GEOLOGICA CARPATHICA, 49, 5, BRATISLAVA, OCTOBER 1998
341–350

NORTH DINARIDIC LATE CRETACEOUS–PALEOGENE SUBDUCTION-RELATED TECTONOSTRATIGRAPHIC UNITS OF SOUTHERN TISIA, CROATIA

JAKOB PAMIĆ

Croatian Academy of Sciences and Arts, Ante Kovačića 5, 10000 Zagreb, Croatia

(Manuscript received February 23, 1998; accepted in revised form September 1, 1998)

Abstract: In order to evaluate the structural position of Mesozoic formations underlying the Neogene South Pannonian Basin, a tentative correlation is proposed between (1) the Late Cretaceous–Paleogene subduction-related magmatic, sedimentary and metamorphic units of the North Dinarides and (2) the apparently exotic blocks of the same units found in the subsurface and at the surface within the Pannonian Basin. The formations are as follows: a — Sedimentary Late Cretaceous to Paleogene flysch sequences, at their base interlayered with basalt, alkali-feldspar rhyolite and pyroclastics and intruded by penecontemporaneous A-type granites; b — Very low-, low- and medium-grade regionally metamorphosed sequences which originated from the surrounding Late Cretaceous–Paleogene rocks; c — Synkinematic Eocene A-type and S-type granitoids, and d — Underlying tectonized ophiolite mélange. Concordant radiometric (71 to 48 Ma) and geological ages were obtained on the rocks of the first three units from both areas. This paper presents diagrams which schematically illustrate and summarize the Late Cretaceous to Miocene evolution of the area adjoining the North Dinarides and South Pannonian Basin. Geological profiles, based on seismic data, are presented. The occurrence of North Dinaridic Late Cretaceous–Paleogene subduction-related exotic fragments found in the South Pannonian Basin can be explained: 1 — by Oligocene uplift of detached fragments of the underthrust North Dinarides in the nascent Drava and Sava depressions, and 2 — by Pliocene strike-slip faulting.

Key words: North Dinarides, South Pannonian Basin, flysch sequences, Alpine metamorphic sequences, synkinematic granitoids, ophiolite mélange, correlation.

Introduction

According to the earliest plate tectonic interpretations, the Pannonian Basin (PB) was regarded as a back-arc basin relative to the Carpathians (Stegena et al. 1975 and others). Later Royden et al. (1983) suggested that the evolution of the PB was controlled by extension, coeval with compression in the Carpathians, extension being induced by subduction of the Eurasian plate and roll-back of the subducted slab. Recent geodynamic interpretations of the PB, considering the mosaic-like pattern of the Mesozoic-Paleogene units occurring in its northwestern parts (the Pelso Megaunit), proposed that its =development was governed by Late Oligocene/Early Miocene escape tectonics from the Eastern Alps (Kázmér & Kovács 1985; Ratschbacher et al. 1991; Csontos et al. 1992 and others).

However, these geodynamic models did not take into consideration that to the south the PB is bounded by another major mountain system, namely the Dinarides. Geometrically, the marginal parts of the South PB are strongly controlled by the tectonic contact between the Dinaride Ophiolite Zone and the overlying Late Cretaceous–Paleogene metamorphic-magmatic-sedimentary units (Fig. 1). These are genetically related to the ancient north-dipping subduction zone of the Dinaridic-Hellenidic Tethys that was first activated during the Late Jurassic/Early Cretaceous and remained active until the Late Eocene. The different Mesozoic-Paleogene units, which are widespread in the North Dinarides, can be correlated with equivalent rock units outcropping and occurring in the subsurface of the South PB.

This paper focuses on Late Cretaceous–Paleogene sedimentary, igneous and metamorphic rocks occurring in the South PB and their correlation with tectonostratigraphic units of the North Dinarides. This correlation and available field and geophysical data suggest that the Late Cretaceous–Paleogene blocks of the South PB were emplaced due to exhumation of underthrust North Dinaridic units during the Oligocene early phases of development of the Sava and Drava depressions and due to Pliocene strike-slip faulting locally giving rise to transpressive thrusting. This transpressive deformation occurred in post-Pannonian time when the northernmost Dinarides were thrust over the southern parts of the Tisia.

Multiple opinions have been proposed regarding the geotectonic setting of the border area between the North Dinarides and Tisia. These have been summarized and their inherent problems discussed by Pamić (1987). Based on field data, analyses of cores from deep wells and seismic data, the surface boundary between the North Dinarides and the Tisia block runs approximately south of the Mts. Moslovačka Gora, Psunj, Požeška Gora, Dilj and Fruška Gora, and thus generally coincides with the northern marginal fault of the Sava Depression (Fig. 1). As such it relates closely to the boundary proposed by Herak et al. (1990).

