GEOL. CROAT.	52/1	83 - 98	4 Figs.			ZAGREB 1999

Tectonic Interrelation of the Dinarides and the Southern Alps

Milan **HERAK**

Key words: Alps, Dinarides, Tisia, Slovenian Trough, Sava Nappe, Pannonian Nappe, Mid-Transdanubian Zone, Bosnian Zone, Tectogenesis and geotectonic classification.

Ključne riječi: Alpe, Dinaridi, Tisia, Slovenski jarek, Savska navlaka, Panonska navlaka, Srednja transdanubijska zona, Bosanska zona, tektogeneza i tektogenetska klasifikacija.

Abstract

The study focuses on northwestern Croatia which, including the Žumberak (Žumberačka gora), Medvednica (Zagrebačka Gora), Kalnik, Ivanščica, and Ravna Gora mountains, make a cross area of the Slovenian "Sava Folds", Southern Alps, Mid-Transdanubian Zone, Tisia, and the Inner Dinarides. This is a complex structural region and cannot be attributed merely to one of the units. Therefore, a geotectonic interpretation is proposed which respects the diversification and multiple superposition of basinal and platform elements. This concept allows linkage of the Slovenian Trough with the Bosnian Zone and its southeastern prolongation as a major coherent tectonic unit overlain by different nappe elements. The possible linkage with the Budva Zone beneath the carbonate nappe is also discussed.

Sažetak

Glavna je pozornost posvećena sjeverozapadnoj Hrvatskoj, koja uključuje Žumberačku goru, Medvednicu, Kalnik, Ivanščicu i Ravnu goru - presjecište susjednih slovenskih "Savskih bora", Južnih Alpa, Srednje transdanubijske zone, Tisije i Unutarnjih Dinarida. To je složeno strukturno područje, pa ne može biti pribrojeno samo jednoj jedinici. Zbog toga se predlaže geotektonska interpretacija koja uvažava diverzifikaciju i višestruku superpoziciju bazenskih i platformskih elemenata. Ovaj koncept omogućuje povezivanje Slovenskog jarka s Bosanskom zonom i njezinim jugoistočnim produženjem u jednu koherentnu tektonsku megajedinicu na kojoj leže različiti navlačni elementi. Također se raspravlja o mogućoj vezi s Budva-zonom.

1. INTRODUCTION

The structural relationships of northwestern Croatia and the adjacent regions of Slovenia and Bosnia were and remain subject to different treatment. The main approaches are as follows:

PETERS (1863) assumed the existence of an ancient "Palaeolithic Land" within the Balkan Peninsula, comprising the "crystalline cores of Slavonia and Siebenburgen". This megastructure was not supposed to have participated in tangential Alpine tectonics. SUESS (1875) attributed northwestern Croatia (including Mt. Medvednica) to the Southern Alps, while DIENER (1903) regarded the area as part of the Eastern Alps. MOJSISOVICS (1880) accepted the "Land" defined by PETERS and introduced the name "Oriental Land". However, he experienced difficulty in defining its boundaries. PILAR (1882) was involved with the geology of western Bosnia and concluded that the "flysch", containing "eruptive rocks" (including ophiolites), continued into Croatia. Later, KIŠPATIĆ (1899), studying ophiolites, accepted the opinion that Mt. Medvednica was a continuation of northern Bosnia (i.e., of the Inner Dinarides), as did also GORJANOVIĆ-KRAMBERGER (1907), with the exception of the part which was attributed to the "Oriental Land". SALOPEK (1914), analysing modern tectonic concepts, concluded that autochthonous relationships characterize NW Croatia. CVIJIĆ (1924) accepted the idea of the ancient land (he called it the Rhodopian Mass) but considered its boundaries as ambiguous. Therefore, he proposed to distinguish transitional zones between the "Land" and its surroundings. KOCH (1924) gave preference to the Dinaridic elements in the whole area, and included even the Slavonian Mountains into the Dinarides. WINKLER (1924) believed in north-vergent allochthony in the adjacent area of the Slovenian "Sava Folds", probably under the influence of Suess's concept of a northward push of the Southern Alps.

In recent times, MIOČ (1975, 1981) paid special attention to the "Sava Folds" and to the area of the Lower Carniolia (Dolenjska, eastern Slovenia). He defined a unit named the Sava Nappe which overlies the Outer Dinarides, and is overlain by a south-vergent nappe composed of elements of the Julian and Savinja Alps. The extension of such relationships should be followed towards Mt. Žumberak (comprising the area of Samobor). PREMRU et al. (1977), by means of some deep boreholes, established a well-marked allochthony in Lower Carniola (Dolenjska) and in the adjacent Mt. Žumberak. They considered the area as a part of the Outer Dinarides. The "Litija anticline" was defined as the Dolsko overthrust (PREMRU, 1983, and earlier).

Croatian Academy of Sciences and Arts, A. Kovačića 5/II, HR-10000 Zagreb, Croatia.

The same unit has been subdivided in detail by MLAKAR (1987). ŠIKIĆ et al. (1978, 1979), ŠIMUNIĆ (1992), ŠIMUNIĆ & HEĆIMOVIĆ (1979), etc., introduced short distance overthrusting with different vergences to explain the tectonic pattern of Mt. Žumberak (with the area of Samobor) and Mt. Medvednica as well as of Hrvatsko Zagorje. They contributed new data to previous interpretations. MILADINOVIĆ (1981) argued for the existence of an extensive allochthonous unit, called the Pannonian Nappe. The idea was born in 1974 (see: MILADINOVIĆ, 1981) on the basis of the study of many published papers and with insight from the geologic mapping data. The maps have been made by numerous authors who registered several inverse contacts but did not evaluate them in a geotectonic sense. MILADINOVIĆ has drawn his tectonic map in 1977 and elaborated in 1981. The nappe concerns only Upper Palaeozoic and Triassic rocks, which overlie Cretaceous and Jurassic formations. The Nappe should cover a broad region stretching from Italy through the Julian Alps, South Karavanke and Savinja Alps, to the "Sava Folds", Mt. Žumberak, Banovina, North Bosnia, Užice, Prizren, Pljevlja, "Pelagonian Massif", etc. Within this megaunit, several tectonic windows and klippen were identified, which include the "Zlatibor" window. Since the most characteristic areas lie outside the Pannonian Depression, the name of the assumed nappe has not been generally accepted. Likewise, there are some regions that cannot be included into such a simple model of this unit, especially the composite structure called the "Pelagonian Massif". As to the Western Dinarides, the idea itself may be generally acceptable. However, the details require refinement.

The possible connection of the Slovenian Trough with the Bosnian Zone has been registered in several papers. In Mt. Žumberak, TORNQUIST (1918) determined pelagic sediments of Late Tithonian, Berriasian and Valanginian age. He considered them as a link between analogous Slovenian and Bosnian deposits. AUBOUIN et al. (1970), COUSIN (1973), and BABIĆ (1973, 1974) were concerned with the same problem, speaking in favour of such a connection. AUBOUIN et al. (1970) assumed the existence of a "Furrow", in which specific ("basinal") formations have been deposited since the Late Triassic. However, they do not explain the type of boundary between this "Furrow" and the oceanic realm of the Inner Dinarides, which is characterized by ophiolites and is visible in their reconstruction of the major structures where they propose a direct overthrust of the ophiolitic complex upon the elements of the "Furrow".

Later, BABIĆ & ZUPANIČ (1978) again evaluated the analogies between the Julian Alps and the Dinarides and contributed some additional elements in favour of a direct connection. However, they also called attention to some difficulties. For instance, between the Tolmin-Selška Sora area and the Žumberak area, differences exist in the timing of their aquisition of basinal character. In the Tolmin-Selška Sora region, the basin may be formed during the Triassic, while in the Žumberak area this occurred no earlier than the end of the Lower Jurassic. In contrast, DIMITRIJEVIĆ (1982) accepted the existence of a homogenous zone extending from the Julian Alps, over the "Sava Folds" and "Zagreb Zone" (i.e., Mid-Transdanubian Zone in the current terminology), but he placed a sharp boundary towards the Dinarides (inclusive of the Vardar Zone, *s.l.*). Though aware of great differences within the area of the so-called Inner Dinarides, I preferred to attribute the area in question to a common Inner Dinaric megaunit (*Supradinaricum*) with possible interior differentiation (HERAK, 1986, 1991, 1995, 1997). For example, the structures consisting of Late Palaeozoic and Triassic rocks were considered as overthrusting parts of the bottom margin of the Inner Dinarides. More recent explanation of the origin of this nappe requires emendation as discussed later. PAMIĆ (1993) was concerned with Eoalpine and Neoalpine magmatic and metamorphic processes in the northwestern Vardar Zone, the easternmost Periadriatic Zone and the southwestern Pannonian Basin. He was of the opinion that the mountains of Hrvatsko Zagorje "can be interpreted as relics of the Sava and/or Julian - Savinja nappes". He proposed to introduce more Dinaridic elements when treating southern marginal parts of the Pannonian Basin. The participation of Dinaridic elements in the Mid-Transdanubian Zone was also acknowledged by BERCZI-MAKK et al. (1993). Authors from the Institute of Geology in Zagreb use the term Mid-Transdanubian Tectonic Zone, which is not delimited towards the Inner Dinarides (ŠIKIĆ, 1995), as did many other authors, e.g. HAAS et al. (1995). However, by some authors sharp tectonic limits towards the Dinarides were assumed (e.g., DIMITRIJEVIĆ, 1982). There are many more papers with controversial concepts, but all of them are within the frame of these ideas and, therefore special commentary of them is omitted.

By comparison of the proven data in NW Croatia and eastern Slovenia, the heterogeneity of the region (called the Mid-Transdanubian Zone) is obvious, with the consequence that Dinaridic and Alpine elements are superimposed. However, the tectogenetic processes and the interior organisation remain under discussion.

Despite the fact that within northwestern Croatia numerous new data, concerning lithostratigraphy and local tectonics, have been collected (ŠIMUNIĆ & PAMIĆ, 1989; HERAK et al., 1990; ŠIMUNIĆ, 1992; ŠIKIĆ, 1995; HALAMIĆ & GORIČAN, 1995, etc.), a general comparative treatment concerning Dinaridic-Alpine geotectonic relations remains elusive. Therefore, the major aim of this paper is to rectify that problem.

