil and soil gas permeability observations that are performed at present.

Table 1. Results of indoor radon observations in Grand-Duchy of Luxembourg.

Region	Number of houses	% of houses	% of houses >150 $Bq.m^{-3}$	% of houses >400 $Bq.m^{-3}$*	% of houses >800 $Bq.m^{-3}$
Luxembourg	110 800	100.0	16.2	3.7	0.8
Gudland	99 600	90.0	6.3	0.7	0.1
Eislek	11 200	10.0	40.1	10.7	2.5

*limit of EU

Radon in the Helsinki metro

The bedrock rocks of the Helsinki metro are granites and metamorphic complexes. Due to the fact that their uranium content is high and that the ground water contains high amounts of natural radioactive elements, mainly uranium and radon, the radon measurements in tunnel workings were started (Annanmäki & Oksanen, 1991). In the Helsinki metro the first radon measurements were made during excavation in 1972 and they showed that radon concentration of 2000 $Bq.m^{-3}$ could be reached, if the ventilation was not working properly. Since 1975 regular measurements along the tunnel were made. The highest radon concentration measured was about 7000 $Bq.m^{-3}$, but normally the concentrations were lower than 500 $Bq.m^{-3}$. In most of places the concentration was lower than 200 $Bq.m^{-3}$. It has been estimated that the mean doses to the lungs of the workers are lower than 2 mSv/a and for typical passenger the dose is about 0.1 mSv/a.

Outline of natural radon occurrences on karstic terrains of Hungary

From 1978 the continuous radon observations were performed at about 150 sub and near-to-surface monitoring stations established in the most important karstic regions of Hungary (Csige et al., 1991). Most of the measuring sites were in cave air, infiltrated and inflowed waters of caves, karstic wells, springs and some in an observation shaft lowered the soil mantle above a cave.

The obtained time series of radon observations in cave air showed a great variety in the mean value (0.2-14 $kBq.m^{-3}$). However a periodical change of one year frequency and a long term variation manifested themselves as common and typical phenomena. In cave air summer maxima and winter minima were observed, their ratio falls in the range of 10-100.

The seasonal changes can be well explained by a simple air circulation model based on the assumption of periodically formed temperature gradient forced airflow of seasonally reversed direction through the fractured karstic strata. The results of soil gas measurements per-formed above a cave show radon maxima in winter and minima in summer (50.0 and 2.5 $kBq.m^{-3}$ respectively). This observation supports the above mentioned model.

Soil gas radon observations in Frederick County, Maryland, USA

A study designed to test the geological-based and soil-gas techniques to estimate the Rn potential has been done in a/m region. This area was chosen for study because it represents a region of diverse geological setting. There are 3 physiographic provinces represented in the Frederick County with underlying rock types including the three major geological classifications of igneous, metamorphic and sedimentary.

The distribution of soil-gas Rn, measured in the depths of 0.75-1.0 m below terrain, varies throughout county and seems to be strongly related to the underlying geological unit or rock type, especially for high and low radon concentrations. In certain areas, such as the quartzite ridges in the western part, the soil-gas Rn concentrations are low. Other areas, such as metamorphic region in the southeast of the county have very high radon concentrations (Reimer, 1991). The overall radon soil-gas distribution and corresponding geological information correlates well with measured average indoor radon concentrations. In general, geological-based techniques seem to provide an excellent approach to estimate the Rn potential of an area.

Relationship between radon and geology in the south-west of England

In the south-west of England many homes have been found with high indoor radon concentrations. The high levels of radon in the dwellings are generally associated with parts of the region on or close to the areas of granite. The uraniferous granite is highly fractured and there are some major faults in the region. These offer a convenient pathway for the migration of radon originating in the bedrock. There may also be secondary uranium mineralisation within the fractures or faults generating higher levels of radon at the source (Varley & Flowers, 1991).

The concentration of radon in the soil gas has been measured at various geologically contrasting sites in the South-West. High levels of radon (up to several thousand $Bq.m^{-3}$) have been recorded over faults, whose position has been confirmed by other geophysical methods. Several houses haven been investigated too. It has been found that the measurement of soil-gas radon concentrations, used with geological data, has significant value as an indicator of high indoor radon levels.

Relations between neotectonics, soil-gas and indoor radon concentrations in Bratislava region, sw. Slovakia

The region of Bratislava Capital and its surroundings is tectonically highly disturbed. This (neo) tectonic setting creates excellent pathways for radon emanations rising up to the surface and, thus, to the dwellings. The area under study is built by Paleozoic granites and Mesozoic sedimentary complexes of Malé Karpaty Mts., by Neogene clayey-sandy sediments of Záhorská Nížina lowland