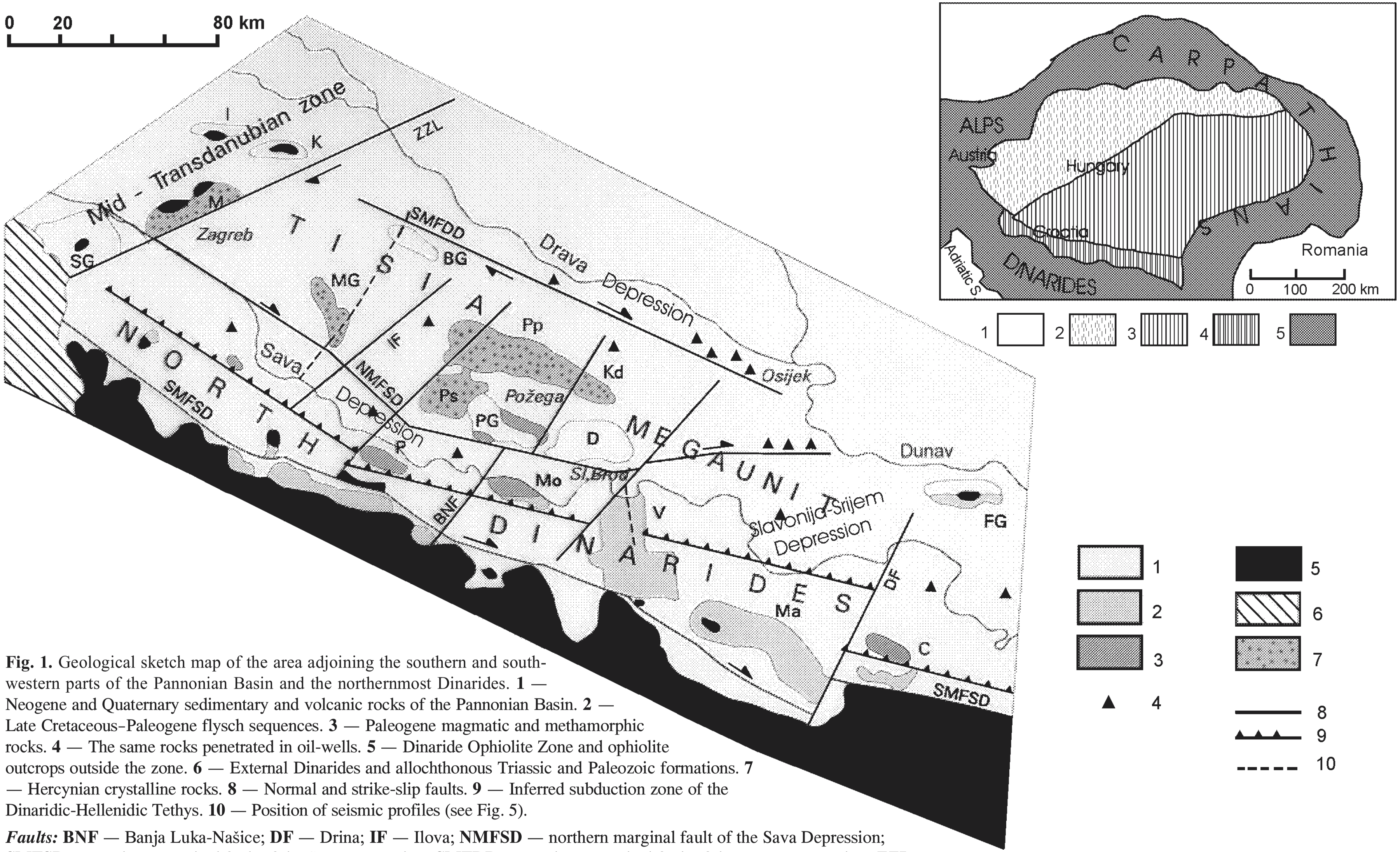


Fig. 1. Geological sketch map of the area adjoining the southern and south-western parts of the Pannonian Basin and the northernmost Dinarides. **1** — Neogene and Quaternary sedimentary and volcanic rocks of the Pannonian Basin. **2** — Late Cretaceous–Paleogene flysch sequences. **3** — Paleogene magmatic and methamorphic rocks. **4** — The same rocks penetrated in oil-wells. **5** — Dinaride Ophiolite Zone and ophiolite outcrops outside the zone. **6** — External Dinarides and allochthonous Triassic and Paleozoic formations. **7** — Hercynian crystalline rocks. **8** — Normal and strike-slip faults. **9** — Inferred subduction zone of the Dinaridic-Hellenidic Tethys. **10** — Position of seismic profiles (see Fig. 5).

Faults: **BNF** — Banja Luka-Našice; **DF** — Drina; **IF** — Ilova; **NMFSD** — northern marginal fault of the Sava Depression; **SMFSD** — southern marginal fault of the Sava Depression; **SMFDD** — southern marginal fault of the Drava Depression; **ZZL** — Zagreb-Zemplen.

Mountains: **BG** — Bilogora; **C** — Cer; **D** — Dilj; **FG** — Fruška Gora; **I** — Ivanščica; **K** — Kalnik; **Kd** — Krndija; **M** — Medvednica; **Ma** — Majevica; **MG** — Moslavačka Gora; **Mo** — Motajica; **P** — Prosara; **PG** — Požeška Gora; **Pp** — Papuk; **Ps** — Psunj; **SG** — Samoborska Gora; **V** — Vučjak.

INDEX-MAP showing the position of the Pannonian Basin: 1— Tertiary sediments ± volcanics of the Pannonian Basin underlain by: 2 — Pelso Unit including Zagorje-Midtransdanubian zone, 3 —Tisia Unit and 4 — Dinarides; 5 —surrounding mountain systems.

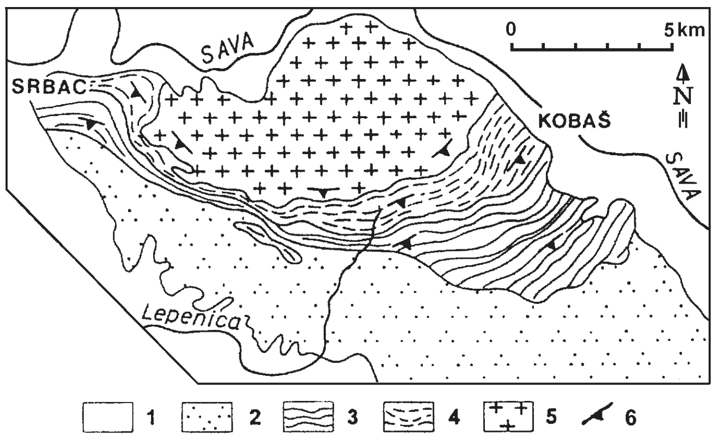
I. Late Cretaceous–Paleogene units of the North Dinarides

These units belong to the Posavina terrane which includes the Mts. Prosara–Motajica–Cer–Bukulja zone of the northernmost Dinarides that continues southeastward into the Vardar Zone *sensu lato* (Pamić 1993; Pamić et al. 1998). The Posavina terrane originated along the active northernmost margin of Apulia consisting of a trench-like basin and a presumed magmatic arc. After Mesozoic ophiolites of the Dinaridic Tethys had been obducted onto the Apulian passive continental margin during the Late Jurassic/Early Cretaceous, subduction-related sedimentary, igneous and metamorphic processes continued along this feature during Late Cretaceous and Paleogene times.

Late Cretaceous–Paleogene unmetamorphic sedimentary sequences consist in their lower parts of Turonian (?) and Lower Senonian shale, marly shale, siltstone and limestone, interlayered with upper mantle derived basalt, and crustal alkali-feldspar rhyolite and pyroclastic rocks (the bimodal basalt-rhyolite formation). This volcanic-sedimentary formation contains rare pre-Upper Cretaceous blueschist olistoliths and blocks (Majer & Lugović 1992; Pamić 1993). This unit is conformably overlain by flysh composed mainly of sandstone and shale in its lower parts (Maastrichtian and Paleocene). Calcareous shales, sandstones, sandy limestones and limestones predominate in its upper, Early to Middle Eocene parts (Jelaska 1978). These rocks are widespread in the Mts. Motajica, Vučjak, Trebovac and Majevica (Fig. 1) where they are unconformably overlain by the Tertiary fill of the South PB.

Regionally metamorphosed sequences laterally grade into unmetamorphosed Upper Cretaceous–Paleogene rocks. Complete sequences showing progressive zonation from unmetamorphosed Upper Cretaceous sedimentary and igneous rocks to very low-, low- and medium-grade metamorphic rocks are best preserved in Mt. Motajica. The following were recognized here: (1) progressive textural changes, (2) mineral zonation of chlorite to biotite to garnet to staurolite and (3) changes in the oxygen isotopic composition and geobarometric data (Pamić et al. 1992). In a first phase, a regional syntectonic medium-pressure and low-temperature metamorphism took place which affected an up to 3–4 km wide zone. This metamorphism was related to a Late Eocene/Oligocene deformational event (about 45–40 Ma). This phase was overprinted by contact metamorphism under increasing tempera-

a)



b)

