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Evolution of the northern and western Dinarides: a tectonostratigraphic approach

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Abstract. The Dinarides are a Late Jurassic to recent, mainly SW-vergent fold and thrust belt that extends from the Southern Alps in the NW to the Albanides/Hellenides in the SE. Main tectonostratigraphic units of the Dinarides are related to:
a) Early and Middle Triassic rifting: was marked by strong magmatism and horst to graben related deposition overlying Variscian basement. Rift-related magmatism migrated westward through the Early to Late Triassic. Deposition was fault controlled and sedimentation patterns demonstrate a strong differentiation between shelf, slope and basin lithologies. Along the "eastern" Apulian margin toward the Sava-Vardar ocean rifting was followed by subduction-generated extension during Early Triassic till Late Jurassic. Subduction-related attenuation of continental crust along the eastern margin of Apulia caused a generation of the back-arc basin type of the oceanic crust. The remnants of that active continental margin lithologies are found within the Eastern thrust belt as the ophiolite melange of the Central Dinarides Ophiolite Belt.
b) Late Jurassic to present day compression that generated:

– Eastern thrust belt, foredeep and foreland: Continental convergence was progressive from Late Jurassic and was first expressed on the eastern margin of the Dinarides as the Eastern thrust belt and its foredeep. The Dinaridic carbonate platform toward he west presented the foreland of the generally west directed thrusting. During Early Cretaceous compressional stresses began to be transmitted westward through the Dinarides, causing the migration of the foredeep basin and regional uplift of the Eastern thrust belt.

– Northern Dinarides accretionary wedge: Subduction of the oceanic plate along the northern margin of the Dinarides culminated from Maastrichtian to Eocene. That is evidenced by accretionary wedge deposits located by oil wells in the basement of the South Pannonian Basin, an east-west trending remnants of the magmatic arc and well exposed retroarc flysch-like deposits.

– Western thrust belt, foredeep and foreland: At the end of the Cretaceous the entire carbonate platform was uplifted until the Early Eocene. During Eocene the Dinaridic carbonate platform was finally drowned under the flysch deposits in the broad foredeep basin of the Western thrust belt.

– Eastern Adria imbricated structures: At the beginning of the Oligocene collision and progressive underthrusting of the Adria below the Dinarides created the imbricate structures of Adria provenience in front of the Western thrust belt.
The structural style of the Dinaridic thrust belt depends on the polyphase tectonic compression and the competence of the sedimentary units involved. The decollements are Permian shales locally interbedded with gypsum, fine-grained Early/Mid Triassic clastics and Late Jurassic-Early Cretaceous anhydrites. The competent carbonate rocks are the most responsible for the structural style of the thrust belt. The compression started with ramping along the deep decollement from the root zone with a southwestern tectonic transport. In this way, by progressive overstepping of the thrust faults the various structural forms were created along the Eastern and Western thrust belt such as fault bend folds, tear fault related folds and folded thrust structures reworked by footwall deformations.

– Wrenching and tectonic inversion: NE-SW striking system of the dextral strike slip faults during Oligocene-Miocene was followed by NW-SE striking wrenching in Early and Middle Miocene, affecting South Pannonian Basin, Western thrust belt and Adriatic foreland. It is reflected as tectonic inversion in Mid-Bosnian Schists Mts. and as the system of the right-lateral strike and oblique slip faults, creating the large Sava and Drava depressions of the South Pannonian Basin and narrow pull-apart basins and large flower structures of the Dinaridic thrust belt.

Key words. Tectonostratigraphic units; extension; compression; collision; thrust belt; Dinarides; Adria