2. MAJOR LITHOSTRATIGRAPHIC SEQUENCES

Mt. Medvednica (Zagrebačka Gora) and Mt. Žumberak (Žumberačka Gora) display the greatest diversity of lithostratigraphic units. In a relatively small space

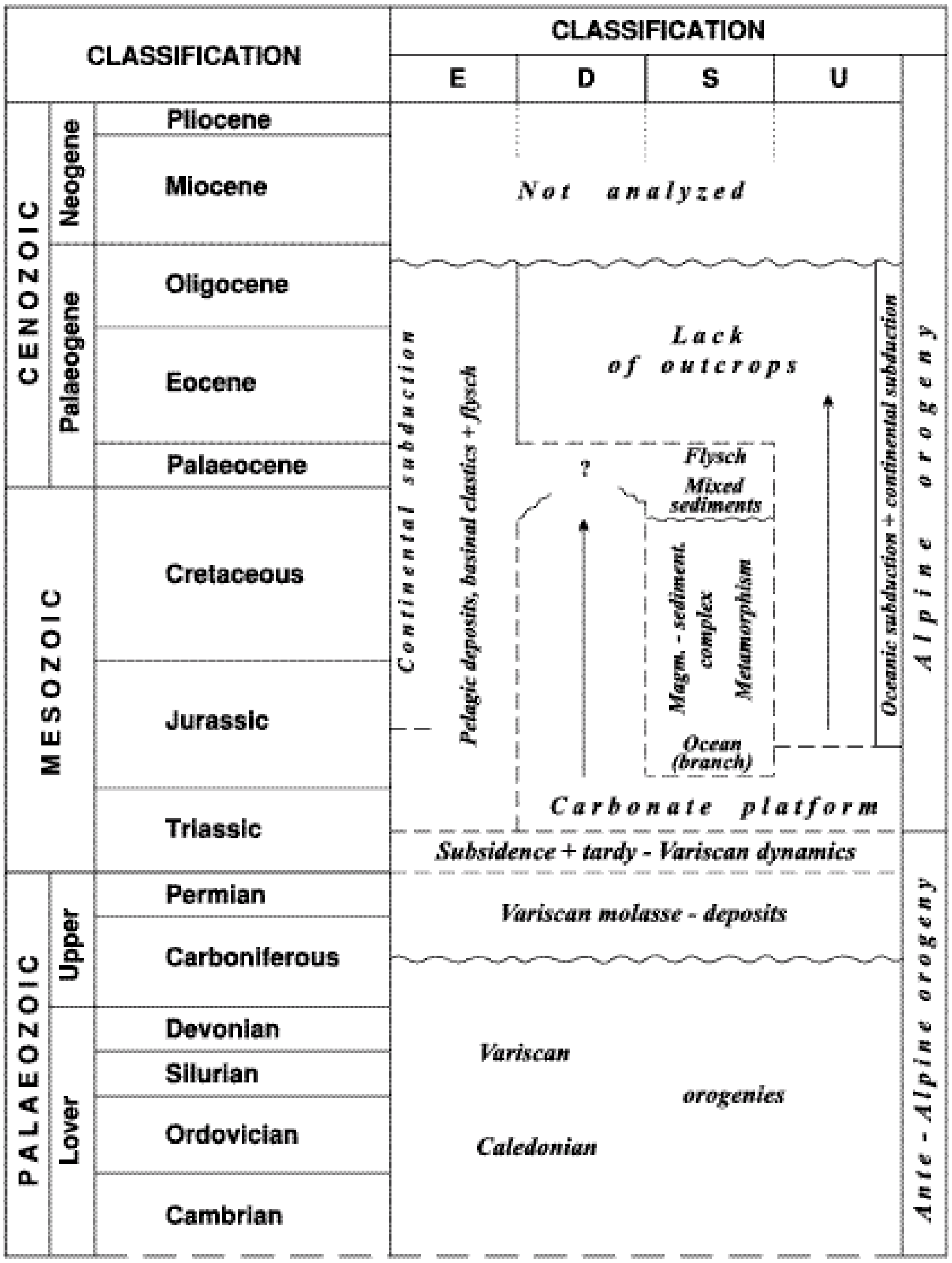

Fig. 1 Diversification of Mesozoic events in the adjacent areas of the Dinarides and the Southern Alps: U) Uppermost platform deposits; S) Supradinaric oceanic rocks; D) Dinaric platform deposits; E) Epiadriatic pelagic deposits and formations with pelagic components.

there are numerous inverse tectonic contacts indicating piling up of various lithocomplexes that require palinspastic reconstruction of the primary environments.

Compiled stratigraphic data on Mt. Medvednica (ŠIKIĆ, 1995) include units ranging in age from the Palaeozoic to the Quaternary. Since the main purpose of this paper is the reconstruction of palaeotectonic relationships, the discussion of Neogene and Quaternary deposits is omitted.

As there is a high degree of stratigraphic diversification, the origin of different stratigraphic complexes cannot be explained by means of lateral facies within single consistent depositional areas. Usable data have been published in numerous papers cited by ŠIKIĆ (1995). In this paper, only the most pertinent ones will be taken into account.

Generally, several primarily consistent lithostratigraphic successions, characterized by features indicating complementary palaeogeographic and tectonic diversification in space and time (Figs. 1-4), can be distinguished in the Alpino-Dinaridic realm, though these are dispersed at the surface.

2.1. VARISCAN BASINAL FORMATIONS

The Palaeozoic, from the Silurian to the Middle Carboniferous, displays prevailingly basinal type of carbonate and clastic sediments. They are exposed in

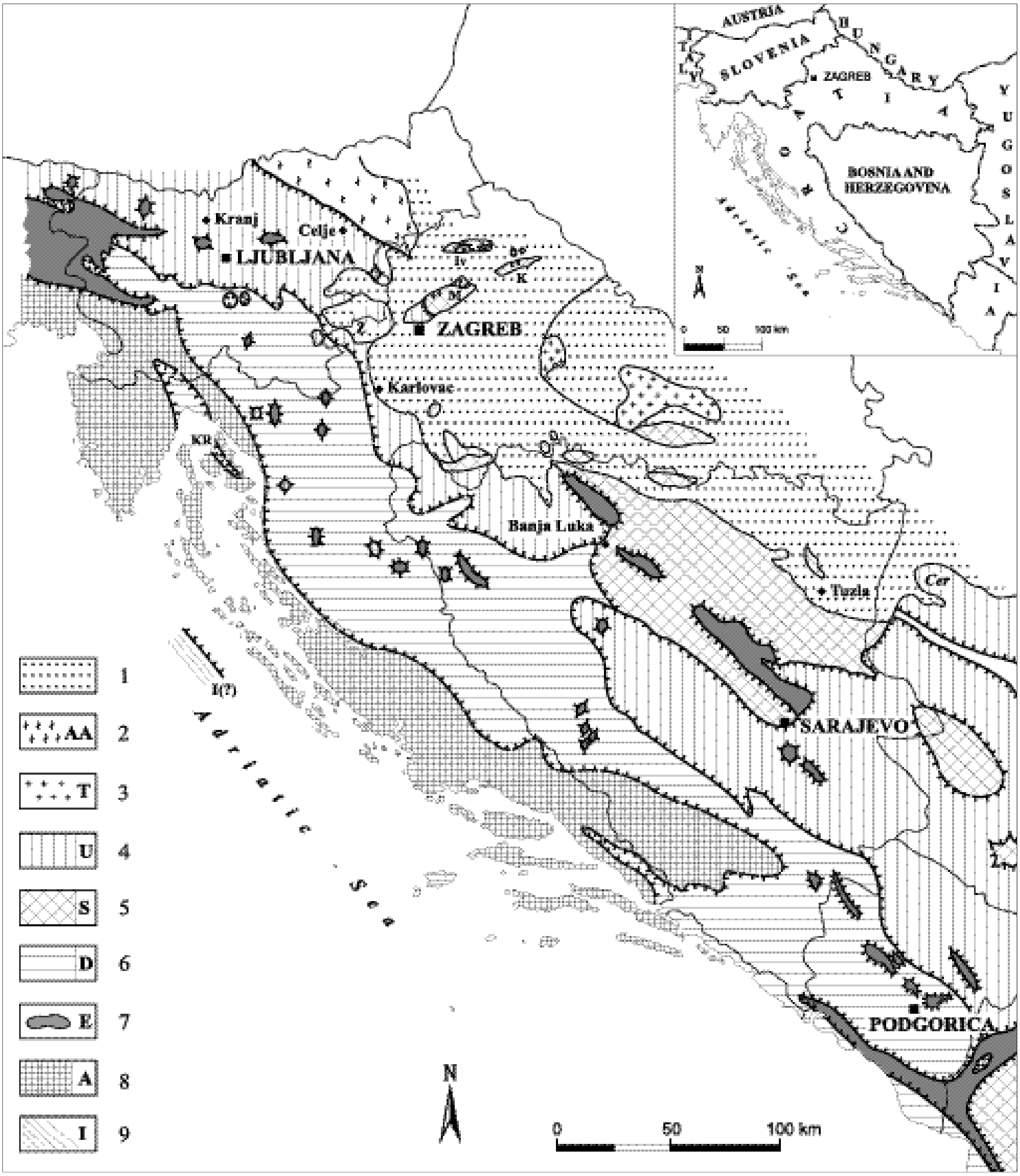

Fig. 2 Proposal of an emended and generalized map of the Dinaridic - South Alpine joint realm for further considerations; subductional tectonic model, based on selected outcrop-areas with simplified and partially enlarged contours: 1) Neogene and Quaternary cover; 2) Austroalpine; 3) Tisia; 4) Uppermost Nappe (with some tectonic windows); 5) *Supradinaricum* (*s. str.*); 6) *Dinaricum*; 7) *Epiadriaticum* (pelagic deposits and clastics with pelagic components); 8) *Adriaticum*; 9) ? Ionian underthrust; K) Mt. Kalnik (see Fig. 3); M) Mt. Medvednica (see Fig. 3); Ž) Mt. Žumberak with the Samobor area (see Fig. 4); Iv) Mt. Ivanščica.

Mt. Medvednica (ĐURĐANOVIĆ, 1973; SREMAC & MIHAJLOVIĆ-PAVLOVIĆ, 1983). Some outcrops are slightly metamorphosed with relatively well-preserved graptolites, conodonts, etc. Even in cases when they are included into the younger metamorphic complex, it is possible to use them as evidence of primary basinal sedimentary conditions. However, in Trgovska Gora W of the Una River, SE of Zagreb, only non-metamorphic outcrops of the Devonian and the Carboniferous with conodonts are present (ĐURĐANOVIĆ, 1973) what indicates that they do not belong to the same tectonic unit. The change from basinal type of sedimentation in the Middle Carboniferous is due to the Variscan orogeny which formed the structural basis for later molasse sediments. However, Variscan megastructures (with some older tectonic elements) are preserved only in the adjacent Slavonian Mountains belonging to the Tisia (JAMIČIĆ, 1983; HERAK et al., 1990).

Palaeozoic fragments (together with Triassic examples) are poorly preserved as protoliths of the younger metamorphics (greenschists and associated schist members). This rock complex with changed mineral composition originated during the process of progressive low-grade metamorphism (BELAK et al., 1995a, b). Therefore, it may be treated as a consequence of the Alpine tectonic deformations and metamorphism.

2.2. VARISCAN MOLASSE DEPOSITS

The Late Palaeozoic is represented by Carboniferous deposits with corals as well as clastics, which contain the remains of land plants (Banovina, SE of Zagreb). Various plant fragments are also found in Mt. Medvednica and Mt. Žumberak.