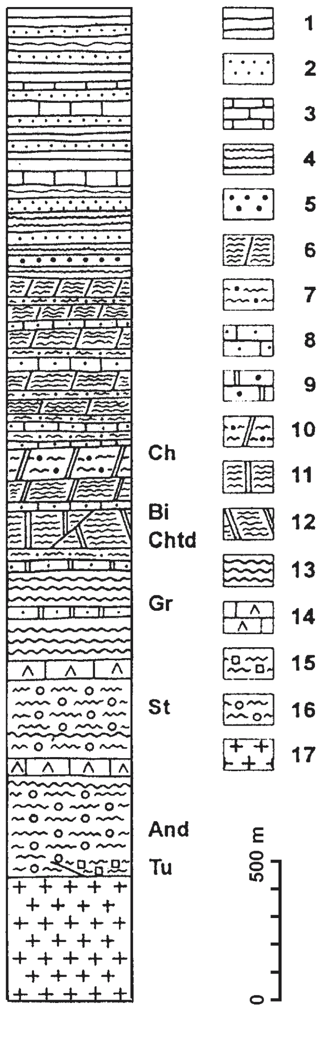


Fig. 2. a) Geological map of Mt. Motajica — modified from Varićak (1965): b) Columnar section showing progresive zonality from unmetamorphosed Upper Cretaceous flysch sediments to very low-, low- and medium-grade metamorphic rocks.

a) 1 — Neogene and Quaternary sedimentary rocks of the Pannonian Basin. **2** — Late Cretaceous flysch sequence. **3** — Paleogene very low- and low-grade metamorphic sequence. **4** — Paleogene medium-grade metamorphic sequence. **5** — S-type granite. **6** — Dip of schistosity.

b) 1 — shale; **2** — sandstone; **3** — limestone; **4** — slate; **5** — metasandstone; **6** — phyllite; **7** — schistose metasandstone and quartz-muscovite schist; **8** — recrystallized limestone; **9** — marble; **10** — augen-phyllite; **11** — biotite-phyllite; **12** — chloritoid phyllite; **13** — mica schist; **14** — amphibolite; **15** — gneiss; **16** — migmatite; **17** — granite.

And — andalusite; **Bi** — biotite; **Ch** — chlorite; **Chtd** — chloritoid; **Gr** — garnet; **St** — staurolite; **Tu** — tourmaline.

tures and decreasing pressures during the final diapiric ascent of granite intrusions. In the country rocks, this ascent gave rise to the development of a narrow andalusite zone, including local partial melting and the formation of migmatites. On the other hand, at the margin of the granite, uneven greisenization of granites took place as evident by numerous occurrences of tourmaline (Fig. 2a–b). In the Mt. Motajica area, fold and thrust structures are north vergent in contrast to the common SW vergence in the Dinarides. Similar structural deflections are also recognized in the surrounding Mt. Prosara and on the northern slopes of Mt. Majevica (Fig. 1).

In the area of Mt. Prosara and in some oil-wells only low- and very low-grade metasediments with poor remains of the Late Cretaceous protolith are preserved, whereas in the western parts of the zone only Alpine metamorphic rocks crop out, without any remainders of Upper Cretaceous pristine rocks.

From the slates and phyllites of the Mts. Motajica and Prosara metamorphic sequences a Late Cretaceous–Paleogene microflora was obtained (Pantić & Jovanović 1979). Radiometric determination, carried out on monomineralic concentrates from medium-grade rocks from a well core yielded K-Ar ages of 48 (on hornblende) and 38 (on biotite) Ma (Lanphere & Pamić 1992).

Synkinematic granitoids occur in Alpine progressively metamorphosed sequences as veins and small- to medium-sized plutons, which, as indicated by geophysical data, are more common in the subsurface than on the surface. The Alpine granitoids belong to the A-type (Mt. Prosara) and S-type (Mt. Motajica) family as indicated by geochemical data (Pamić & Lanphere 1991). Rb-Sr measurements carried out on the Mts. Motajica and Prosara granites yielded a Sr-isochrone age of 48 Ma. However, two granite samples obtained from oil-wells drilled in the western part of the zone yielded a Rb-Sr reference age of 56 Ma. Generally, these ages fit with the K-Ar ages obtained from penecontemporaneous medium-grade metamorphic rocks (Lanphere & Pamić 1992).

The tectonized ophiolite mélange is in some places unconformably overlain by Late Cretaceous–Paleogene sequences. This mélange is strongly and pervasively sheared and includes almost the same fragments as the olistostrome mélange of the Dinaride Ophiolite Zone (Dimitrijević & Dimitrijević 1973). However, the tectonized mélange which does not include larger peridotite and gabbro bodies, also contains exotic blocks of Upper Cretaceous limestones which to date have not been found in the olistostrome mélange of the Dinaride Ophiolite Zone (Pamić 1993). This suggests that generation of ophiolites and mélange must have also taken place during the Late Cretaceous as indicated by K-Ar ages of 110 to 66 Ma obtained on diabase and gabbro fragments (Pamić 1997).

II. Late Cretaceous–Paleogene units of South Tisia

In this paper the term Tisia Megaunit is used in the same way as it is used in recent papers published by Hungarian geologists (Fülöp et al. 1987; Csontos et al. 1992 and others). Within the southern part of Tisia outcropping in Croatia, Late Cretaceous–Paleogene rocks are developed in almost the same facies as in the North Dinarides. They occur as allochthonous masses, both on the surface and in the subsurface, as evidenced by numerous deep wells.

II a) Surface occurrences

Late Cretaceous–Paleogene rocks are found at the Mts. Požeška Gora and Papuk in Slavonija.

Mt. Požeška Gora (Fig. 1) is composed mainly of Neogene sedimentary rocks associated with Late Cretaceous igneous and sedimentary rocks. Predominant volcanic rocks, represented by about equal proportions of basalt and alkali-feldspar rhyolite lavas with some tuffs, cover a surface area of about 30 km^2. Along the southeastern margin of the mountain, the volcanic rocks interfinger and alternate with fossiliferous Senonian, mainly Maastrichtian shales, limestones and sandstones. These rocks are cut by diabase dykes and larger A-type granite bodies (Fig. 3A). The entire magmatic-sedimentary complex of Mt. Požeška Gora is allochthonous and subhorizontally overlies the Neogene sediments of the PB, including clastics of Pannonian age (Šparica & Pamić 1986).

In the southwestern parts of Mt. Požeška Gora and at the base of the allochthonous thrust sheet, Late Cretaceous low-grade metamorphic rocks crop out. These are muscovite-quartzite schists originating from primary cherts, and some phyllites, quartz-muscovite schists, greenschists, metatuffs and marbles. These rocks can be correlated with low-grade parts of Paleogene metamorphic sequences of the Mts. Motajica and Prosara of the North Dinarides (Šparica & Pamić 1986). K-Ar measurement carried out on a whole-rock phyllite from Mt. Požeška Gora yielded an age of 44 Ma (Lanphere & Pamić 1992).

The area of Mt. Papuk, near Voćin. Here, a Late Cretaceous volcanic flow is composed of about equal proportions of basalts, alkali-feldspar rhyolites and volcanic breccias and agglomerates with tuffs (Fig. 3B). The Voćin volcanic body is in tectonic contact with Hercynian migmatites, S-type granites and Miocene sedimentary rocks. The Hercynian country rocks are intruded by diabase and A-type graniteporphyry veins and are included as xenoliths in Upper Cretaceous rhyolites. Only in a few places are volcanic rocks interlayered with platy mudstones and Senonian fossiliferous marly shales (Pamić 1997).