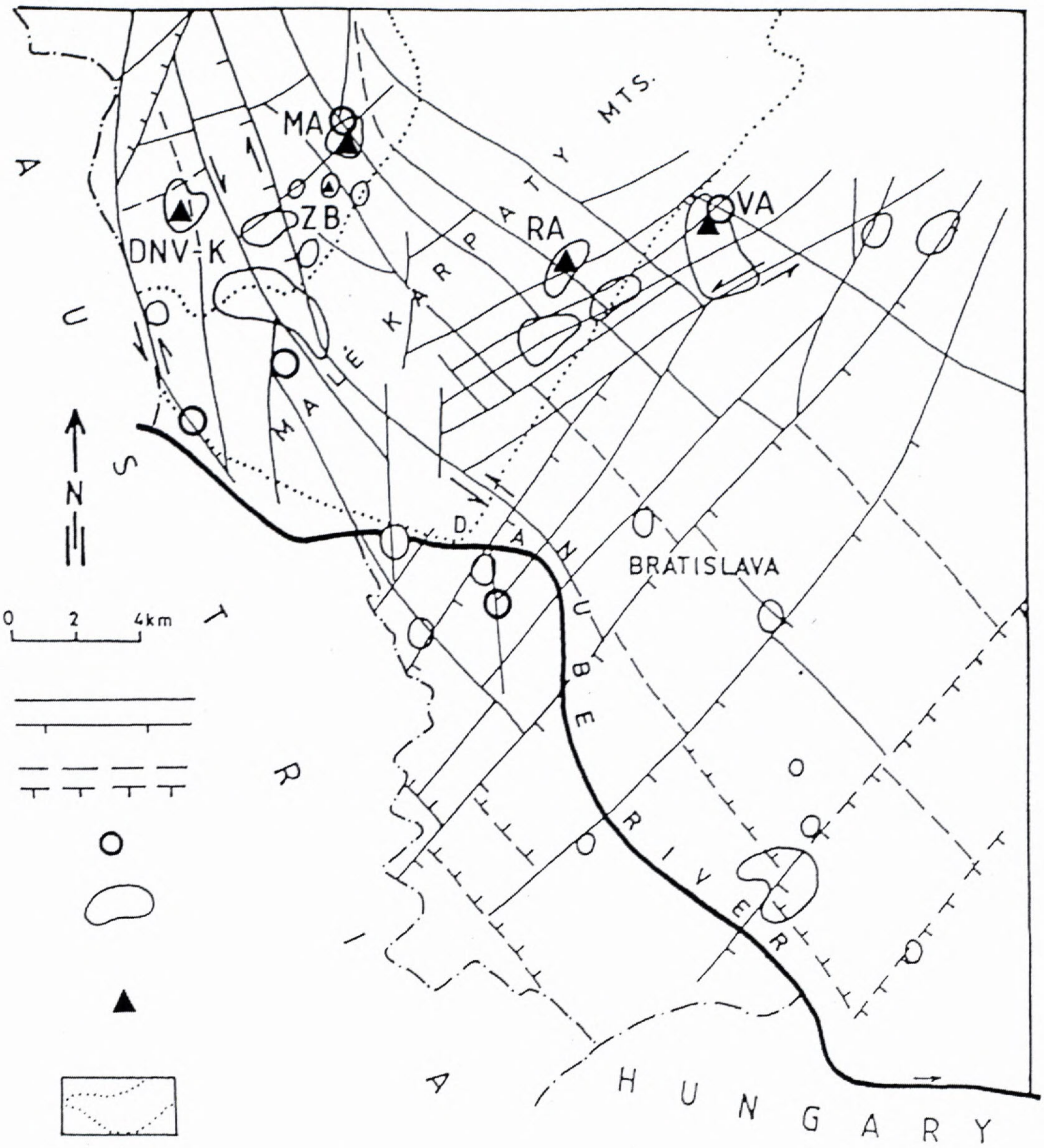

Fig. 1 Relation between neotectonics and radon risk in Bratislava region with location of indoor observations (J. Hricko, 1998).
1 – neotectonic and seismoactive fault expressive, 2 – neotectonic and seismoactive fault unexpressive, 3 – epicentre of the registered earthquake, 4 – area of high radon risk (in soil gasa of surficial layer), 5 – indoor radon observations (DNV-K: Devínska N. Ves – kolónia, ZB: Záhorská Bystrica, MA: Marianka, RA: Rača, VA: Vajnory, 6 – Malé Karpaty Mts. area.

and by Neogene and Quaternary sediments of Podunajská nížina lowland. The region is affected by tectonics of different ages and courses (Fig. 1). Some of the fault systems are seismo-active and still active (Hricko, 1998).

In frame of the multidisciplinary environmental project „Bratislava-environment, abiotic component“ (Hricko, 1993) the Bratislava region was covered by regular soil-gas observations. The volume radon activity was determined in 0.80 m deep holes. The density of observations was 3 reference areas (each represented by 20 measuring stations at 20 x 20 m network) per 1 sq.km. The maps of radon risk prognosis on the scales of 1 : 25 000 and 1 : 50 000 are results of this radon survey. The 56.8 % of the area under study possess low radon risk, 37.6 % medium one and 5.6 % the high radon risk. The relationship between (neo) tectonic setting and distribution of areas with high radon risk is shown in Fig. 1. Follow-up indoor radon observations in dwellings lying at places with high radon risk of geological bedrock have manifested high radon levels. The indoor radon measurements have been performed in Devínska Nová Ves, Marianka, Rača and Vajnory localities. The values of equivalent volume radon activity (EVRA) from 6 months long observations have brought unfavourable results in some houses. The examples of the highest radon level: Marianka: 698.0 $Bq.m^{-3}$; Rača: 905.0 $Bq.m^{-3}$; Vajnory: 566.0 $Bq.m^{-3}$ (Nikodemová et al. in Hricko, 1993). All these houses lie in high radon risk area and they are situated at neotectonic faults.

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For assessment of healthy risk of the inhabitants, the results of long-term measurements in 257 dwellings of Bratislava Capital have been used. The further dosemeters were placed to the flats lying in high radon risk, determined by soil-gas radon observations: 27 in Marianka and 48 in Devínska Nová Ves, Záhorská Bystrica, Rača and Vajnory villages. The assessment of healthy risk of the inhabitants concerning assumed deaths on lung cancer has brought following results: In Bratislava City, seven deaths on lung cancer per annum for 100 000 persons may be assumed, while in Marianka village twenty-eight (!) ones, caused by radon presence (Nikodémová et al. in Hricko, 1993).

Conclusions

The soil-gas and indoor radon observations done in different countries have brought evidence that there is a close relationship between geological-tectonic setting and radon levels in the bedrock gas and in the dwellings.

The most convenient pathways for rising up radon emanations to the surface and then to the dwellings are (neo) tectonic faults and fault systems.

The highest radon levels have been measured at dwelling, located in the areas with high values of the radon volume activity in soil gas of the bedrock surficial layer.

The permanent high level of radon and its daughters´products in dwellings may cause the lung cancer of their inhabitants.

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The reason of the faults orthogonal relationship in the Western Carpathians basins and depressions

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Abstract. The structural trend of the Neogene depressions in the Western Carpathians is usually controlled by the youngest fault systems, which participated on their opening or were sin-sedimentary with the basin filling. For the Vienna basin and for the partial depressions of the Danube basin (Blatné, Rišňovce and Komjatice) such structural trend controlling faults are faults with NE-SW strike. Roughly, from N-S oriented Central Slovakian Fault Belt toward the east the orientation of the controlling fault systems is changed and in the South Slovakian depressions, especially in the Ipeľská kotlina Depression, the structural trend is controlled by faults with NW-SE and NNW-SSE strikes. The reason of the orthogonal relationship of the mentioned fault systems is in various age of origin, and/or activity of the faults and in the relationship to the rotation of viscoelastic lithosphere blocks. The faults with NE-SW strike, controlling the structure of the Vienna Basin and the northern promontories of the Danube Basin, originated or they were reactivated since the Middle Badenian, when the rotation of the block was already finished. The faults with NW-SE and NNW-SSE strike in the South Slovakian depressions originated or they were reactivated in the Early Miocene and/or in the Early Badenian, respectivelly. Their origin or activity was preceded by the block rotation, or the faults with NNW strike had been formed before the second phase of the rotation. The fact, that after the Early Badenian the South Slovakian depressions did not subsided caused, that the faults originating in the Middle Miocene paleostress field with the maximum compression in the NE-SW direction did not have controlling role on the structure of depressions.

Key words: Western Carpathians, Neogene sedimentary basins, fault structure, paleostress, block rotations.