The molasse deposists in the region of Samobor are most characteristic. They consist of Permian (possibly also of some Carboniferous) clastics composed of quartz conglomerates, lithoclastic graywackes, siltites, shales, and sporadic dolomites. The terrestrial origin of the clastic components is further proven by the remains of land plants *Calamites* and *Sigillaria* (JENKO, 1944).

Evaporites were deposited in the transition time between the Permian and the Early Triassic. They are followed continuously by variegated clastics, what may be decisive in the interpretation of the Uppermost Nappe (Fig. 2, U), unifying Palaeozoic and Triassic deposits as an integral unit which overlies oceanic formations of the Inner Dinarides.

Some isolated platform outcrops are "strange" within Variscan molasse deposits. Possibly they can derive from the subducted (?) Dinaric platform. In an Eocene breccia in Hrvatsko Zagorje (Vinica and Višnjica W of Varaždin), MILANOVIĆ (1982) found Middle Carboniferous limestone fragments with foraminifera and calcareous algae. He correlated them with analogous deposits in Mt. Velebit, Banovina, etc. In the area northwest of Samobor (near the Bregana Village), in a small isolated carbonate area, calcareous algae (*Gymnocodium*, *Atractyliopsis*, etc.) have been determined (HERAK & ŠKALEC, 1967). In Mt. Medvednica a boulder has been found which contains remains of *Neoschwagerina* (DEVIDÉ-NEDĚLA & KOCHANSKY-DEVIDÉ, 1990). ŠIMUNIĆ (1979) registered Lower Permian algae in a non-metamorphosed limestone in Mt. Medvednica.

2.3. TARDY-VARISCAN DYNAMICS AND THE ORIGIN OF CARBONATE PLATFORMS

The main Lower Triassic components include: sandstones, siltites, marly limestones, oolitic limestones, and some dolomites (in the upper part of the limestones ammonites are preserved). The general tendency of subsidence is obvious.

The Middle Triassic was a time of relative tectonic disquiet, especially in the Anisian. Some rifting with volcanism (mostly several types of basalts) and clastic sedimentation occurred. However, generally dolomites and dolomitized limestones prevail, continuing also into the Ladinian. At several horizons of the Middle Triassic, small areas of ammonitic limestones have been found. The tectonic dynamics in the Middle Triassic was tardy-Variscan (final), forming the basis for the origin of later carbonate platform areas.

In the Upper Triassic, stromatolitic dolomites and some limestones with megalodontids predominate. Carbonate sedimentation lasted until the Palaeogene with some oscillations indicated by shallow water clastics and small gaps (CRNJAKOVIĆ, 1981).

2.4. MESOZOIC DEPOSITS WITH PELAGIC INFLUENCES

The outcrops of Late Triassic pelagic deposits are encircled either by platform or by oceanic facies from which they can be distinguished: from the platform formations by the type of sediments (platy limestones, radiolarites, etc.), and from the oceanic formations by a lack of a magmatic-sedimentary complex with ultramafics and mafic intrusives. On the NW side they outcrop in the Slovenian Trough (GRAD, 1961; COUSIN, 1973; LAPAJNE & ŠRIBAR, 1973; PREMRU, 1975, 1983; BUSER, 1977, 1989; BABIĆ & ZUPANIČ, 1978; BABIĆ, 1980/81; JURKOVŠEK et al., 1990, etc.). Towards the E and SE they are present at many isolated sites.

In recent times, very important dispersed pelagic outcrops have been described on the northern slope of Mt. Medvednica and on Mt. Kalnik (Fig. 3), and then on Mt. Žumberak (Fig. 4).

At the localities of Mt. Kalnik the metabasalts, shales and radiolarites outcrop. Primary contacts with the surrounding facies are not clearly visible. Locally, the outcrops are composed of heavily tectonized rocks. The lower part of the succession is composed of calcitized, porphyritic, ophitic metabasalts. The age of the radiolarites corresponds to the Carnian-Norian time interval (HALAMIĆ & GORIČAN, 1995).

On the northwest slope of Mt. Medvednica radiolarian cherts alternate with silty shales. The sediments are intensely folded, partially even overturned. Their base is not known due to intensive tectonics, and they are non-conformably overlain by Palaeocene calcitic siltstones. However, it is probable that the examined Triassic radiolarites are partially overlain by similar silty siliceous sediments (radiolarian cherts, shales, etc.) of uncertain Jurassic age (HALAMIĆ & GORIČAN, 1995, p. 135).

In the adjacent area of Mt. Hum, NW of Mt. Medvednica (valley of Burnjak), limestones with intercala-

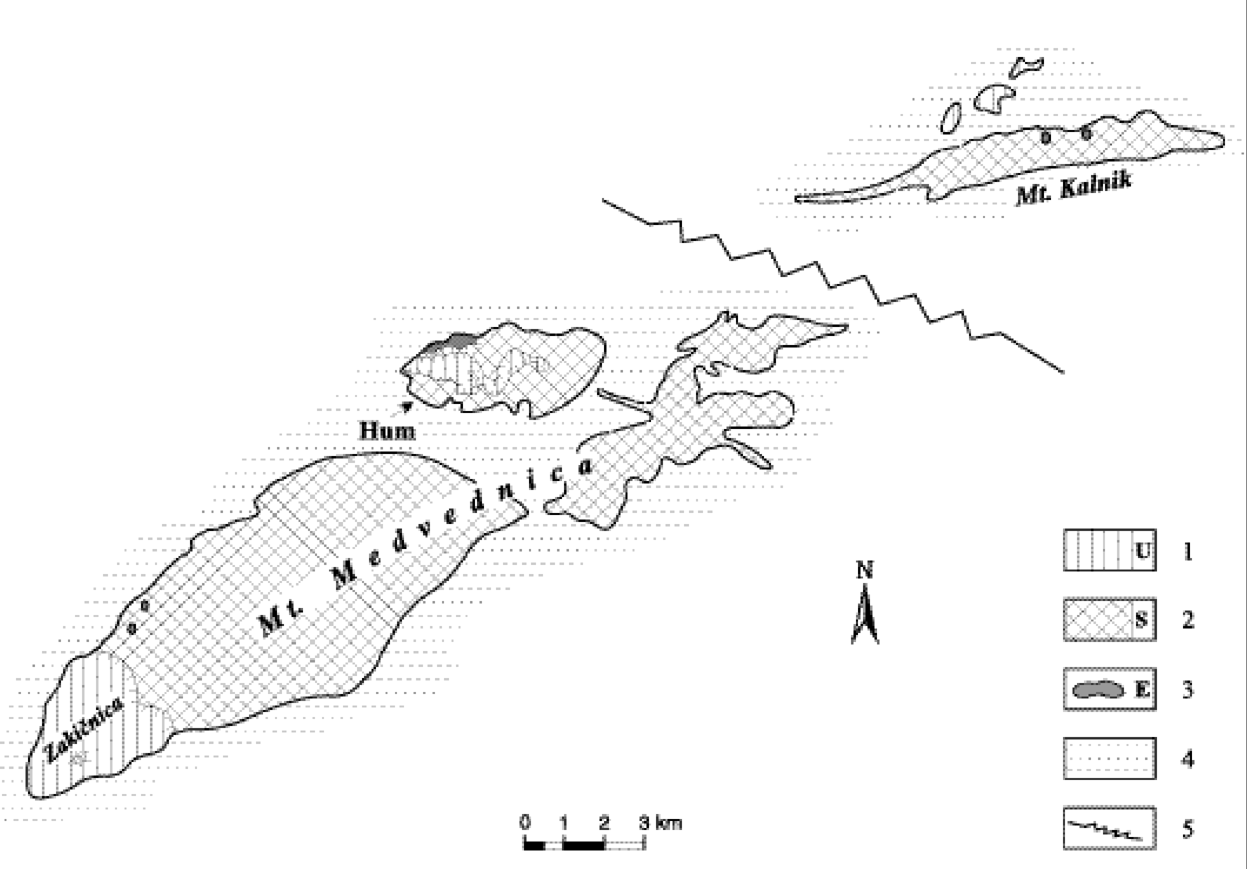

Fig. 3 Simplified main tectonic units in the mountains Medvednica and Kalnik; basic data from ŠIKIĆ (1995) and ŠIMUNIĆ (pers. comm.), reinterpreted: 1) Uppermost Nappe; 2) *Supradinaricum* (with possible small Dinaric outcrops) disturbed by strong interior tectonism; 3) pelagic deposits and formations with pelagic influences (interpreted as *Epiadriaticum*); 4) Neogene and Quaternary cover; 5) place of graphical shortening of the terrain.

tions and lenses of chert outcrop (ŠIKIĆ, 1995). Discontinuous fragments of pelagic outcrops, belonging to the transition between the Upper Triassic and the Lias are also present, as well as pelagic limestones with radiolarians and lagenid foraminifera of Late Lias - Dogger age. Some isolated outcrops belong to the Jurassic-Neocomian, others to the Tithonian-Berriasian, with a possible "hard ground" at the contact with Triassic dolomites (BABIĆ & ZUPANIČ, 1973; BABIĆ, 1975; ŠIKIĆ, 1995, p. 15). The incompleteness of the columns is ascribed to the condensed sedimentation. In Mt. Ivanščica, ZUPANIČ et al. (1981), and ŠIMUNIĆ (1992) also emphasized that, due to the "hard ground", Tithonian-Valanginian deposits non-conformably overlie different stages of the Triassic. Explanation of such a phenomenon in that way would anticipate intensive tectonics at the end of the Triassic with the consequence that the lack of sedimentation would last until the Late Tithonian. Such a hiatus there has not been substantiated. Moreover, the origin of ophiolites, accompanied by younger magmatic-sedimentary rocks in the same area, argues in favour of intensive tectonics during the Jurassic and the Early Cretaceous. Besides, the Triassic in question does not necessarily belong to the same tectonic unit as the Triassic which constitutes the overlying nappe.