In Mt. Fruška Gora, Upper Cretaceous clastic rocks, containing re-deposited blueschist pebbles, occur, together with tectonized ophiolite mélange (Majer & Lugović 1992). Unfortunatelly, there are no radiometric ages for those blueschists, which are probably pre-Upper Cretaceous in age.

A concordant isotopic age of 71.5 Ma has been determined by a five point Rb/Sr isochron based on 2 rhyolites and 3 cogenetic A-type granites from Mt. Požeška Gora (Pamić et al. 1988). K-Ar measurements on diabases gave a crystallization age of 66.0 Ma and decreased ages of 54.5 and 48.7 Ma. From the Voćin area, five whole-rock basalt samples yielded concordant K-Ar ages of 72.8–62.1 Ma (Pamić 1997).

II b) Subsurface data

Fourteen oil-wells drilled in the **Drava Depression** (Fig. 1), penetrated at depths of up to 3686 m, into Upper Cretaceous-(?)Paleogene basalts, metabasalts, alkali-feldspar rhyolites and granite porphyries with subordinate alkali-feldspar syenite porphyries, some of them cataclasized and schistosed. Some of these volcanic bodies may attain thicknesses of up to 1000 m. In some of the deep wells the oldest sediments underlying these igneous rocks are Albian and Barremian-Aptian limestones and limestone breccias, indicating a Late Cretaceous geological age of the magmatic activity. K-Ar measurements carried out on 13 whole-rock samples of basalt and alkali-feldspar rhyolite gave 3 groups of radiometric ages: 1) crystallization ages ranging between 75.5 and 62.4 Ma; 2) cooling ages spanned between 59.3 and 51 Ma and 3) strongly decreased ages spanned between 38.7 and 36.3 Ma (Pamić 1997).

In the **Sava Depression**, where fewer wells were drilled than in the Drava Depression, Upper Cretaceous basalts and metabasalts were encountered only in a few deep wells (Fig. 1). K-Ar measurements on two whole-rock basalt samples gave crystallization ages of 83.4 and 68.7 Ma and a metabasalt sample gave a cooling(?) age of 48.9 Ma (Pamić 1997).

In 3 oil-wells from the **Slavonija-Srijem Depression**, the oldest sedimentary rocks overlying basalts and alkali-feldspar rhyolites are of a Late Cretaceous age. However, K-Ar measurements, carried out on whole-rock metabasalts, yielded a decreased age interval ranging between 61.1 and 44.1 Ma (Pamić 1997). In a few oil-wells, gabbro and diabase fragments from ophiolite mélange were also penetrated. K-Ar measurements on these rocks gave two groups of ages, namely 110–80 Ma and 67–59 Ma.

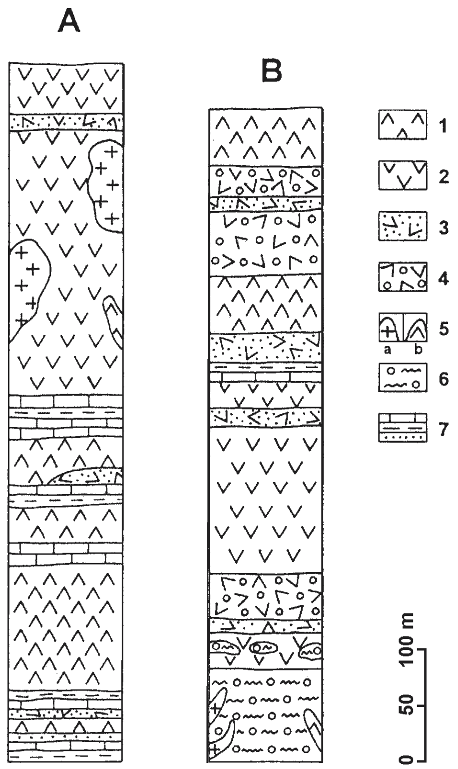


Fig. 3. Partial geological columns for the Late Cretaceous volcanic masses: **A** — Mt. Požeška gora; **B** — The Vocin area. 1 — basalt; 2 — rhyolite; 3 — tuff; 4 — volcanic breccia; 5 — small intrusive bodies: a) A-type granite and b) diabase; 6 — Hercynian migmatite; 7 — Upper Cretaceous bedded shale, limestone and sandstone.

Discussion

The Late Cretaceous–Paleogene tectonostratigraphic units of the Posavina terrane represent the main and the most characteristic members of the North Dinarides. Initial Late Jurassic/Early Cretaceous subduction processes, which took place along the northern Tethyan margin, were accompanied by penecontemporaneous obduction of ophiolites over the Apulian passive continental margin, thus documenting significant shortening of the Dinaridic-Hellenidic Tethys.

The average width of the Dinaride Ophiolite Zone is about 70–80 km but its thickness cannot be calculated due to the chaotic character of the ophiolite mélange. However, the mélange also includes large bodies of peridotite thrust sheets, some of them 1000–2000 m thick and smaller bodies of gabbros, diabase and basalts. The best preserved complete fragments of oceanic crust are more than 2000 m thick excluding the underlying tectonic peridotites and the overlying volcanic sedimentary formations (Pamić & Desmons 1989).

The obducted ophiolitic complex partly emerged, underwent weathering (including lateritization) and erosion. The erosion products were re-deposited during the Late Jurassic/Early Cretaceous in shoals and depressions located between the emerging ridges (Fig. 4A). The occurrence of blueschist olistoliths and pebbles at the base of the Late Cretaceous flysch sequence suggests that exhumation must have taken place during this first post-emplacement period (e.g. Ernst 1971; Michard et al. 1994 and others).

These basins, which unconformably overlay the emplaced ophiolites, can be traced along strike for 10–20 km and their sedimentary fill is up 1000 m thick. The basins display variations in lithostratigraphy (Pamić 1964) that may be important in paleogeographical and even palinspastic considerations.

In the southern part of the Ophiolite Zone, these basins contain at their base clastic sediments which contain fragments of ophiolites and related sedimentary rocks, including re-deposited ophiolite weathering crusts represented by nickeliferrous iron-poor ores and bauxites. This lower part of the sequence which is Tithonian-Valanginian in age, is conformably (?) overlain by fossiliferous Upper Cretaceous marly shales and bedded Upper Cretaceous limestones.