Introduction

Faults breaking down the basins and depressions of Western Carpathians usually create fault systems of certain strikes. However, in majority of basins and depressions there is one dominating fault system, it breaks down or overlaps others. It is usually the youngest fault system synsedimentary with basin filling, which creates characteristic structural trends of basins/depressions. In the western part of the Western Carpathians the dominating fault system has NE-SW strike (Vienna Basin, Danube Basin – its northern promontories: Blatné, Rišňovce, Komjatice and partly also Želiezovce depressions). Roughly, eastward from the Central Slovakian Fault Belt running in N-E direction the strike of controlling fault system changes. The South Slovakian depressions, especially Ipeľská kotlina Depression, have the structural trends controlled by faults with NW-SE or NNW-SSE strikes (fig. 1). New information about faults opening and structural modelling of the young Western Carpathians basins, especially information obtained by structural measuring of the brittle deformations, as well as results of paleomagnetic researches, help to understand reasons of orthogonal relationship of the fault systems controlling the recent basins/depressions structure.

Time and reasons of origin of NE-SW fault system – the most significant fault system of the Vienna and Danube basins

Faults, which have opened Vienna Basin in transtensional regime and longitudinally split up the basin to series of horsts and grabens (Buday in Buday et al., 1967; Gaža et al., 1983), are synsedimentary with Badenian and Sarmatian basin filling. Stress field recorded by the brittle deformations of deposits from both sides of the Malé Karpaty Mts. gave birth of faults and stimulated their activity in this period. In the Middle Miocene paleostress field the direction of the main compression was NE-SW or NNE-SSW and the direction of the extension was NW-SE (Marko et al., 1991; Marko et al., 1995). This stress field, invoked activity or birth of faults with NE and NNE strike (fig. 2).

The Vienna Basin had its first stage of tectonic development in Lower Miocene. In Late Karpatian and Early Badenian it had suffered structural remodelling. However, the depressions at the northern margin of the Danube Basin - depressions Blatné, Rišňovce and Komjatice started to open in Middle and Late Badenian, in the same stress field in which the Vienna Basin was opened after the structural remodelling. It means that the depressions were opened under the control of faults with NE-SW to NNE-SSW strikes (fig. 3), (Adam & Dlabač 1961; Gaža et al., 1985). The orientation of these faults as well as orientation of the depressions, which were confined by the faults, was final. Rotation of lithospheric blocks during Miocene (proved by paleomagnetic measurements, the total value of the rotation was about 60-70° CCW) ceased in Early Miocene (Kováč & Túnyi, 1995). The paleomeridians of younger rocks are identical with the recent ones, what means that they did not rotate.

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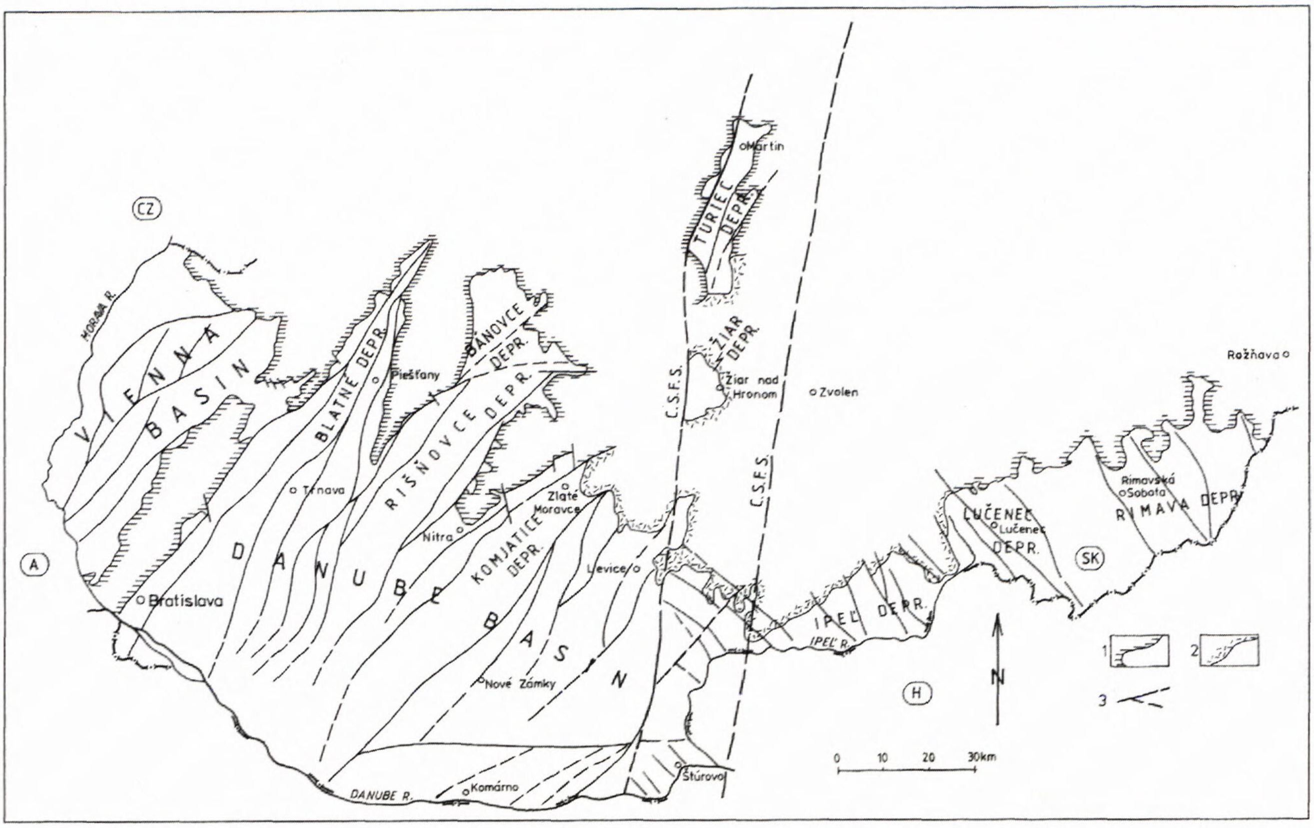

Fig. 1. Dominant faults of the Vienna and Danube basins and South Slovakian depressions.
The relationship of both Vienna and Danube basins faults with faults in South Slovakian depressions is orthogonal. Westward of the Central Slovakian Fault Belt (CSFB) the faults have NE-SW, NNE-SSW strike, and eastward of the belt the prevailing fault strike is NNW -SSE, NW- SE.
Explanations: 1 – present day margin of the Neogene basin and depressions, 2 – neovolcanics at the margin of basins and depressions 3 – faults

It must be remarked that mechanism of NE-SW fault system activity was not equal in the Vienna Basin and in partial depressions of the Danube Basin. In Vienna basin, which lay near subduction zone of Outer Carpathians, the NE-SW fault system opened the basin by pull-apart mechanism (Royden, 1985; Vass et al., 1988), whereas faults with the same strike in partial depressions of the Danube Basin originated or revived under heterogeneous stretching of the lithosphere. The thermal stretching of the lithosphere in the central zone of the Danube Basin passed through to basin outer zone, where this effect caused break down of the upper crust and opening of the depressions (Vass & Pereszlényi, 1998). The faults were mainly normal and only some of them were strike-slips.