Some other Lower Cretaceous outcrops also indicate basinal sedimentation (with pelagic influences). Such is the "Oštrc formation" in Mt. Ivanščica described by ZUPANIČ et al. (1981). It overlies the afore mentioned Tithonian-Valanginian pelagic deposits. The formation consists of calcarenites, sandstones, marly shale, and deposits with radiolaria and spicules. The calcarenites frequently show silicification and recrystallization phenomena. The authors concluded that the part of the basin within the Mt. Ivanščica area originated upon the continental crust. Analogous relationships also occur at Mt. Žumberak (BABIĆ, 1974). Moreover, correlation is assumed with the Vranduk area in Bosnia belonging to the Bosnian Zone (defined by AUBOUIN et al., 1970), which displays essential differences in sediments beginning with the Late Triassic, and continuing during the Jurassic and Cretaceous. The Zone may be followed in Montenegro. In Western Serbia OBRADOVIĆ & VASIĆ (1996, p. 191) speak of "isolated bedded series" with radiolarites of different ages within various complexes. Analogous deposits outcrop even in Albania, however not as a continuous zone but as local-

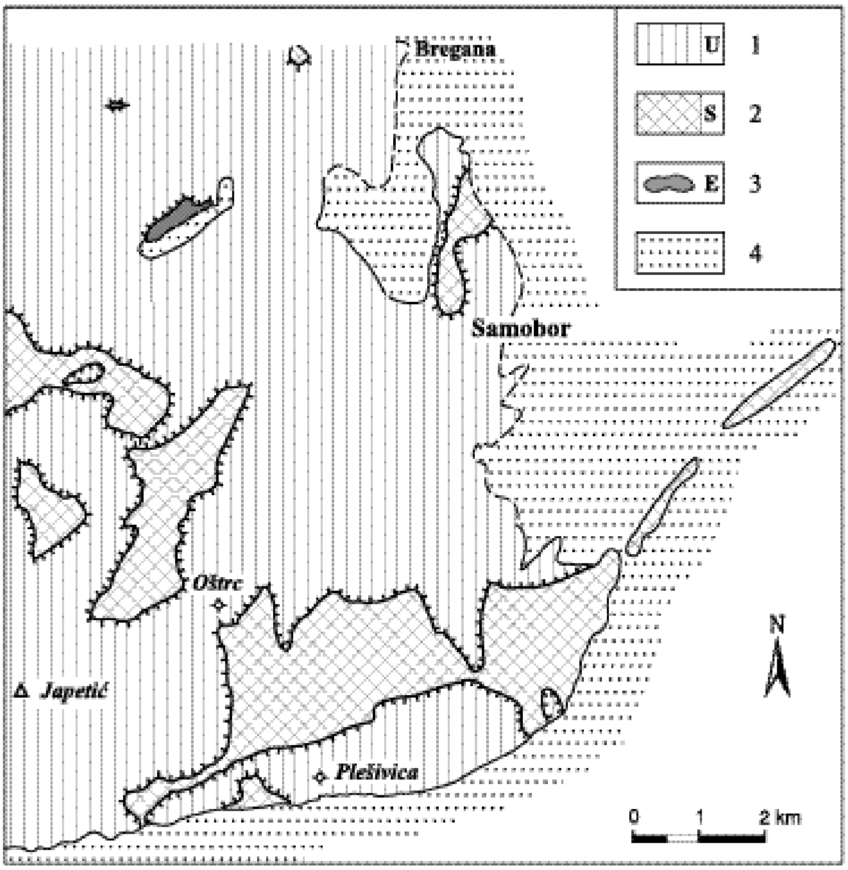

Fig. 4 Simplified tectonic map of the eastern part of Mt. Žumberak (with the area of Samobor), supplemented by J. BUKOVAC: 1) Uppermost Nappe; 2) *Supradinaricum* (with possible small Dinaric outcrops); 3) pelagic deposits and formations with pelagic influences (interpreted as *Epiadriaticum*); 4) Neogene and Quaternary cover.

ized "strange" bodies within the Mirdita Zone. All this suggests that these deposits with pelagic elements are tectonically emplaced within heterogeneous areas.

Similar heterogeneity has been found even in other morphotectonic units like the North Karavanke Alps (MIOČ & ŠRIBAR, 1975), and in the Outer Dinarides. The latter were discussed by many authors (cited in HERAK, 1993). The age of dispersed pelagic deposits within the Outer Dinarides range from the Triassic (outcrops in the Budva Zone, and in the Slovenian Trough) to the Late Cretaceous, with a predominance of Upper Jurassic outcrops. At the margin towards the Inner Dinarides even Palaeogene outcrops occur. They all require a common provenance influenced by the same open sea environment. The lack of both intrusives and metamorphic rocks means that the distribution area of pelagic components was outside the active orogenic realm. Therefore, their recent position can only be explained by entangled tectonics, discussed later.

2.5. OCEANIC MEGAENVIRONMENT

The origin of a belt with oceanic components started within the area most often called the Inner Dinarides. According to GUŠIĆ & BABIĆ (1972, p. 336), the lithology and fossil contents of the fragments in the Senonian breccia in Mt. Medvednica "show that the Norian-Rhaetian limestones had been deposited in a very shallow sea, whereas the Liassic sediments had originated in a considerably deeper and quiet marine environment". It is important to mention that on the northwestern slope of Mt. Medvednica a tectonically delimited, narrow Upper Triassic - Dogger limestone zone, partially dolomitized and recrystallized, is present (ŠIKIĆ, 1995). This means that, due to tectonic forces, two major environments have been brought close to one another. This fact requires additional investigation, as pointed out by ŠIKIĆ (1995, p. 14). For our purpose, it seems acceptable that, in the area where the tectonic dynamics later increased, the deepening within the Triassic-Liassic carbonate platform started not earlier than the end of the Lias. Consequently, the above mentioned, tectonically delimited pelagic limestones with chert of Upper Triassic age (HALAMIĆ & GORIČAN, 1995; ŠIKIĆ, 1995) should be "strange" in the areas where they are outcropping.

The oceanic opening made possible the uplift of ultramafic rocks. The isolated outcrops have been found in Mt. Medvednica and in Mt. Kalnik, secondarily emplaced into Cretaceous clastics. They are also present in some deep bore-holes north-eastward of Mt. Medvednica (ŠIMUNIĆ & PAMIĆ, 1989; ŠIKIĆ, 1995; PAMIĆ, 1997). Furthermore, a magmatic-sedimentary complex originated, composed of clastics and magmatic rocks: gabbro, diabases, spilites, etc. (CRNKOVIĆ, 1963).

As to the origin of the adjacent Tisia, there are different opinions discussed in numerous papers (see: CLOETINGH et al., 1993). Later, SZEDERKENY

(1996) is of the opinion that during the Jurassic (Bathonian) the Tisia fragments were broken-off the southern margin of the Variscan Europe and after a complicated drifting, accompanied by rotation, came to their present tectonic position. In this case, the general platform area split into two branches. One is nowadays extended in the Mid-Transdanubian Unit, Bükk Unit, etc., the other remained southward of the Tisia. However, general agreement does not yet exist. Anyhow, the oceanic formations were subducted northward under the platform elements, disintegrated them and, possibly, in a latter phase even obducted upon the Slavonian part of the Tisia (in contrast, MATEJ et al., 1997, assume the subduction of Tisia). During the oceanic dynamics metamorphic rocks (greenschists, etc.) were formed (BELAK et al., 1995a, b). Analogous rocks have been found at places outside of our area, e.g. anchizonal metamorphism has been described in Hungary in the Mid-Transdanubian Unit. BERCZI-MAKK et al. (1993, p. 280) accepts the opinion that it presumably belongs "to a nappe unit of lower position" (i.e., to the *Supradinaricum, s. str.*, as it will be treated in this paper).

Tectonic consolidation processes, approximately at the beginning of the Turonian interrupted the tectonic dynamics, responsible for the origin of the magmatic-sedimentary complex. The deposition was influenced not only from the open sea, but also from the near-shore and land surfaces due to oscillation of basin bottom depth with changes of depositional environments, followed by subduction processes within the crust. All this changed the future sedimentation processes, which included conglomerates, sandstones, siltites, shales, rudist bioherms, platy limestones with globotruncanids, turbidites (with slope and bottom influences), etc. They are either in superposition or represent only lateral facies. The true relationships are difficult to explain due to subsequent tectonic disturbances.

2.6. PREDOMINANCE OF FLYSCH DEPOSITS

From the Senonian the "continental" and "oceanic" troughs were not so well delimited being narrowed due to subduction and bottom uplift. The transgression upon the adjacent land surfaces is often mentioned because flysch elements also overlie different platform surfaces. Despite the interfingering with other facies, the predominance of the flysch in the time span from the Maastrichtian to the Palaeocene is evident (CRNJAKOVIĆ, 1981; DEVIDÉ-NEDĚLA et al., 1982; BUKOVAC, 1988; MARINČIĆ et al., 1995; ŠIKIĆ, 1995, etc.).

2.7. FINAL TECTOGENETIC CONSEQUENCES

After the Palaeocene continental subduction processes caused piling up and squeezing of different tectonic units, emplacement of granites, etc. Afterwards, uplift occurred, followed by Oligocene and Neogene volcanism, tilting, strike-slip faulting, rotation, and, possibly, slow subduction and/or obduction. However, these events are not the topic of this paper.

3. TECTONIC EVOLUTION AND CLASSIFICATION

The recent general characteristic of the area under discussion is intensive fragmentation of the previously described lithostratigraphic complexes. They have been disturbed by continental (A) subduction, oceanic (B) subduction, then by more or less vertical movements connected with gravitational displacements, and finally by erosion. According to the presented lithostratigraphy, the main events should be the following.

Before the Late Triassic, the major events were more or less uniform over the whole area, only displaying interior differentiations, sometimes of a high degree, but not specific enough to be used as diagnostic features in recognizing single well defined megatectonic units.

At the beginning of the Late Triassic, the new major differentiation started. According to the afore mentioned lithostratigraphic sequences and their position between two carbonate complexes visible at many places, a labile ("miodynamic") continental trough originated, being connected with the open sea. It enabled the open sea to influence the platform areas. The first deposits in this trough were Late Triassic pelagic sediments (limestones, cherts, etc.). The longitudinal distribution of their outcrops suggests an adequate (longitudinal) common "furrow". It remains to be seen if it was within the carbonate platforms (HERAK, 1986, 1991, 1995, 1997, etc.) or within the oceanic realm itself, at the oceanic margin of the platform (AUBOUIN et al., 1970). The latter opinion was common before the mobilistic concept was introduced. However, there are still many adherents (e.g., PAMIĆ et al., 1998). My concept is based on the fact that at several places the pelagic deposits are emplaced between two carbonate platform units (Budva Zone, Una spring area, Slovenian Trough, etc.) which would be impossible if the "furrow" were adjacent to the oceanic realm. Initially, the deposition was confined to the "furrow" itself, then the surfaces widened upon the platform margins, lagoons and basins of clastic deposition.

After the Lias, within the northern (northeastern) part of the platform a new deep oceanic trough was formed, being characterized by "eudynamic" processes during the Jurassic and a larger part of the Cretaceous.

Later on, the events in all labile areas were characterized predominantly by clastic deposits not only within the basins but also upon the adjacent platforms.

According to the mentioned interrelationships, it is obvious that the reconstruction of single major tectonic zones is very difficult. However, this may be attempted, taking into account their composition and recent position. It is possible to distinguish several homogenous nappe units. They will be differently named in order to distinguish them from the morphotectonic entities (Outer Dinarides, Inner Dinarides, Southern Alps, Mid-Transdanubian Zone, etc.), which are usually heterogeneous, composed of elements of two or more subducted (underthrusted) homogeneous units. As the names are a question of convention, the possibility is open for new proposals if they can be supported by better reasons.