In the northern part of the Ophiolite Zone, close to the Tethyan active continental margin, the Maglaj Basin unconformably overlies the Dinaridic ophiolites. It contains mainly breccia-conglomerates and coarse-grained lithic sandstones (Fig. 6). The detrital component of these rocks consists of ophiolites and genetically related sediments but also of abundant coarse-grained and reddish granitoids of presumed Variscan age (Varićak 1965). The granites might come from Tisia which was broken off from the southern margin of Hercynian Europe during the Bathonian (Vörös 1993; Szedeké-

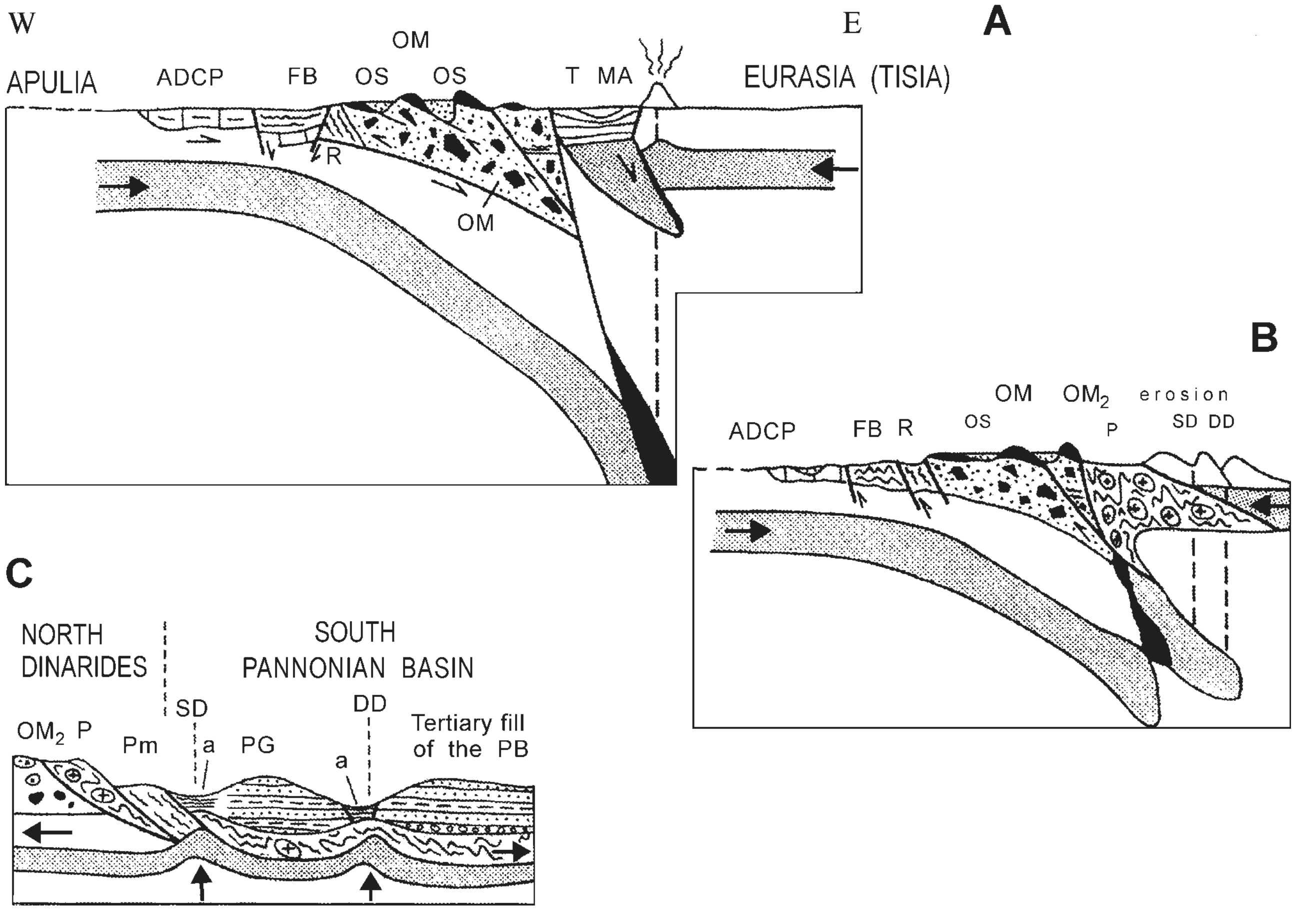


Fig. 4. Schematical diagrams illustrating and summarizing the evolution of the north Dinarides and south Pannonian Basin: **A** — during the Late Cretaceous; **B** — during the Late Eocene/Oligocene; **C** — during the Early Miocene extension. **a** — rifting related volcanics interlayered in Early Miocene sediments; **ADCP** — Adriatic-Dinaridic carbonate platform; **DD** — nascent Drava Depression; **FB** — Apulian passive continental margin (flysch bosniaque); **MA** — magmatic arc (Eurasian active continental margin); **OM** — ophiolite mélange obducted in Late Jurassic/Early Cretaceous; **OM_2** — ophliolite mélange obducted in Late Eocene/Oligocene; **OS** — Late Jurassic/Cretaceous marine overstep sequences; **P** — Posavina terrane; **Pm** — Alpine metamorphic sequence originating from Late Cretaceous/Paleogene protolith; **PG** — Mt. Požeška Gora; **R** — Radiolarite formation; **SD** — nascent Sava Depression; **T** — trench in front of the magmatic arc.

nyi 1996) or Tertiary (Csontos et al. 1992). The granites occur as pebbles and exotic blocks, 1–2 m in diametre, in breccia-conglomerates and as the most common components of the lithic sandstones. In some areas these conglomerates interfinger with Tithonian-Valanginian reefal limestones whereas the uppermost parts of the clastic sequence are in some areas unconformably(?) covered by bedded Upper Cretaceous limestones.

These data indicate that the Maglaj Basin, which oversteps the northern marginal parts of the Dinaride Ophiolite Zone, was not charged by only detritus from adjacent southerly located ophiolite terranes, but also from a northerly located European continental margin terrane.

Late Jurassic/Early Cretaceous subduction initiated the gradual closure and finally a strong shortening of the Dinaridic Tethys and the development of a magmatic arc. The arc was located north of the obducted ophiolites along the northern Tethyan margin. In the trench associated with this magmatic arc Late Cretaceous–Paleogene flysch sequences accumulated. Persisting subduction processes along this arc-trench system were the driving mechanism for continued magmatic activity during the Late Cretaceous and Paleogene. Sr isotope data suggest a twofold magma generation activity: 1) basalts and diabases derived from an upper mantle source and 2) A-type granites with cogenetic alkali-feldspar rhyolites derived from a continental crustal source (Pamić et al. 1988). This indicates that continental crustal rocks were also subducted, metasomatically reactivated and thus took part in magma generation.

Consequently, in the area of this magmatic arc, granite plutonism and bimodal basalt-rhyolite volcanism were active. It is quite concievable that this magmatic arc may represent the westernmost part of the north Tethyan subduction zone which extends southeastward to Greece (the Vardar Zone), the Zagros and Afghanistan (Camoin et al. 1993).

Strong compressional movements, which took place by the end of the Eocene (45–40 Ma) were accompanied by the uplift of the Dinarides. This phase was characterized by: 1) tectonization of the pristine Jurassic olistostrome mélange and its emplacement on top of the main mass of the Dinaridic ophiolites that were obducted during the Late Jurassic/Early Cretaceous; 2) medium-grade metamorphism of the Upper Cretaceous–Paleogene trench-sediments, and 3) synkinematic granite plutonism. With this Eocene final orogenic phase, structuration of the Dinarides was completed (Fig. 4B).

However, within the emerging parts of the Dinarides, numerous smaller and larger Oligocene and Neogene intramontane basins developed. In the area north of the Dinarides, a system of larger shallow- to deep-water transtensional depressions came into evidence during the Oligocene, in which marine, brackish and fresh-water sediments accumulated (the South Paratethys). In the area of the present South PB, including the nascent Sava and Drava depressions intensive Oligocene andesite volcanic activity took place during this transpression phase (Laubscher 1983). This magmatic activity, which was penecontemporaneous with magmatic activity along the Periadriatic Line, might have derived from partial melting of retarding blocks remained after the Eocene final subduction.