In the South Slovakian depressions and south-eastern part of the Danube Lowland, where Štúrovo Paleogene crops out, the dominating fault system has strike NW-SE to NNW-SSE (Seneš, 1960; Vass et al., 1979; Vass & Elečko et al., 1989, 1992). Although the faults with NW strike were active in Quaternary, they are older. Faults, which split up the Štúrovo Paleogene and Gerecse Hills, were brought to existence or reactivated in Middle to Late Paleogene in the stress field with maximum compression in NW-SE, or WNW-ESE direction and extension in the NE-SW direction. In the Gerecse Hills there were normal or normal – strike-slip faults, which controlled Eocene and Oligocene sedimentation (Fodor, 1992). According to Seneš (1960) faults with NW-SE strike splitting up Štúrovo Paleogene deposits were created or reactivated before Lutetian (after biostratigraphical revision in Early Lutetian, Samuel & Váňová, 1967) and they were active as synsedimentary faults until the end of Eocene, some of them also during Oligocene. In this period, probably in stress field, which was estimated from the measurements in the Gerecse Hills, were born also faults confaining the buried graben of Cerovo-Dačov Lom, which are not recorded in present day structure of Ipeľská kotlina Depression and Krupinská planina Plateau (Vass et al., 1993). Faults of NW-SE system, expressive in the recent structure of the Ipeľská kotlina Depression and also in the structure of two other depressions (Lučenská kotlina and Rimavská kotlina), were born in the Early Miocene paloestress field characteristic by the extensions in NE-SW direction and by compression in vertical position (Vass et al., 1993). In this stress field Dačov Lom Graben was generated. The faults confining the graben controlled the distribution of depositional centres of Číž, Krupiná and Lučenec formations (Kiscelian and Egerian), influenced deposition of Bukovinka Formation, especially rhyodacite tuffs within the formation (late Eggenburgian) and coal seams within the Pôtor Member of Šalgótarján Formation (Ottnangian). The coal seams in the most

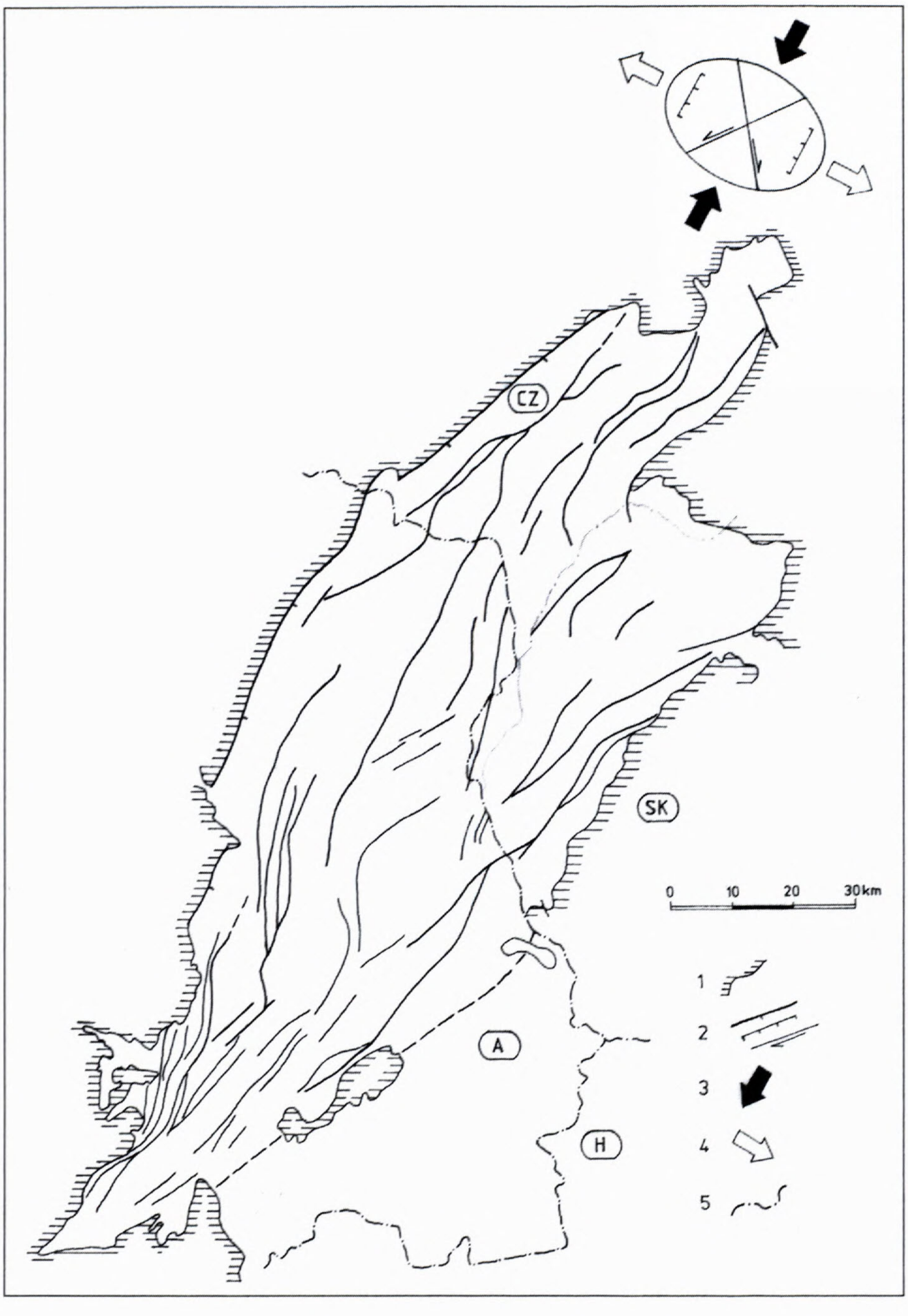

Fig. 2. The fault system of NE-SW direction controlling the most expressive grabens and horsts of the Vienna Basin (normal faults and strike-slips; after Buday, Hronec, Jiříček, Kocák, Friedl, Grill, Janoschek, Unterwelz compiled by Jiříček & Wessely 1989, in Hamilton et al., 1990). The faults were born or reactivated in Middle Badenian paleostress field, the diagram (after Marko et al., 1995) see in upper right corner of the figure. Explanations: 1 – margin of the basin, 2 – normal and strike-slip faults, 3 – direction of the maximum compression, 4 – direction of the maximum extension, 5 – state borders between Slovakia (SK), Hungary (H), Austria (A) and Czech Republic (CZ).

complete development (i.e. three seams) are spread in the central and eastern part of the Dočov Lom Graben. In the graben there was also the main deposition centre of the Modrý Kameň Formation (Karpatian) in the outhern Slovakia (fig. 4). The faults of the eastern wing of the graben must been active after Karpatian and before Badenian, because they controlled erosional truncation of the Lower Miocene deposits at the eastern edge of the Ipeľská kotlina Depression. So, the Badenian deposits lay discordantly upon various members of Modrý Kameň or Šalgótarján formations.