3.1. THE UPPERMOST NAPPE (U)

The overlying components of the region under discussion (Figs. 1-4, U) form a nappe composed predominantly of Triassic dolomites with some limestones, accompanied by Lower Triassic clastics including well-bedded limestones, as well as by Upper Palaeozoic molasse deposits (which do not derive from the Inner Dinarides). They are characterized by west-east, or southwest-northeast extension. The nappe is disintegrated and it comprises elements which have been described as the Pannonian Nappe (MILADINOVIĆ, 1981, and earlier), as well as the Sava Nappe (MIOČ, 1981, and earlier), or the inverse basement of the Inner Dinarides (HERAK, 1991) as a part of the *Supradinaricum*. Recent additional data (ŠIKIĆ, 1995) justify the tectonic distinction of this Uppermost Nappe deriving outside the Dinaric realm (*s. str.*), i.e., from the Southern Alpine area, emplaced on the northern side of the Oceanic Trough (*Supradinaricum*, *s. str.*). This Nappe overlies not only the oceanic *Supradinaricum*, but also parts of Jurassic and Cretaceous carbonate rocks of the Dinaric carbonate platform (*Dinaricum*), mostly in the form of klippen. The final emplacement may be at least partly caused by gravitation.

At this point, it is necessary to note that some Triassic and Palaeozoic deposits may not belong to the Uppermost Nappe but to Dinaridic major units as their direct basement. Therefore, the utmost care is required in interpretation of the tectonic position of different Triassic and Palaeozoic outcrops.

3.2. THE SUPRADINARIC NAPPE (*Supradinaricum*, s. str., S)

This Nappe (Figs. 1-4, S) comprises the oceanic part of the *Supradinaricum* (*s. l.*), overlain by the Uppermost Nappe. The Nappe is characterized by formations originated as a consequence of "eudynamics" from the Lias to the Turonian. In the Senonian, differentiation increased under pelagic and terrestrial influences. Simultaneous uplifts widened the influences of this basin upon adjacent platform margins, in the form of extensions of flysch deposits (marginal flysch) which hide the boundaries between the basin and the platforms. Therefore, only flysch deposits, which are tectonically connected with oceanic formations, belong to this Nappe. The rest of it (the marginal epiplatform flysch) is to be treated together with the next tectonic megaunit (*Dinaricum*). The Vardar elements are also included in the *Supradinaricum*. However, their frame exceeds the frame of the Vardar Zone as defined by KOSSMAT (1924). The western extension of the *Supradinaricum* is covered by the Uppermost Nappe.

3.3. THE DINARIC NAPPE (*Dinaricum*, D)

At the southern (southwestern) side, the rocks of the Dinaric carbonate platform (Figs. 1 and 2, D) bordered the oceanic belt (*Supradinaricum*, *s. str.*). As a major tectonic unit, it is called *Dinaricum* and it underlies the Supradinaric Nappe. Within the *Dinaricum* several "strange" outcrops of pelagic deposits have been found. Their origin and tectonic position were repeatedly discussed (citations in HERAK, 1993). In the contact area of the *Supradinaricum* and *Dinaricum*, including the marginal flysch (with some karstifications in the basement), the nappe relations are obvious (PREMRU et al., 1977; HERAK, 1986; BUKOVAC, 1988). Consequently, "La sous-zone prékarstique" (BLANCHET et al., 1970) is also included into this megaunit.

Previously, the contact zone of the Dinaric platform and oceanic formations was treated as a "flexion" or "bending" zone, making a slope of the platform towards the basinal complexes including magmatites. It was supposed that this zone existed probably since the Triassic, representing "the Adriatic microplate toward the Tethys ocean" (DIMITRIJEVIĆ, 1982, p. 11). However, it is obvious that this contact zone was created as a consequence of two events. The first, was the opening of the ocean after the Lias (more or less vertical contacts). The second was continental subduction during the Palaeogene, when the Dinaric carbonate platform, together with the overlying marginal flysch, was subducted under the basinal "magmatic-sedimentary" complex (*Supradinaricum*) and even under the Uppermost Nappe. The corresponding contacts are inclined.

The opposite margin of this megaunit, together with the underlying "strange" pelagic outcrops, are discussed below.

3.4. THE INTERPLATFORM MEGAUNIT (*Epiadriaticum*, E)

The range of the isolated outcrops of pelagic and basinal deposits without ultramafic and mafic intrusions range from the Upper Triassic to the Upper Cretaceous, and are to be found as well in the Outer as in the Inner Dinarides (Figs. 1-4, U). Their distribution is extremely difficult to explain in a generally acceptable way. The continuous outcrops extend only in the Budva-Krasta-Pindus Zone on the southeastern side and in the Slovenian Trough on the northwestern side. Between these areas, numerous tectonically delimited outcrops may indicate that their interconnection could be traced beneath the nappes mentioned earlier. In such a case even the Bosnian Zone (AUBOUIN et al., 1970) may be connected with the Budva-Krasta-Pindus Zone below the *Dinaricum* due to continental subduction. The indications of such a connection were noticed earlier. MEDWENITSCH (1964, in SIKOŠEK & MEDWENITSCH, 1965) distinguished the Subdinaricum which should consist of Budva, Mirdita and Raduša elements together with the central ophiolites. Their extension is supposed to be beneath the carbonate Dinarides. In this way, typical Inner Dinaric elements (Mirdita, Raduša, central ophiolites), which normally overlie the Outer Dinarides, were connected with the Budva Zone which underlies them and now can be interpreted as a subducted unit. On the contrary, PAMIĆ (1993, etc.), tried to connect the Bosnian Zone with the Budva Zone (united with the Mirdita Zone) upon the surface lithologic analogies.

However, the main problem, concerning all the pelagic outcrops, is that they are delimited to small areas, which are dispersed and tectonically encircled with deposits of different provenance, belonging to various morphostructural units. For instance, the deposits in question in western Slovenia are in contact with the Dinaric platform, the Julian Alps and the "Sava Folds" (= Sava Nappe sensu MIOČ, 1981). In Mt. Žumberak, Mt. Medvednica, Mt. Ivanščica and Mt. Kalnik pelagic outcrops occur within "magmatic-sedimentary" formations and, exceptionally, within platform elements. Likewise, the pelagic elements of the Bosnian Zone (AUBOUIN et al., 1970) are mostly in tectonic contact with different Inner Dinaric rocks, including the ophiolites. Also there are localities in Western Serbia (OBRADOVIĆ & VASIĆ, 1996), as well as in Albania, where localized "strange" bodies (Rubik complex, Kalur cherts, and Lumi i Zi sections) are distributed as isolated bodies within the Mirdita Zone (CAROSI et al., 1996; MARCUCCI & PRELA, 1996).

Besides, numerous Jurassic and less numerous Cretaceous isolated pelagic outcrops, often in visible tectonic contacts with shallow-water carbonate rocks, are widespread within the Dinaric carbonate platform in Slovenia, Croatia, Hercegovina and Montenegro, while the Budva Zone is overthrust upon the Adriatic carbonate platform (HERAK, 1986, with older citations). These facts and opinions require comparison with other possible alternative explanations, to determine which is the most convincing.

The first possibility would concern the model with facies differentiation. In that case, tectonic contacts with adjacent facies would be uncommon. Besides, it is impossible to assume that similar pelagic environments would prevail at the same time within a basin, which is influenced by magmatic activity and on a stabilized carbonate platform without influences from a common source of the pelagic components. Comparing recent and fossil global radiolarian localities, DE WEVER & BAUDIN (1996) came to the following conclusions: (a) "Distal basinal or oceanic environments are often optimal sites for the preservation of siliceous and lipid-rich organic material derived from plankton" (p. 310); (b) "The long held assumption of a relationship between abundance of radiolarians and volcanic processes is largely erroneous" (p. 311). Even in the case when the basins are separated from the ocean by a platform, they have to be partially open to the ocean (p. 313). However, due to oscillations the deposition itself, characterized by pelagic fossils, occurred in various depressions, i.e. even upon the platforms (in lagoons). The only condition is in the interference with the open sea (in our case the eastern Tethys).

Consequently, the pelagic components had neither oceanic nor platform characteristics. Within the derivation trough itself the pelagic column seems to be more or less complete. Upon both the adjacent marginal parts of the carbonate platforms the range and extension varied. The peripheral common boundary (at different horizons) has been characterized by the transition of pelagic deposits to carbonate shallow-water sediments. Such exposures are, in a tectonical sense, part of the platforms, while, below the *Dinaricum* a consistent tectonic complex is to be supposed.

The fragmental exposures require an explanation introducing either erosion of a common overlying and tectonically disintegrated megaunit or by numerous localized uplifts of a consistent major unit outcropping in tectonic windows which were afterwards slightly disturbed, i.e. fractured, tilted, and eroded.

The erosion as a main factor, which would disintegrate a homogeneous pelagic major unit, cannot be accepted, because, in that case, this unit should primarily cover the deposits of different ages and environments. Such a case is improbable even when there were no tectonic contacts of single outcrops with adjacent deposits. However, in many cases the contacts are distinct. At some localities younger deposits outcrop through the older ones, thus favouring allochthony. The relationships within carbonate terrains are characterized by a very important phenomenon: the rocks of the Adriatic carbonate platform primarily and tectonically underlie the pelagic deposits. At the same time, the *Dinaricum* overlies the pelagic distal deposits (together with the underlying rocks of the Adriatic platform) suggesting nappe relationships. The participation of pelagic deposits in the *Dinaricum* is not obvious due to subductional contact. In the subduction process within the continental crust, the ductile deposits were a detachment level, making possible long-rate continental subduction even under the "magmatic-sedimentary" formations, indicating that the dispersed pelagic outcrops within them are tectonic windows. Such a concept respects the dispersion of pelagic and other deposits with open sea influences within the belts of different provenance and their contacts with platform and basinal formations. The relationships of platform and pelagic deposits are still hidden due to nappe relationships. The interior reconstruction of their allochthonous disturbances are omitted.

3.5. THE ADRIATIC NAPPE (*Adriaticum*, A)

The next lower tectonic major unit consists predominantly of carbonate rocks with some pelagic sediments and flysch. It is extended on the southwestern side of the overlying *Epiadriaticum* (Fig. 2, A). There are also some detached bodies of the *Dinaricum* overlying the *Adriaticum* (possibly, due to younger gravitational displacements). The differences between them are difficult to establish, and require detailed analyses and regional correlations. Recently, DROBNE & TRUTIN (1997) palaeontologically confirmed the existence of a tectonic window of the marginal part of the *Adriaticum* through the *Dinaricum* at Bunić in the Lika. BLAŠKOVIĆ (1999) proposed a major tectonic classification based on the *Adriaticum*, *Epiadriaticum* and *Dinaricum* for purpose of oil prospection. ROMANDIĆ & ALJINOVIĆ (1999) easily recognized the *Adriaticum* beneath the *Dinaricum* in strongly disturbed sedimentary sequences, with cumulative thickness of up to 17 km, using geoelectric and palaeomagnetic methods.