Due to the N-dipping subduction of Apulia (see right side of Fig. 4B) it is likely that the Posavina terrane was overthrust at a low angle by the South Tisia terrane and was exhumed during transtensional development of the Sava and Drava depressions. This hypothesis is supported by the results of numerous oil-wells.

Consequently, the fragments of the previously subducted Posavina terrane occurring at present in the subsurface of the South PB could be best explained as exhumed blocks of the underlying northernmost Dinarides that were uplifted probably along (sub)vertical faults.

The final Eocene deformation of the Dinarides resulting from underplating of Apulia beneath the Tisia (the present Pannonian terranes) was followed by termination of subduction processes. After the Oligocene transpressional deformation of the area northeast of the uplifted Dinarides, geodynamic processes controlling the evolution of the PB changed fundamentally. Diapirism of the upper mantle and

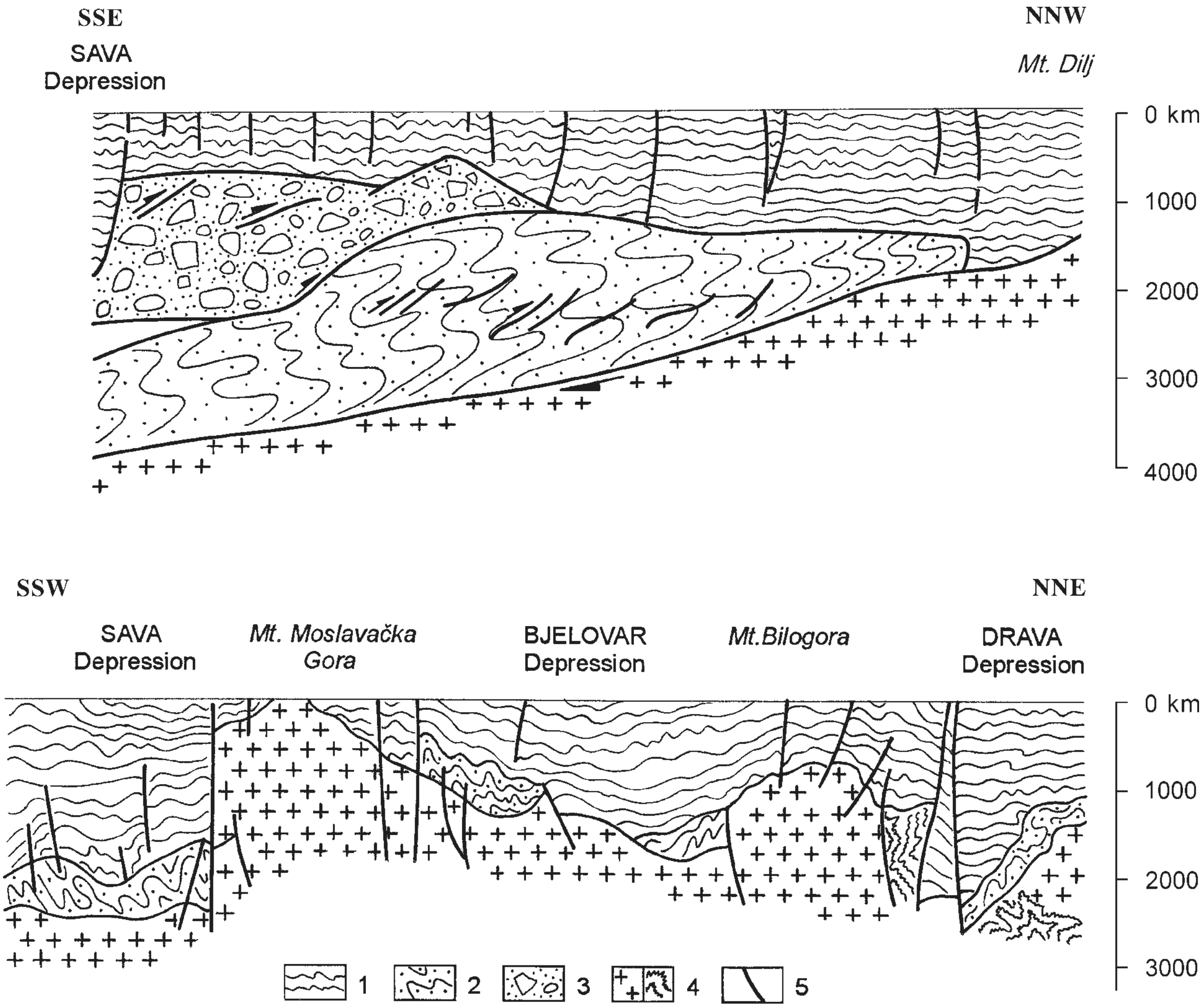


Fig. 5. Geological profiles based on seismical data (Tari-Kovačić & Pamić 1997); profile positions are presented on the geological map — Fig. 1. **1** — Tertiary fill of the Pannonian Basin; **2** — Late Cretaceous–Paleogene sedimentary, igneous and metamorphic rocks of Posavina terrane; **3** — tectonized ophiolite mélange; **4** — Hercynian crystalline rocks of the Tisia Megaunit; **5** — fault.

resulting attenuation of the lower continental crust gave rise to extensional processes, i.e., the evolution of the PB (Royden et al. 1983 and others). Details on the evolution of the southwestern and southern parts of the PB are presented elsewhere (Tari-Kovačić & Pamić 1997).

The Neogene evolution of the South PB, which was penecontemporaneous with the Neogene evolution of intramontane basins within the uplifted Dinarides, can be divided in two main phases. After the preceding Oligocene magmatic activity, synsedimentary Early-Middle Miocene volcanic activity was genetically related to rifting processes. This volcanism produced (1) trachyandesites of upper mantle origin during the Karpatian, (2) basalts and andesites with subordinate dacites and rhyolites of a continental crustal origin during the Badenian, and (3) basalts and alkali-basalts of upper mantle origin during the Sarmatian–Pannonian (Pamić et al. 1995). Following the late Sarmatian sea level low stand, sedimentation in the evolving PB was dominated by Late Miocene and Pliocene lacustrine fresh-water deposits (Horváth et al. 1996).