During the Early Badenian in the paleostress field with maximum compression in the NNW-SSE direction the Želiezovce depression with axis of NW-SE direction in the eastern part of the Danube Basin was formed. Its edges were probably controlled by faults of the same direction (Vass et al., 1993). The depression was confined by the faults especially at its northeastern edge, where they confined the partial Semerovce depression, the Santovka-Turovce Horst and the Plášťovce Depression. The synsedimentary activity of the folts confining the Santovka - Turovce Horst is confirmed by the fact, that the horst as barrier hampered the dense currents of the volcanidetritic material running down the slopes of rising Štiavnica Stratovolcano, and the horst prevented its spreading over the Želiezovce Depression as turbidity currents. The material from dense currents was deposited in the Plášťovce Depression as Plášťovce Member (Vass, 1971; Vass & Krystek, 1975; Vass et al., 1995).

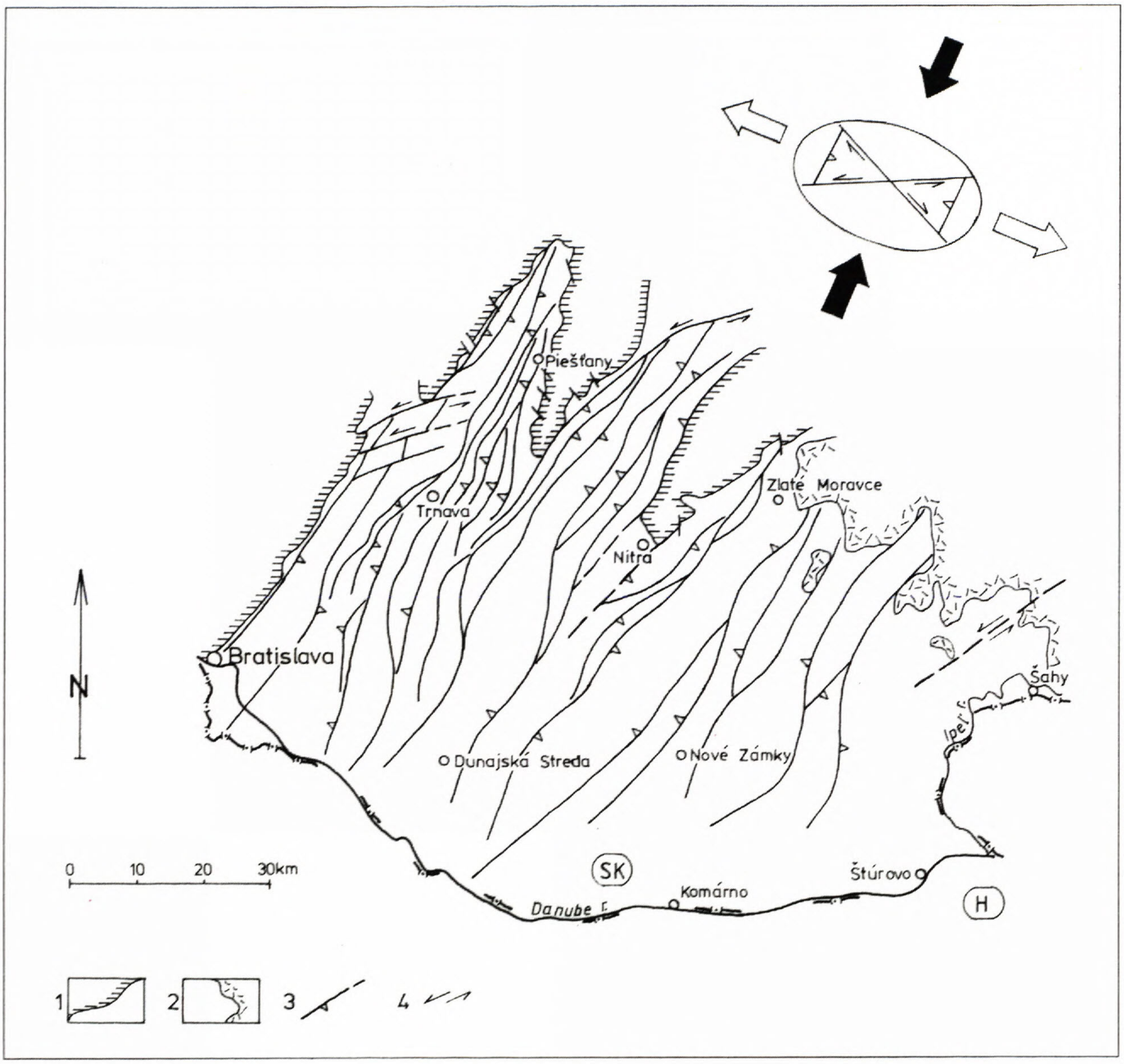

Fig. 3. The dominating fault system of Danube Basin (Pěničková & Dvořáková in Gaža, 1985) born or reactivated in Middle - Late Badenian paleostress field (Marko et al., 1991; Vass et al., 1993).
Explanations: 1 – today basin margin, 2 – neovolcanics at northeast basin margin, 3 – normal fault, 4 – strike-slip

The normal faults with NNW-SSE or NW-SE strike were generated in South Slovakian depressions during Early Badenian in the stress field with the main compression in the NNW-SSE or NW-SE direction (in today coordinates). Most of them epigenetically broke up the pre-Badenian rocks and modelled young expressive structure of the South Slovakian depressions. These faults split up the Rimava, Lučenec and Ipeľ depressions into series of horsts and grabens (fig. 5; Vass, et al., 1979, 1981; Vass & Elečko, et al., 1989, 1992). Among them the Strháre - Trenč Graben is the most significant (Vass in Vass, et al., 1979; Vass & Elečko, et al., 1989, 1992). In this graben we could date the fault activity. The faults were controlling the sedimentation of the volcaniclastic material of Early Badenian Vinica Formation (Vass, 1963). On the crossings of the Šahy-Lysec volcani-tectonic zone with the faults of NNW-SSE strike there were opened ascending ways for andesite magma, products of which built up already mentioned Vinica Formation and also younger Opava and Lysec formations (Konečný in Vass et al., 1979).