The *Adriaticum* is delimited by the *Epiadriaticum* on one side and by (?)Ionian deposits on the other. Longitudinally it continues toward the southeast into the Gavrovo-Tripolitza domain. Sporadically, it occurs within the *Dinaricum* as tectonic windows. Remarkable is also the Hercegovinian half-window.

3.6. ?THE IONIAN UNDERTHRUST (?*Ionicum*, I)

The insular region of the Adriaticum is underlain by Cretaceous-Palaeogene deposits (LAWRENCE et al., 1995), possibly belonging to the Ionian Basin, and subducted under the Adriaticum (Fig. 2, I). This fact may justify the distinguishing of the Adriatic and Apulian platforms.

4. CONCLUSIONS

To avoid some discrepancies in the interpretation of the Alpino-Dinaridic realm in a “geosynclinal” way, one of the posibilities is to follow the partially emended concept of continental subductions as accompanying process of oceanic subduction, based upon new lithostratigraphic and structural notions previously cited.

The approach to the subduction mechanism encounters great difficulty due to the fact that the traces of the oceanic subduction are quite hidden. Only the presence of restricted outcrops of ultramafic rocks (ŠIMUNIĆ & PAMIĆ, 1989; PAMIĆ, 1997), secondarily emplaced into Cretaceous deposits, testifies such a process. Therefore, they do not reflect primary relationships which would define their origin and later tectonic displacements. Even the essential problem related to our part of Tethys is not obvious; it concerns the question of whether we are dealing only with a branch of Tethys or if there was a connection with the Penninic Belt below the Southern Alps and the Austroalpine Nappes. Also, the time of the tectonic emplacement of the Slavonian Mountains (as a part of Tisia) is still under discussion.

The only certain geotectonic phenomena are the consequences of continental subductions. Their traces are preserved within all the major facies, indicating a general northward (northeastward) movement (caused by the movements in the asthenophere). All the complexes of the Outer and Inner Dinarides behaved according to their constitution, being either brittle or ductile. Anyway, the rate of the disturbances suggests the existence of weak zones at several levels, which made a strong allochtonous imbrication possible. The continental subductions were preceded by very complex dynamics, and have been followed by uplift of the area (vertical faulting), tilting, possible additional subduction and obduction, rotation, and often neglected gravitational displacements. The time relations of the tectogenetic process are relatively easily distinguished.

1. During the Variscan orogeny, vast continental surfaces originated, upon which, later, intensive deposition of terrigenous fragments occurred. However, in that time the continental crust was not completely stabilized. Rifting and magmatic processes in the Middle Triassic (and at the beginning of the Late Triassic) were renewed, and accompanied by andesitic extrusions (tardy-Variscan dynamics). This disquiet was relatively short and final, and it prepared the basis for vast and temporally extensive sedimentation of carbonate platform deposits. In the Upper Triassic an oscillating interplatform trough was formed. It remained directly connected with the open sea, from which pelagic components were supplied during the whole Mesozoic era. The oscillations within the trough caused periodic ingressions of pelagic deposits upon the adjacent platforms, especially in the Late Jurassic and the Late Cretaceous.
2. North of the interplatform trough, after the Lias, the opening of the ocean (including our western branch) occurred with simultaneous extrusions of already consolidated mantle rocks (ultramafites). So, the “miodynamics” and “eudynamics” were contemporaneous with mutual influences in their final phase. After the extrusions of the mantle rocks (peridotites, serpentinites), the equilibrium was disturbed and northward movements of lithospheric complexes were initiated (as a consequence of adequate dynamics in the asthenosphere). All this resulted in oceanic subduction and the consuming of subducted material, while the more resistent ultramafites remained on the surface, submitted to further disturbances.
3. The asthenospheric northward movements were not only localised under the oceanic lithosphere, but were also active under the continental part, including the trough between the Adriatic and Dinaric platforms. The influence was different upon the platform surfaces in comparison with the oscillating trough, in which continental subduction started. Therefore, the trough narrowed and the sea level rose, with the ingression of pelagic material upon

the marginal platform areas, overlying platform formations and interfingering with them.

4. The Oceanic Trough was, in the Late Jurassic and the Early Cretaceous, still a place of intensive "eudynamics" accompanied by strong magmatism and low to medium-grade metamorphism. The closure of the Trough, approximately in the Middle Cretaceous, was followed by deposition of clastics accompanied by small reefs, platy limestones, and by flysch deposits. At that time, there were no sharp boundaries of the sedimentary basins within the frame of the Dinaridic part of the Tethys.

5. Due to the closure of epicontinental and oceanic belts, the crust generally coalesced and afterwards behaved more or less as a single major unit composed of rigid and weak domains. This fact determined the future behaviour in respect to the northward movement in the asthenosphere, which continued. The multiple continental subductions were influenced by ductile horizons. In this way a complex allochthonous structural pattern has originated. Along the Interplatform Trough, the subduction was most intensive, resulting in the carbonate rocks with the flysch of the Adriatic platform (*Adriaticum*) underlying not only the pelagic elements (of Epiadriatic provenance), but elsewhere are also directly overlain by the carbonate rocks of the Dinaric platform (*Dinaricum*). The *Dinaricum* has been subducted under the oceanic formations (*Supradinaricum*, *s. str.*) which underlie Palaeozoic and Triassic platform elements of the Uppermost Nappe. Moreover, in the frames of the major nappes imbrication is also present. Delimitation and gradation of tectonic units is difficult due to the fact that parts of pelagic and flysch deposits primarily overlie platform margins, and are, in the tectonic sense, only parts of the platform nappe units. Along the major contact zones, the underthrusting character of contacts is obvious, though not necessarily equal to one another. Then, subduction process increased towards the west (northwest) and, therefore, the zones wedge out. In this way the Dinaric strike (SE-NW) was finally established. Only the elements of the Uppermost Nappe have not been essentially influenced, and so the difference in strike between this Nappe and the Dinaridic structural units (nappes) could be explained. Such a dynamics lasted approximately until the end of the Oligocene and, thus, the basis for the Neogene indentation process was prepared. The consequences of the process itself have been interpreted in several papers (e.g., RATSCHBACHER et al., 1991), though the moving forces were not well defined. According to this proposal, they should be represented by continental subductions.

6. Simultaneously, in the main Alpine and Carpathian domains, the subductions were directed generally toward the south. Therefore, our region was squeezed and the thickness of sedimentary complexes increased, not only due to piling up of subducted units but also due to the rise of the Cretaceous-Palaeogene S-granites, final volcanism, etc.

7. The concentrated thermal "diapirism" was distributed within all the tectonic units, and in this way numerous tectonic windows originated, predominantly of the ductile flysch and pelagic deposits. At such places the chaotic carbonate breccias on the northern slope of Mt. Medvednica ("Horvatove stube", Pronjak), as well as in Mt. Kalnik and Mt. Ravna Gora, have been interesting to many authors (e.g. BABIĆ et al., 1973; ŠIMUNIĆ et al., 1993; PRTOLJAN et al., 1995), but a final explanation has not yet been found. Their emplacement is characterized by tectonic contacts with the adjacent rocks. The age of the fragments belong to different horizons of the Mesozoic, with a matrix of Campanian age. ŠIMUNIĆ et al. (1993, p. 614) assume that the upper boundary of these "exotic breccias" is post-Palaeocene, and suggest "that they might have been originated along subduction zones". It could be added that also localized rise of parts belonging to different subducted nappes contributed to the genesis of the breccias, making in fact the (additionally disturbed) tectonic windows. I am conscious that such an unconfirmed opinion might be considered as too courageous, but it should be taken into account in future discussions.

8. The mentioned vertical diversification was intensified during the Neogene, and caused disintegration, tilting, rotation and gravitational displacements of parts of the nappes. Therefore, fragments with different vergencies are to be found even upon Neogene sediments. The process itself is considered as very complicated (possibly combined with slight subductions), and an explanation exceeds the topic of this paper.

9. The proposed model can be understood on the basis of the mobilistic interpretation of geotectonic problems. The assumption of continental subductions helps to explain not only major structures but also "strange", "uncommon", "isolated", and "exotic" phenomena, as single constituents of major tectonic units, within logical, though not anticipated structural frameworks.

10. Due to a nappe system, it is necessary to distinguish not only the previously discussed homogeneous tectogenetic units (Uppermost Nappe, *Supradinaricum*, s. str., *Dinaricum*, *Epiadriaticum*, *Adriaticum* and (?)Ionian underthrust) but also some more or less individualized morphotectonic complexes, e.g., the Adriatic area, High Karst Belt, Outer Dinarides, Inner Dinarides, the Pannonian Basin, etc. To this category of terms also belong the Mid-Transdanubian Zone, Zagreb Zone, and "Sava Folds". They all are characterized by a heterogeneous, composite

constitution terminated during neotectonic dynamics, and are used in the regional geology and geomorphology.

11. I hope that the intention of this paper to explain the tectonic setting of the Alpino-Dinaridic realm in a mobilistic sense may be generally acceptable base for further discussions. Therefore, the concept may not be considered as final. Many pecularities remain open to further confrontations, based upon additional, more accurate (confirming or emending) data.

Acknowledgements

The preparation of the manuscript required additional discussions of some elementary data with experts of different research fields, e.g., with Ljubomir BABIĆ, Stjepan BAHUN, Mirko BELAK, Josip BUKOVAC, Ivan GUŠIĆ, Domagoj JAMIČIĆ, Vladimir JELASKA, Vladimir MAJER, Pero MIOČ, Jakob PAMIĆ, Branko SOKAČ, Antun ŠIMUNIĆ, Marko ŠPARICA, Ivo VELIĆ, etc. The drawings have been executed by Miroslav KLADNIČKI. To all of them I express my sincere gratitude.

5. REFERENCES

AUBOUIN, J., BLANCHET, R., CADET, J.-P., CELET, P., CHARVET, J., CHOROWICZ, J., COUSIN, M. & RAMPNOUX, J.-P. (1970): Essai sur la géologie des Dinarides.- Bull. Soc. géol. de France, 12, 1060-1095.

BABIĆ, Lj. (1973): Bazenski sedimenti gornjeg titona i valendisa zapadno od Bregane (Upper Tithonian to Valanginian basinal sediments west of Bregana).- Geol. vjesnik, 26, 11-27.

BABIĆ, Lj. (1974): Razdoblje otriv-cenoman u Žumberku: stratigrafija, postanak sedimenata i razvoj prostora (Hauterivian to Cenomanian time in the region of Žumberak, Northwestern Croatia: stratigraphy, sediments, paleogeographic, paleotectonic evolution).- Geol. vjesnik, 27, 11-33.