However, strong contractional tectonic activity occurred at the beginning of the Pliocene (about 5 Ma). Reflection seismic data indicate that in the South PB, units of the northernmost Dinarides are thrust over the Tisia Megaunit (Tari-Kovačić & Pamić 1997) — see Figs. 5A–B. This change of the lithosphere structure in the area adjoining the South PB and the North Dinarides must have taken place in post-Pannonian times. This is evidenced by the fact that the Late Cretaceous magmatic-metamorphic-sedimentary complex of the North Dinarides was thrust in Mt. Požeška Gora over Neogene sedimentary sequences as young as Pannonian in age. Moreover, fold and thrust structures within the Late Cretaceous–Paleogene complex of the North Dinarides display an obvious north vergence (Fig. 2a). The post-Pannonian movements fit with the idea presented by Horváth et al. (1996) that strong tectonic movements must have taken place by the beginning of the Pliocene (4–5 Ma) in the whole PB. This new tectonic regime reflects an increase in intraplate compressional stress producing localized deformations and broad buckling and uplift of the PB. This deformation phase is

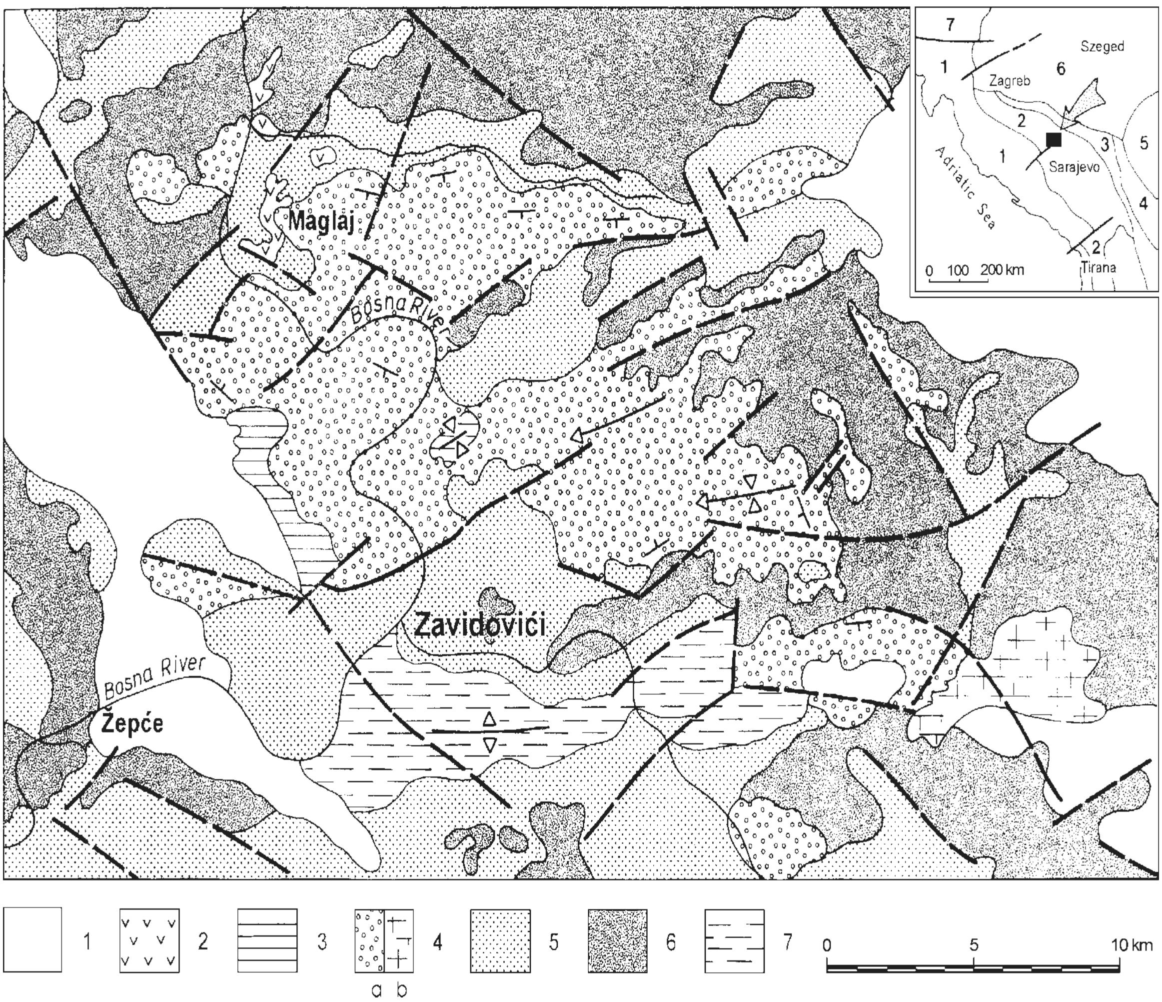


Fig. 6. Geological map of the Žepče-Zavidovići-Maglaj area, the northern part of the central Dinarides (Sunarić-Pamić et al. 1973): **1** — Post-orogenic Tertiary intramontane basins; **2** — Tertiary andesites and dacites; **3** — Upper Cretaceous limestones and limestone conglomerates; **4** — Berriasian: *a)* breccia-conglomerates and sandstones and *b)* massive limestones; **5** — ophiolite mélange, mainly shales and graywackes; **6** — dismembered ophiolites, mainly ultramafics; **7** — Lower Jurassic marly shales, limestones and cherts. ***Index-map:*** 1 — external Dinarides; 2 — internal Dinarides; 3 — Vardar Zone s.l.; 4 — Serbo-Mazedonian Massif; 5 — Carpathians; 6 — Pannonian Basin; 7 — Eastern Alps.

probably the expression of continued convergence of Africa-Arabia with Europe.

It is likely that during this Pliocene phase of tectonic activity, wrench faulting played an important role. Thus, it is conceivable that, for example, along the Banja Luka–Našice NNE-SSW trending strike-slip fault (BNF in Fig. 1), the Late Cretaceous–Paleogene complex of the Dinarides was transported northward by about 30 km from its root in the North Dinarides and was thrust onto the Neogene sequences of Mt. Požeška Gora, presumably at a restraining bend of the Banja Luka-Našice fault.

Consequently, the occurrence of the Dinaridic Late Cretaceous–Paleogene tectonostratigraphic units in the South PB can be explained by twofold mechanisms of tectonic transport. 1) Those located at depths of 3000–4000 m at the base of the Neogene fill of the South PB were uplifted during the Oligocene phase of wrench faulting controlling the initial development of the Drava and Sava depressions. 2) The North Dinaridic Late Cretaceous–Paleogene complexes found at the surface were emplaced during the Pliocene phase of strike-slip faulting.

Horváth (1993) emphasized the opinion that the evolution of the PB was controlled by continued orogenic activity in the Carpathian arc, involving northeastward and eastward transport of the Pannonian, Tisian and Dacides blocks. Data presented in this paper expand his idea and show that the evolution of the South PB within the Tisia Megaunit was controlled by contemporaneous but post-orogenic activity related to the North Dinarides, as shown by the northward transport of the Dinaridic lithologies and their incorporation into the South PB.

Data presented in this paper also pose the problem of the boundary between the Tisia and the North Dinarides. This boundary has been commonly identified with the southern margin of the PB stretching south of the Sava River. However, the southern margin of the Tisia is underthrust below the North Dinarides and thus incorporated in their deep structure. On the other hand, allochthonous masses of the Late Cretaceous–Paleogene subduction-related complexes of the North Dinarides are incorporated in the structure of the South PB due to Pliocene strike-slip faulting.

Acknowledgments: This paper was financially supported by the Ministry of Science and Technology of the Republic of Croatia, Grant 195004. The author is indebted to Profs. P. Ziegler and S. Schmid of Basel University for critical reading of the draft of the manuscript, numerous and useful suggestions which significantly improved the quality of the paper. Thanks also to P. Árkai, L. Csontos and D. Plašienka for their support during the editing procedure.