Remanent magnetism measurements of Cenozoic rocks in the area of the Eastern Alps, Carpathians and Pannonian basin (ALCAPA) proved, that during the Cenozoic there was rotation of blocks of viscoelastic lithosphere. In the western part of the Western Carpathian arch the left (CCW) rotation achieved the value 42°-80° (Túnyi & Kováč, 1991; Kováč & Túnyi, 1995). The referred authors originally thought about two pulses of rotations, after Eggenburgian and after Karpatian. Leter on they thing about one rotation pulse, at the boundary between Early and Middle Miocene. Thus, in the given area

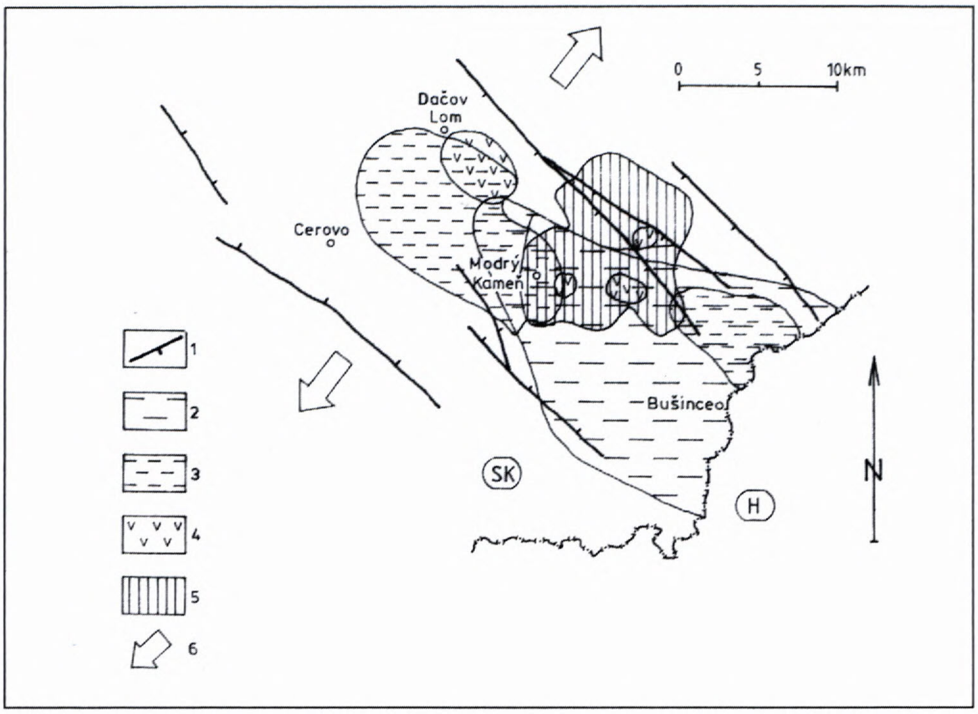

Fig. 4. The Dačov Lom Graben (Vass in Vass et al., 1979), originated by the Early Miocene extension (present day coordinates). The graben's faults controlled depositional centres of Číž, Krupiná and Lučenec formations (Kiscellian and Egerian). They influenced the sedimentation of the Bukovinka Formation (Eggenburgian), the coal seams of Šalgótarján Formation (Ottnangian) and the deposition centres of Modrý Kameň Formations (Karpatian).
Explanations: 1 – fault, 2 – zone of maximum thickness of Číž, Krupiná and Lučenec formations (Kiscellian and Egerian, Oligocene to oldest Miocene), 3 – maximum accumulation of Modrý Kameň Formation, 4 – rhyodacite tuffs of Bukovinka Formation, 5 – area of the Pôtor Member full sequence extension (3 seams) in Šalgótarján Formation, 6 – direction of extension

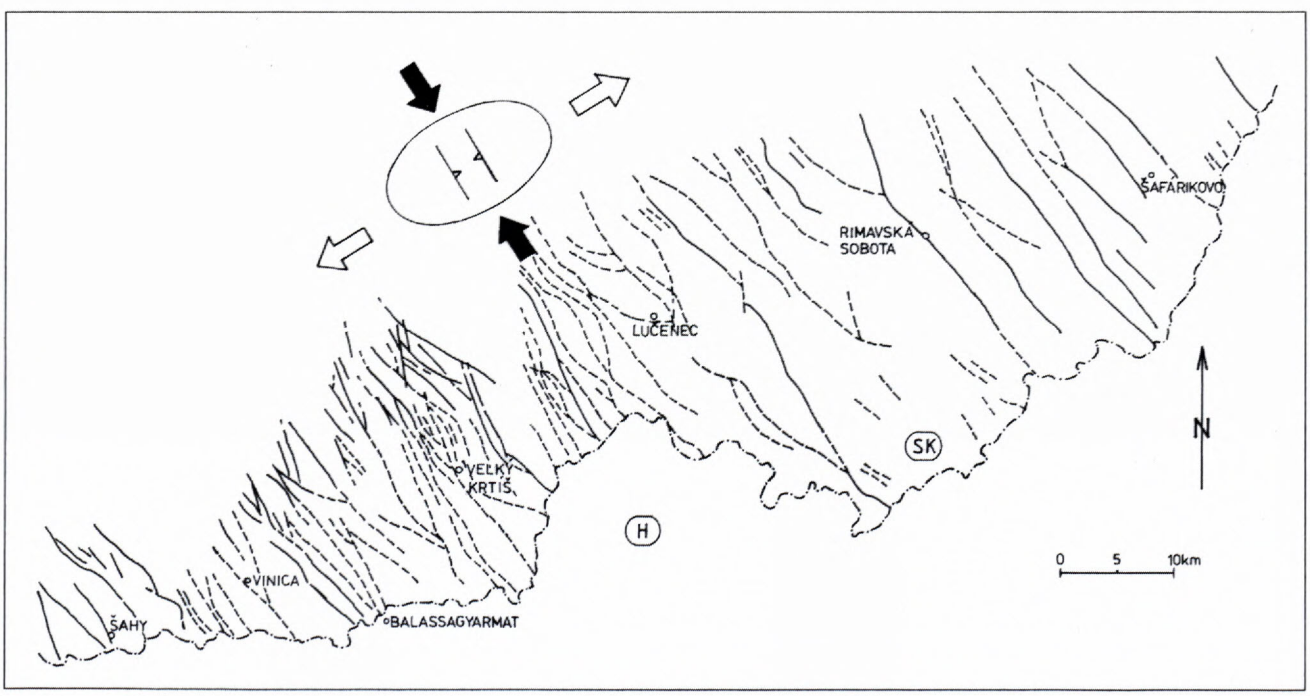

Fig. 5. Faults of South Slovakian depressions dominating in present day structure (after maps in scales 1:50 000 by Konečný et al., 1979; Elečko et al., 1985; Vass et al., 1992) and Early Badenian paleostress field (Vass et al., 1993) which caused the faults birth or reactivation (in recent coordinates).