BABIĆ, Lj. (1975): Kondenzirani lijas Medvednice i Ivanščice i njegovo značenje za interpretaciju paleogeografskog razvoja unutarnje dinarske regije (Condensed Liassic sedimentation on Mt. Medvednica and Mt. Ivanščica - northern Croatia - and its significance for the interpretation of the paleogeographic evolution of the Inner Dinaric belt).- Geol. vjesnik, Zagreb, 28, 11-18.

BABIĆ, Lj. (1980/81): The origin of "Krn Breccia" and the role of the Krn area in the Upper Triassic and Jurassic history of the Julian Alps (Postanak "Breče Krna" i uloga predjela Krna u povijesti Julijskih Alpa u gornjem trijasu i juri).- Vesnik Zav. geol. geofiz. istraž., (A), Beograd, 38-39, 59-75.

BABIĆ, Lj. & ZUPANIČ, J. (1973): Najmlađa jura i najstarija donja kreda u Ivanščici (uppermost Jurassic and Early Cretaceous deposits on Mt. Ivanščica - northern Croatia).- Geol. vjesnik, 26 (1972), 267-272.

BABIĆ, Lj. & ZUPANIČ, J. (1978): Kossmatovi "Železnikarski vapnenci i dolomiti" i "Zaliloški krovni škriljavci" u predgorju Julijskih Alpa; podaci o stratigrafiji, facijesu i paleogeografskom značenju (Kossmat's "Kalke und Dolomite von Eisnern" and "Dachschiefer von Salilog" in the Julian Prealps: data about stratigraphy, facies and paleogeography).- Geol. vjesnik, 30/1, 21-42.

BABIĆ, Lj., GUŠIĆ, I., & DEVIDÉ-NEDĚLA, D. (1973): Senonski kršnici na Medvednici i njihova krovina (Senonian breccias and overlying deposits on Mt. Medvednica - northern Croatia).- Geol. vjesnik, 25 (1971), 11-27.

BELAK, M., PAMIĆ, J., KOLAR-JURKOVŠEK, T., PECSKAY, Z. & KARAN, D. (1995a): Alpinski regionalnometamorfni kompleks Medvednice - sjeverozapadna Hrvatska.- 1. hrv. geol. kongres (Opatija, 1995), Zbornik radova, 1, 67-70, Zagreb.

BELAK, M., SREMAC, J., CRNKO, J. & KOLAR-JURKOVŠEK, T. (1995b): Paleozojske stijene niskog stupnja metamorfizma na jugoistočnoj strani Medvednice (sjeverozapadna Hrvatska).- 1. hrv. geol. kongres (Opatija, 1995), Zbornik radova, 1, 71-74, Zagreb.

BERCZI-MAKK, A., HAAS, J., RALISCH-FELGENHAUER, E., & ORAVECZ-SCHEFFER, A. (1993): Upper Paleozoic-Mesozoic formations of the Mid-Transdanubian Unit and their relationships.- Acta geol. Hungar., 36/3, 263-296.

BLANCHET, R., CADET, J.P. & CHARVET, J. (1970): Sur l'existence d'unités intermediaires entre la Zone Haut-Karst l'unité du flysch bosniaque, en Yougoslavie: la sous-zone prékarstique.- Bull. Soc. géol. de France, 12, 227-236.

BLAŠKOVIĆ, I. (1999): Subsurface tectonic relations - a basis for determination of the zones of petroleum-geological prospectivity.- Working materials, 2nd intern. Symposium of Petroleum Geology, Croat. Acad of Sci. and Arts, Faculty of Mining, Geology and Petroleum Engineering and INA, 133-145, Zagreb.

BUKOVAC, J. (1988): Tectonics of the contact zone of the Dinaricum and Supradinaricum in the area of Krnjak-Barilović-Karlovac, Croatia, Yugoslavia (Tektonski odnosi u kontaktnoj zoni Dinarika i Supradinarika u području Krnjak-Barilović-Karlovac, Hrvatska, Jugoslavija).- Acta geol., 18/1, 1-12, Zagreb.

BUSER, S. (1977): Osnovna geološka karta SFRJ 1:100.000. List Celje L33-67.- Geol. zavod Ljubljana (1972-1976), Savezni geološki zavod, Beograd.

BUSER, S. (1989): Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian basin (NW Jugoslavia).- Mem. Soc. geol. It., 40 (1987), 313-330.

CAROSI, R., CODRA, A., MARRONI, M. & MUSTAFA, F. (1996): Deformation history of Jurassic Kalur cherts from the Mirdita nappe, Albanian ophiolites.- Ofiolit, 21/1, 41-45, Pisa.

CLOETINGH, S., SASSI, W. & HORVÁTH, F. (eds.) (1993): The origin of sedimentary basins: Interferences of the quantitative modelling and basin analyses.- Tectonophysics, 226, Elsevier, 518 p.

COUSIN, M. (1973): Le sillon Slovène: les formations triassiques, jurassiques et neocomiennes au Nord-Est de Tolmin (Slovenie occidentale, Alpes méridionales) et leur affinites dinariques.- Bull. Soc. géol. France, 15/3-4, 326-338.

CRNKOVIĆ, B. (1963): Petrografija i petrogeneza magmatita sjeverne strane Medvednice (Petrography and petrogenesis of the magmatites of the northern part of Medvednica Mountain).- Geol. vjesnik, 16 (1962), 63-160.

CRNJAKOVIĆ, M. (1981): Mastrihtski fliš jugozapadnog dijela Medvednice (Maastrichtian flysch sediments in the southwest part of Mt. Medvednica).- Geol. vjesnik, 34, 47-61.

CVIJIĆ, J. (1924): Geomorfologija.- Drž. štamparija, Beograd, XXI+588 p.

DEVIDÉ-NEDĚLA, D. & KOCHANSKY-DEVIDÉ, V. (1990): Neoschwagerinenfund in Medvednica-Gebirge (Zagrebačka gora).- Rad Jugosl. akad. znan. i umjetn., 449, 29-34, Zagreb.

DEVIDÉ-NEDĚLA, D., BABIĆ, Lj. & ZUPANIČ, J. (1982): Mastrihtska starost fliša Vivodine u Žumberku i kod Ozlja (zapadna Hrvatska) na temelju planktonskih foraminifera (Age maestrichtien du Flysch de Vivodina dans le Žumberak et des environs d'Ozalj en Croatie occidentale - Yougoslavie).- Geol. vjesnik, 35, 21-36.

DE WEVER, P. & BAUDIN, F. (1996): Palaeogeography of radiolarite and organic-rich deposits in Mesozoic Tethys.- Geol. Rundschau, 85, 310-326, Berlin.

DIENER, C. (1903): Bau und Bild der Ostalpen und des Karstgebietes.- Bau und Bild Österreichs, Wien, 2, 1-328.

DIMITRIJEVIĆ, M.D. (1982): "Pregib", gledan mobilistički ("Flexion zone" - a mobilistic viewpoint).- Radovi Znan. savjeta za naftu Jugosl. akad znan. i umjetn., A, 10, 7-11, Zagreb.

DROBNE, K. & TRUTIN, M. (1997): Alveolinas from the Bunić section.- Geol. Croatica, 50/2, 215-223.

ĐURĐANOVIĆ, Ž. (1973): O paleozoiku i trijasu Medvednice (Zagrebačke gore) i područja Dvora na Uni na temelju konodonta (About the Paleozoic and Triassic of Medvednica Mountain and the area near Dvor na Uni on the basis of Conodonts).- Geol. vjesnik, 25 (1971), 29-49.

GORJANOVIĆ-KRAMBERGER, D. (1907): Geologija gore Samoborske i Žumberačke.- Rad Jugosl. akad. znan. i umjetn., 120 (Matem.-prir, razred, 18), 1-82, Zagreb.

GRAD, K. (1961): Obavestilo o raziskavah krednih sedimentov v Posavskih gubah (Note on the investigation of Cretaceous sediments in the Sava folds).- Geologija, 6 (1960), 313-315, Ljubljana.

GUŠIĆ, I. & BABIĆ, Lj. (1972): Die Mikrofazies und Mikrofauna der Obertrias und des Lias des Medvednica Gebirges (Nordkroatien).- Mitt. Ge. Geol. Bergbaustud., 21, 327-340, Innsbruck.

HAAS, J., KOVÁCS, S., KRYSTYN, L. & LEIN, R. (1995): Significance of Late Permian-Triassic facies zones in terrane reconstruction of Alpine - North Pannonian domain.- Tectonophysics, 242, 19-40.

HALAMIĆ, J. & GORIČAN, Š. (1995): Triassic radiolarites from Mts. Kalnik and Medvednica.- Geol. Croat., 48/2, 129-146.

HERAK, M. (1986): A new concept of geotectonics of the Dinarides (Nova koncepcija geotektonike Dinarida).- Acta geol., 16/1, 1-42, Zagreb.

HERAK, M. (1991): Dinaridi - mobilistički osvrt na genezu i strukturu (Dinarides - Mobilistic view of the genesis and structure).- Acta geol., 21/2, 35-117, Zagreb.

HERAK, M. (1993): Additional considerations on the Epiadriaticum, Outer Dinarides.- Geol. Croat., 46/1, 165-168.

HERAK, M. (1995): Koncepcijski doseg geologije Hrvatske (Conceptional scope of the geology of Croatia).- 1. hrv. geol. kongres (Opatija, 1995), Zbornik radova, 1, 25-33, Zagreb.

HERAK, M. (1997): Croatia.- In: MOORES, E.M. & FAIRBRIDGE, R.W. (eds): Encyclopedia of European and Asian Regional Geology. Chapman & Hall, London, 155-160.

HERAK, M., JAMIČIĆ, D., ŠIMUNIĆ, A. & BUKOVAC, J. (1990): The northern boundary of the Dinarides (Sjeverna granica Dinarida).- Acta geol., 20/1, (Prir. istraž., 60), 5-27, Zagreb.

HERAK, M. & ŠKALEC, D. (1967): Vapnenačke alge u permu Samoborskog gorja (Kalkalgen im Perm des Samoborer Gebirges).- Geol. vjesnik, 20, 37-40.

JAMIČIĆ, D. (1983): Strukturni sklop metamorfnih stijena Krndije i južnih padina Papuka (Structural fabric of the metamorphosed rocks of Mt. Krndija and the eastern part of Mt. Papuk).- Geol. vjesnik, 36, 51-72.

JENKO, K. (1944): Geološki rad na listu Samobor 1:75000.- Vjesnik Hrv. drž. geol. zav., 2/3, 19-23, Zagreb.

JURKOVŠEK, B., ŠRIBAR, Lj. & KOLAR-JURKOVŠEK, T. (1990): Pelagičke jurske in kredne plasti v zahodnem delu Julijskih Alp (Pelagic Jurassic and Cretaceous beds in the western part of the Julian Alps).- Geologija, 31-32 (1988-89), 285-328, Ljubljana.

KIŠPATIĆ, M. (1899): Nastavak bosanske serpentinske zone u Hrvatskoj.- Rad. Jugosl. akad. znan. i umjetn., 139 (Matem.-prir. razred, 27), 44-73, Zagreb.