References

Camoin G., Bellion Y., Dercourt J., Guirand R., Lucas J., Poisson A., Ricou E.L.E. & Vrielynck B., 1993: Late Maastrichtian (69.5–65 Ma). In: Dercourt J., Ricou E.L. & Vrielynck B. (Eds.): *Atlas Tethys Paleoenvironmental Maps*. Explanatory notes. *Gauthiers-Villars,* Paris, 179–196.

Csontos L., Nagymarosy A., Horváth F. & Kovács M., 1992: Tertiary evolution of the intra-Carpathian area: a model. *Tectonophysics*, 208, 221–241.

Dimitrijević M.D. & Dimitrijević M.N., 1973: Olistostrome mélange in the Yugoslavian Dinarides and Late Mesozoic plate tectonics. *J. Geol.*, 81, 328–340.

Ernst W.G., 1971: Metamorphic zonations on presumably subducted lithospheric plates from Japan, California and the Alps. *Contr. Mineral. Petrology,* 34, 43–59.

Fülöp J., Brezsnyanszky K. & Haas J., 1987: The new map of basin basement of Hungary. *Acta Geol. Hung.*, 30, 3–29.

Herak M., Jamičić D., Šimunić A. & Bukovac J., 1990: The northern boundary of the Dinarides. *Acta Geol. (Zagreb)*, 20, 5–27.

Horváth F., 1993: Towards a mechanical model for the formation of the Pannonian Basin. *Tectonophysics,* 226, 333–357.

Horváth F., Tari G., Sikhegyi F., Toth T., Magyari O., Sacchi M. & Marsi F., 1996: Neotectonics of the Pannonian Basin. *Abstracts of PANCARDI Workshop*, Wien, 112.

Jelaska V., 1978: Stratigrafski i sedimentološki odnosi senonsko-paleogenskog fliša šireg područja Trebovca (sjeverna Bosna). *Geol. vjesn.*, 30, 95-117 (in Croatian, English Summary).

Kázmér M. & Kovács S., 1985: Permian-Paleogene paleogeography along the eastern part of the Insubric-Periadriatic Lineament system: evidence for continental escape of the Bakony-Drauzug. *Acta Geol. Hung.*, 28, 71–84.

Lanphere M. & Pamić J., 1992: K-Ar and Rb-Sr ages of Alpine granite—metamorphic complexes in the northwestern Dinarides and the south-western part of the Pannonian Basin in North Croatia. *Acta Geol. (Zagreb)*, 22, 1–15.

Laubscher H., 1983: The late Alpine (Periadriatic) intrusions and the Insubric Line. *Mem. Soc. Geol. Ital.*, 26, 21–30.

Majer V. & Lugović B., 1992: The blueschists of Yugoslavia. *Rad Jug. akad. znan. umjetn.*, 458, 103–139.

Michard A., Goffe B., Saddiki R., Oberhansli R. & Windt A.S., 1994: Late Cretaceous exhumation of the Oman blueschists and eclogites: a two-stage extensional mechanism. *Terra Nova*, 6, 404–413.

Pamić J., 1964: Magmatske i tektonske strukture u ultramafitima Bosanske serpetinske zone. *Poseb. Izd. Geol. glas.*, 2, 108, Sarajevo (in Croatian, English Summary).

Pamić J., 1987: Magmatic and metamorhic complexes of the adjoining area of the northernmost Dinarides and Pannonian mass. *Acta Geol. Hung.*, 29, 203–220.

Pamić J., 1993: Eoalpine to Neoalpine magmatic and metamorphic processes in the northwestern Vardar zone, the easternmost Periadriatic Zone and the southwestern Pannonian Basin. *Tectonophysics*, 226, 503–518.

Pamić J., 1997: Vulkanske stijene Savsko-dravskog međuriječja i Baranje (Hrvatska). *Poseb. izd. Nafta*, Zagreb, 192 (in Croatian, English Summary).

Pamić J. & Desmons J., 1989: A complete ophiolite sequence in Rzav, area of Zlatibor and Varda ultramafic massifs, the Dinaride Ophiolite zone. *Ofioliti,* 14, 3–32.

Pamić J. & Lanphere M., 1991: Alpine A-type granites from the collisional area of the northernmost Dinarides and Pannonian Basin, Yugoslavia. *Neu. Jb. Mineral., Abh.*, 162, 215–236.

Pamić J., Lanphere M. & McKee E., 1988: Radiometric ages of metamorphic and associated igneous rocks of the Slavonian Mountains in the southern part of the Pannonian Basin. *Acta Geol. (Zagreb)*, 18,13–39.

Pamić J., Árkai P., O'Neil J.O. & Lantai C., 1992: Very low- and low-grade progressive metamorphism of Upper Cretaceous sediments of Mt. Motajica, northern Dinarides, Yugoslavia. In: J. Vozár (Ed.): *Western Carpathian, Eastern Alps, Dinarides. IGCP Proj. 276*, Bratislava, 131–146.

Pamić J., McKee E., Bullen T. & Lanphere M., 1995: Tertiary volcanic rocks from the southern Pannonian Basin. *Int. Geol. Rev.*, 37, 259–283.

Pamić J., Gušić I. & Jelaska V., 1998: Geodynamic evolution of the Central Dinarides. *Tectonophysics*, in press.

Pantić N. & Jovanović O., 1970: O starosti "azoika" ili "paleozojskih škriljaca" na Motajici na osnovu mikroflorističkih podataka. *Geol. glas.*, 14, 190–204 (in Serbian, English Summary).

Ratschbacher L., Frisch W., Linzer H.G. & Merle O., 1991: Lateral extrusion in the Eastern Alps, part 1: boundary conditions and experiments scaled for gravity. *Tectonics*, 10, 245–256.

Royden L., Horváth F. & Rumpler J., 1983: Evolution of the Pannonian Basin system: tectonics. *Tectonics*, 2, 63–90.

Stegena J., Geczy B. & Horváth F., 1975: Late Cenozoic evolution of the Pannonian Basin. *Tectonophysics*, 26, 71–90.

Sunarić-Pamić O., Pamić J., Kapeler I., Olujić J. & Zec F., 1973: Basic geological map of SFRJ, 1:100,000, sheet Zavidovići. *Sav. geol. zavod,* Beograd (in Croatian; English summary).

Szederkényi T., 1996: Metamorphic formations and their correlation in the Hungarian part of the Tisia megaunit. In: Knežević V. & Krstić B. (Eds.): *Terranes of Serbia*, Belgrade Univ., Belgrade, 9.

Šparica M. & Pamić J.,1986: Prilog poznavanju tektonike Pozeške gore. *Rad Jug. akad. znan. umjetn*., 424, 85–96 (in Croatian, English Summary).

Tari-Kovačić V. & Pamić J., 1997: Geodynamic evolution of the northern Dinarides and South Pannonian Basin. *Tectonophysics*, in press.

Varićak D., 1965: Petrološka studija motajičkog granitskog masiva. *Poseb. izd. Geol. glas.*, 9, Sarajevo, 170 (in Serbian, English Summary).

Vörös A., 1993: Jurassic microplate movements and brachiopod migrations in the Western part of the Tethys. *Paleogeogr., Paleoclim., Paleoecol*., 100, 125–145.