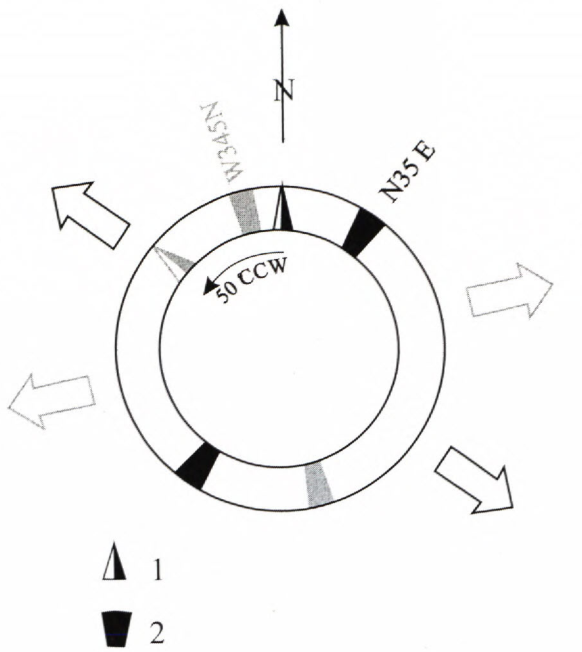

Fig. 6. The early Miocene extension (empty arrows) in the NW-SE direction. The brittle deformations and normal faults, which were generated or activated by the extension, had the general strike N35E (i.e. NE-SW). The 50° contrclockwise rotation (CCW: Márton et al., 1995, 1996) reoriented the brittle deformations and faults to the direction W345N (i.e. NNW-SSE) before Middle Miocene. The direction and size of rotation,the ratated paleomeridian, structural trend and apparent extension after the rotation are on the figure in light-grey colour.
Explanations: 1 – direction of paleomeridian, 2 – structural trend.

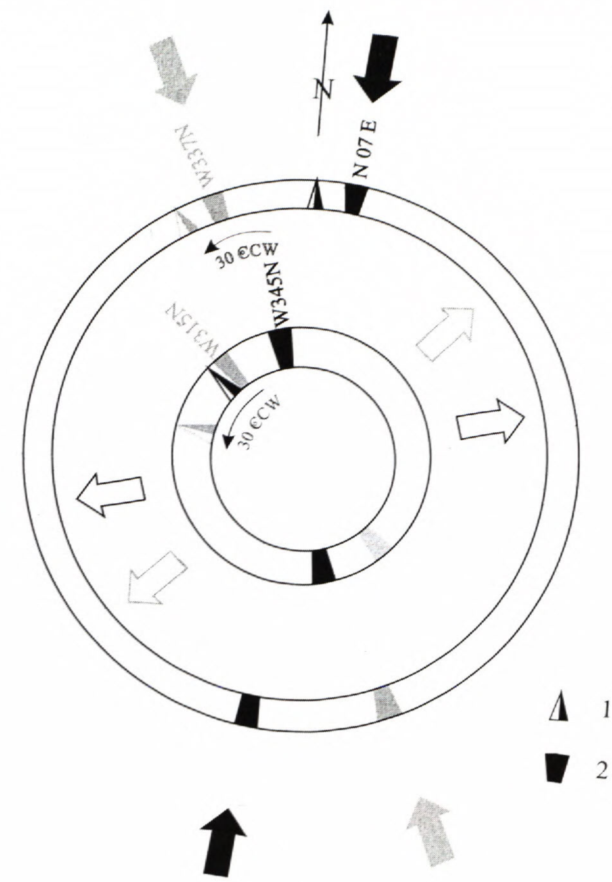

Fig. 7. The Early Badenian compression (full arrows) in the direction N07E.The brittle deformations and normal faults, formed due to the compression, had the general direction identical with the direction of the maximum compression. The 30° contrclockwise rotation (CCW, Márton 1995, 1996) during or at the end or Early Badenian turned the Early Badenian brittle deformations and faults to the direction W337N (NNW-SSE, outer circle) and Early Miocene brittle deformations and faults (inner circle) to the direction W315N (NW-SE). Direction and the size of the rotation, the rotated paleomeridians, both structural trends, apparent Early Badenian compression and Early Miocene compression are in light-grey colour.
Explanations:1 – direction of paleomeridians, 2 – structural trend

there were conditions for at least one rotation. It happened before the Middle Miocene opening of partial depressions at the north of the Danube Basin, i. e. before birth, or reactivation of faults, which the opening enabled.

In the area of the Southern Slovakia and Northern Hungary (westward of the Hornád Fault Zone) there were also Miocene rotations of viscoelastic lithosphere block. Two phases of rotations were identified, with the total rotation angle value 80° (Márton et al., 1995, 1996; Márton & Márton, 1996). The first rotation phase (50° CCW) took place in Late Ottnangian, or after Ottnangian in extension conditions with vertical compression (see above), i.e. during a stress relax, what is kinetic situation favourable for large block rotation.

The second rotation phase 30° CCW took place after Karpatian and before Middle Badenian. The rotation was preceded by the period of the region uplifting, what is proved by the erosional truncation of Early Miocene deposits and discordant position of Early Badenian rocks on various members of Modrý Kameň and Šalgótarján formations (Vass in Vass et al., 1979), as well as by degree of the smectite illitisation in the Plachtince Clay, a member of the Šalgótarján Formation. This indicates 600 m truncation of Karpatian and Ottnangian deposits before Early Badenian (Vass & Šucha, 1994). During Early Badenian the forces controlling the uplift retreated. The area of Ipeľská kotlina Depression starts to subside again and thank to this the sea penetrate into depression up to Sahy - Lysec Zone, where the andesite volcanism was activated. Probably during Early Badenian a new stress turnover appeared, the sea retreated and simultaneously the building up of Vinica andesite formation was over and its erosion began.