KOCH, F. (1924): Geotektonische Beobachtungen in Alpino-Dinarischem Grenzgebiete.- Zbornik radova posv. Jovanu Cvijiću,341-358, Beograd.

KOSSMAT, F. (1924): Geologie ser zentralen Balkanhalbinsel; mit einer Übersicht des dinarischen Gebirgsbaues. Die Kriegsschauplätze 1914-1916.- Bornträger, Berlin, V+198 p.

LAPAJNE, V. & ŠRIBAR, Lj. (1973): Zgornjokredni sedimenti na območju Posavskih gub (Upper Cretaceous deposits in the Sava folds).- Geologija, 16, 237-244, Ljubljana.

LAWRENCE, S.R., TARI-KOVAČIĆ, V. & GJUKIĆ, B. (1995): Geological evolution model of the Dinarides.- Nafta, 46/2, 103-113, Zagreb.

MARCUCCI, M. & PRELA, M. (1996): The Lumi i Zi (Puke) section of the Kallur cherts: Radiolarian assemblages and comparison with other sections in northern Albania.- Ofioliti, 21, 71-84, Pisa.

MARINČIĆ, S., ŠPARICA, M., BENIĆ, J. & KOROLIJA, B. (1995): Sedimenti senona u dolini Mikulić potoka.- In: ŠIKIĆ, K. (ed.): Geološki vodič Medvednice. Inst. za geol. istraž. & INA-Naftaplin, 73-76, Zagreb.

MATEJ, S., NOVOSELEC, E. & TARI-KOVAČIĆ, V. (1997): Neogene extension and compression processes in the central part of the Sava Depression, South Pannonian Basin, Croatia.- Dynamics of the Pannonian-Carpathian-Dinaride System, Polish Acad. of Sci., 1091, Krakow - Zakopane.

MILADINOVIĆ, M. (1981): Pregled tektonske građe zapadnog dela Jugoslavije (Vue sur la téctonique des Dinarides occidentales Yougoslaves).- Geol. glasnik, 9, 89-106, Titograd.

MILANOVIĆ, M. (1982): Carboniferous microfossils from Gorski kotar, Hrvatsko zagorje and Banija (Karbonske mikrofosilne asocijacije Gorskog kotara, Hrvatskog zagorja i Banije).- Palaeont. Jugosl., 28, 1-34, Zagreb.

MIOČ, P. (1975): Prilog poznavanju tektonskih odnosa granične zone istočnih Posavskih bora i dinarskog šelfa (Contribution to the knowledge of the tectonic relations of the boundary zone of the eastern Sava Folds and Dinaric shelf).- 2. god. znan. skup Sekcije za primjenu geol., geofiz. i geokem. Znan. savjeta za naftu Jugosl. akad. znan. i umjetn., 223-228, Zagreb.

MIOČ, P. (1981): Tektonski odnosi Savske navlake u Sloveniji te njena veza sa širim jugoslavenskim područjem (Tectonic relationship of Sava thrust compared to the adjacent units in Slovenia and its relation with the broader Yugoslav area).- Nafta, 32/11, 543-548, Zagreb.

MIOČ, P. & ŠRIBAR, Lj. (1975): Jurski skladi v Severnih Karavankah (The Jurassic beds in the North Karavanke Mountains).- Geologija, 18, 87-97, Ljubljana.

MLAKAR, I, (1987): Prispevek k poznavanju geološke zgradbe Posavskih gub in njihovega južnega obrobja (A contribution to the knowledge of the geological structure of the Sava Folds and their southern border).- Geologija, 28-29 (1985-86), 157-182, Ljubljana.

MOJSISOVICS, E. (1880): West Bosnien und Türkisch-Croatien.- In: MOJSISOVICS, E., TIETZE, E. & BITTNER, A. (eds.): Grundlinien der Geologie von Bosnien-Herzegowina. Jahrb. Geol. Reichsanst., 30, 1-100, Wien.

OBRADOVIĆ, J. & VASIĆ, N. (1996): The significance of the radiolarites in the evolution of depositional basins - some examples in Yugoslavia.- In: Terranes of Serbia. Univ. of Belgrade & Serbian Acad. of Sci. and Arts, 191-195, Beograd.

PAMIĆ, J. (1993): Eoalpine to Neoalpine magmatic processes in the northwestern Vardar Zone, the easternmost Periadriatic Zone and the southwestern Pannonian Basin.- Tectonophysics, 226, 503-518.

PAMIĆ, J. (1997): The northwesternmost outcrops of the Dinaric ophiolites: a case study of Mt. Kalnik (North Croatia).- Acta geol. Hungar., 40/1, 37-56.

PAMIĆ, J., GUŠIĆ, I. & JELASKA, V. (1998): Geodynamic evolution of the Central Dinarides.- Tectonophysics, 297, 251-264.

PETERS, F.K. (1863): Bemerkungen über die Bedeutung der Balkan-Halbinsel als Festland in der Liasperiode.- Sitzungsber. Akad. Wiss. (Matem.-naturwiss. Klasse), 6-10, 418-426, Wien.

PILAR, Gj. (1882): Geološka zapažanja u zapadnoj Bosni. Iztraživanja od 1879.- Rad Jugosl. akad. znan. i umjetn., 65, 1-68, Zagreb.

PREMRU, U. (1975): Starost ponikvastih skladov (Das Alter der Ponikva-Schichten).- Geologija, 18, 75-86, Ljubljana.

PREMRU, U. (1983): Osnovna geološka karta SFRJ 1:100.000. List Ljubljana L33-66.- Geol. zavod

Ljubljana (1969-1978), Savezni geološki zavod, Beograd.

PREMRU, U., OGORELEC, B. & ŠRIBAR, Lj. (1977): O geološkoj zgradbi Dolenjske (On the geological structure of the Lower Carniola).- Geologija, 20, 167-192, Ljubljana.

PRTOLJAN, B., OŠTRIĆ, N., FUČEK, L., VELIĆ, I. & TIŠLJAR, J. (1995): Mezozojske vapnenačke stijene u predjelu Horvatove stube - Markov travnik.- In: ŠIKIĆ, K. (ed.): Geološki vodič Medvednice.- Inst. geol. istraž. & INA-Naftaplin, 137-139, Zagreb.

RATSCHBACHER, L., FRISCH, W., LINZER, H.G. & MERLE, O. (1991): Lateral extrusion in the Eastern Alps; Part 2: structural analysis.- Tectonics, 10/2, 257-271.

ROMANDIĆ, S. & ALJINOVIĆ, B. (1999): Interpretation of geophysical data in SW part of Dinarides.- Working materials, 2nd Intern. Symposium of Petroleum Geology. Croat. Acad. of Sci. and Arts, Faculty of Mining, Geology and Petroleum Engineering & INA, 195-205, Zagreb.

SALOPEK, M. (1914): Moderna alpinska tektonika i geologija Hrvatske i Slavonije.- Glasnik Hrv. prir. društva, 26/2, 85-109, Zagreb.

SIKOŠEK, B. & MEDWENITSCH, W. (1965): Neue daten zur fazies und tektonik der Dinariden.- Verh. Geol. Bundesanst., Sonderheft G, 86-102, Wien.

SREMAC, J. & MIHAJLOVIĆ-PAVLOVIĆ, M. (1983): Graptoliti Medvednice (Zagrebačke gore) (Graptolites of Mt. Medvednica - Zagrebačka Gora).- Rad Jugosl. akad. znan. i umjetn., 404, (Razr. prir. znan., 19), 65-68, Zagreb.

SUESS, E. (1875): Die Entstehung der Alpen.- Bornträger, Berlin, 158 p.

SZEDERKENY, T. (1996): Metamorphic formations and their correlation in the Hungarian part of Tisia Megaunit (Tisia composite terrane).- In: Terranes of Serbia. Univ. of Belgrade & Serbian Acad. of Sci. and Arts, 229, Beograd.

ŠIKIĆ, K. (ed.) (1995): Geološki vodič Medvednice.- Inst. za geol. istraž. & INA, Zagreb, 199 p.

ŠIKIĆ, K., BASCH, O. & ŠIMUNIĆ, A. (1978): Osnovna geološka karta SFRJ 1:100000. List Zagreb, L38-80.- Inst. geol. istraž. (1972), Savezni geol. zavod, Beograd.

ŠIKIĆ, K., BASCH, O. & ŠIMUNIĆ, A. (1979): Osnovna geol. karta SFRJ 1:100000. Tumač za list Zagreb, L38-80.- Inst. geol. istraž. (1972), Savezni geol. zavod, Beograd, 81 p.

ŠIMUNIĆ, A. (1979): The deep marine development of Paleozoic and Mesozoic in Northwestern Croatia.- 16th European micropaleont. colloquium, 107-111, Ljubljana.

ŠIMUNIĆ, A. (1992): Geološki odnosi središnjeg dijela Hrvatskog zagorja.- Unpublished PhD Thesis, University of Zagreb, 193 p.

ŠIMUNIĆ, A. & HEĆIMOVIĆ, I. (1979): Tektonski odnosi sjeverozapadne Hrvatske - Ivanščica, Kalnik i Ravna gora (Tectonic relationships of the northwest Croatia - Ivanščica, Kalnik and Ravna Gora).- Zbornik radova 4. god. skupa Sekcije za primjenu geol., geofiz. and geokem. Znan. savjeta za naftu, Stubičke toplice, 1978, Jugosl. akad. znan. i umjetn., 187-198, Zagreb.

ŠIMUNIĆ, A. & PAMIĆ, J. (1989): Ultramafitne stijene kod Gornjeg Orešja na sjeveroistočnim obroncima Medvednice (Ultramafic rocks on the northeastern flanks of Mt. Medvednica - northern Croatia).- Geol. vjesnik, 42, 93-101.

ŠIMUNIĆ, A., NAJDANOVSKI, J. & PAMIĆ, J. (1993): Chaotic rock-complexes, possible hydrocarbon accumulations in southwestern parts of the Pannonian Basin (R. of Croatia).- Nafta, 44/11, 609-616, Zagreb.

TORNQUIST, A. (1918): Das Erdbeben von Rann an der Save.- Mitt. Erdbebenkommission, N.F., 52, 1-117, Wien.

WINKLER, A. (1924): Über den Bau der östlichen Südalpen.- Mitt. geol. Ges., 16 (1923), 1-272, Wien.

ZUPANIČ, J., BABIĆ, Lj. & CRNJAKOVIĆ, M. (1981): Bazenski klastiti donje krede (Oštrc formacija) Ivanščice u sjeverozapadnoj Hrvatskoj (Lower Cretaceous basinal clastics (Oštrc formation) in Mt. Ivanščica (northwestern Croatia)).- Acta geol., 11, 1-44, Zagreb.

Manuscript received February 3, 1998.
Revised manuscript accepted May 28, 1999.