This period was favourable for left rotation about 30° CCW. The faults controlling sedimentation during Early Miocene from the direction cca E35 N, in which they originated, or were reactivated under the influence of the NE-SW extension, turned by 50° CCW rotation into new direction cca N345 W (fig. 6). After the first and before the second rotation phase, during Early Badenian the pa-

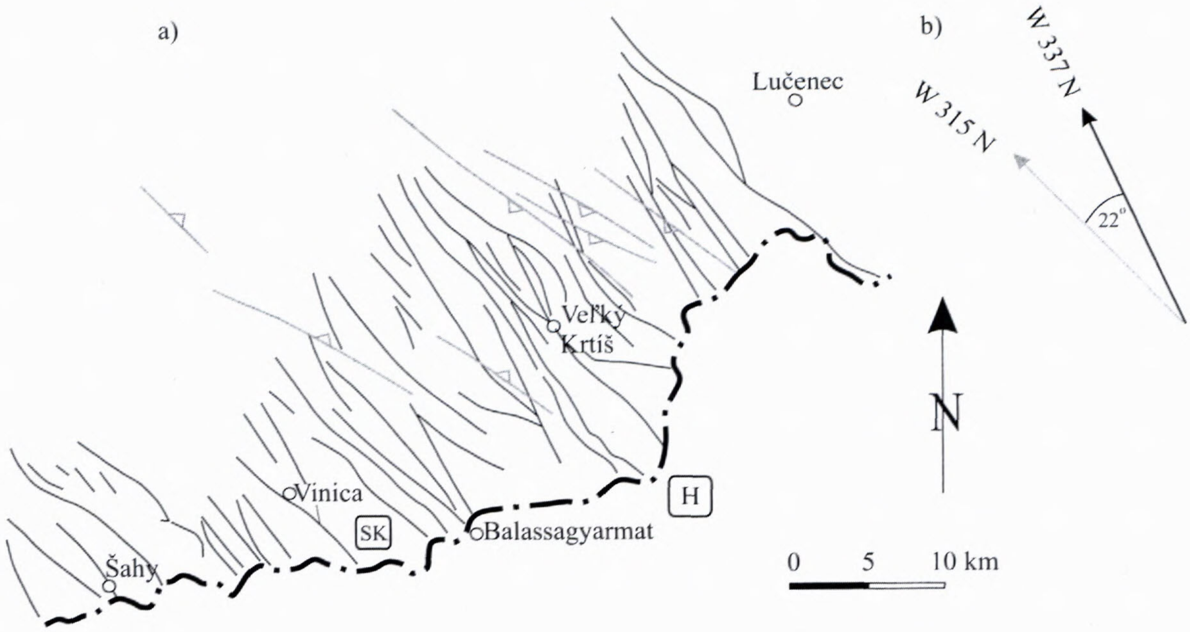

Fig. 8. a) Mutual spatial relationship of the Early Miocene (light-grey) and Early Badenian faults (black) in the Ipeľská kotlina Depression .b) the general trend of Early Miocene (light-grey) and Early Badenian faults is oblique under the angle 22°

leostress situation was changed. The maximum extension was oriented in the direction cca N-S (N 07 E). In such stress field new normal faults originated parallel with the direction of the maximum compression. After the second rotation 30° CCW the older Early Miocene faults were turned into direction N315 W and younger Early Badenian into the direction cca N337 W (fig. 7). This spatial relationship of faults at the Southern Slovakia is obvious in the Ipeľská kotlina Depression, where older faults forming the Dočov Lom Graben have NW-SE direction and the younger faults synsedimentary with Early Badenian forming the Strháre-Trenč Graben and also other blocks have NNW-SSE strike (fig. 8). This fact was noted by Vass (1963), when he described the mutual relationship of older and younger faults in the area of Strháre – Trenč Graben as a structure of normal faults crossing. One of the possible explanations of such structure origin is the above mentioned time schedule of fault generation in the relation to left rotation of viscoelastic lithosphere block.

It is obvious from the above, that the faults in South Slovakian depressions with NW strike originated in Early Miocene before the first left block rotation of viscoelastic lithosphere. In the period of Early Badenian between the first and the second phase of the rotation faults with NNW strike originated.

After the rotations, the whole South Slovakian - North Hungarian domain was uplifted, what is proved by the fact, that in this domain the younger

Middle Miocene deposits (Middle Badenian - Sarmatian) as well as the Late Miocene and Pliocene lacustrine deposits, massively developed in South Hungary and in Danube Basin are missing, or they do not form considerable accumulations, with exception of the southern margins of uplifted domain.

The paleostress field for the period younger than Early Badenian in the Central West Carpathians was characteristic by a compression in the NE-SW direction. Doubtlessly this direction found responds also in uplifted South Slovakian - North Hungarian domain, where the normal faults of NW-SE direction were created or reactivated. However, these faults broke up the domain epigenetically and they did not have any opportunity to act as synsedimentary faults. Thus as a dominating structural elements in the South Slovakian Depressions the faults of NW-SE and NNW-SSE strike remained. Transversal faults (NE-SW strike) are less significant, although there are proves about their activity during Quaternary (river valleys orientation, asymmetry of river terraces). Nevertheless, also the faults with NW-SE strike were active during Quaternary (Vass & Elečko eds. 1989, 1992).

Conclusion

The reason of faults orthogonal relationship in the Western Carpathians determining dominating structure in young basins and depressions westward and eastward of Central Slovakian Fault Belt (fig. 1) is various age of the faults. Faults of the NE-SW fault system of the Vienna Basin as well as the faults of Blatné, Rišňovce and Komjatice depressions in the Danube Basin or faults of the horsts Malé Karpaty, Považský Inovec and Tríbeč Mts. and of the Levice Horst were born or reactivated in Middle Badenian and were active as synsedimentary faults until the end of Sarmatian, partly also in Late Pannonian. The matter is about faults origin or activity after the rotation of viscoelastic block of the western domain of the Western Carpathians. Those faults controlled synrift stage in the outer zone of Danube (thermal) basin.

The faults with NW-SE and NNW-SSE strike, being the most important structural element of the South Slovakian depressions were born or reactivated in Early Miocene and in Early Badenian. Their original orientation was about NE-SW. Due to rotation of viscoelastic block of lithosphere by 80° CCW the faults were turned to recent NW - SE direction. In the Early Badenian, after the first rotation phase the normal faults originated having approximate N-S strike. Due to the second rotation phase by 30° CCW they were turned to the recent position, thus their recent orientation is NNW-SSE.

After finishing the left rotation the whole South Slovakian - North Hungarian domain began to rise. In the paleostress field with main compression of NE – SW direction (in which the Western Carpathians were since the Middle Badenian) not only the crust of newly formed Danube Basin but also the crust of South Slovakian - North Hungarian domain were broken up by parallel faults with main compression. Because the domain was uplifted, any important accumulation of Middle Miocene marine and Late Miocene - Pliocene lacustrine deposits occurred here, with exception of the southern marginal areas. Thus the faults with NE-SW strike only epigenetically broke up the domain and they did not controlled syngenetic accumulation of deposits. Thus as the dominant structural element in the South Slovakian depressions are the faults of NW-SE and WNW-SSE strike, i.e. faults which are in orthogonal relation to the main faults controlling the post - Early Badenian sedimentary filling of depressions on the Danube Basin northern margin.

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