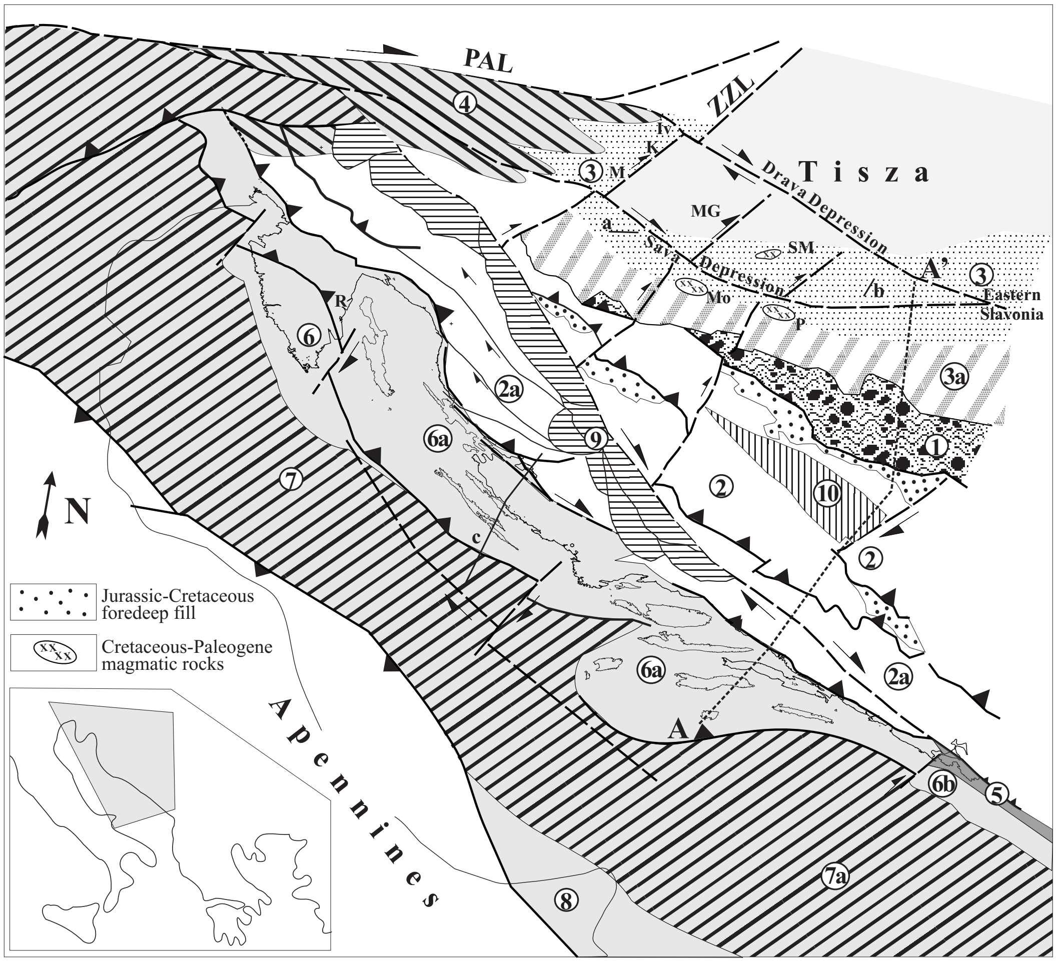

Fig. 1. Tectonostratigraphic units of the Dinarides and Adria. Dinarides: 1) Eastern thrust belt; 2) Dinaridic carbonate platform, foreland of the Eastern thrust belt; 2a) Frontal thrust of the Western thrust belt; 3) Maastrichtian-Paleogene accretionary wedge; 3a) Maastrichtian-Paleogene retroarc area, North-Bosnian flysch; 4) Slovenian Basin; 5) Budva-Cukali Basin; Adria: 6) Gently tectonised Adriatic carbonate platform; 6a) Imbricated Adriatic carbonate platform; 6b) Imbricated Adriatic (Kruja) carbonate platform; 7) Adriatic Basin; 7a) Ionian Basin; 8) Gargano-Sazani-Paxos carbonate platform; 9) Miocene wrenching; 10) Miocene tectonic inversion.
A-A' – geological cross section, see Fig. 3., B-B' – geological cross section, see Fig. 9., PAL – Periadriatic Lineament; ZZL – Zagreb-Zemplin Lineament; M – Medvednica Mt.; K – Kalnik Mt.; Iv – Ivanšcica Mt.; MG – Moslavačka Gora Mt.; SM – Slavonian Mountains; Mo – Motajica Mt.; P – Prosara Mt.; R – Raša coal mine. a, b and c – approximate position of seismic lines presented on Figs. 7., 8. and 9.

1 Introduction

The Dinarides, a product of alpine orogeny, represents the north-eastern part of the Apulian continental plate, which was separated from Africa and Europe during most of the Mesozoic (Yilmaz et al., 1996; Dercourt et al., 1993; Robertson and Dixon, 1984) by Tethyian Sava-Vardar "ocean" since latest Paleozoic, the Slovenian trench since the Late Triassic, Budva intra-plate Basin since Early Triassic and Adria, including Adriatic carbonate platform, Adriatic-Ionian Basin and Gargano-Sazani-Paxos carbonate platform, since Liassic (Fig. 1). Dinarides became a part of the alpine orogenic system by effective closure of Tethyan oceanic realms and associated basins in the period from Late Jurassic to the Quaternary. To the N and NE, Dinaride units were overprinted by tectonic processes controlling the evolution of the petroliferous Neogene Panonian Basin. Towards the E, the Dinarides are separated from the Carpathian/Balkanides by the Eastern Ophiolite Belt (Smith and Spray, 1984) and crystalline schists of the Serbo-Macedonian Massif. The boundary towards the Albanides is marked with the leading edge of the Western Dinaride Thrust Belt including the Gashi Zone of Albania which overthrusts the imbricated Budva (-Cukali) Zone and Albanian Alps. Towards the SW, Dinaridic units are thrust on to the partially deformed Adriatic foreland.

The Dinarides are composed of a set of tectonic units derived from the complex area between the Adriatic plate in the SW (in present day coordinates) and Europe in the NE. From SW to NE, the main tectonostratigraphic domains of this composing the area are (Figs. 1, 2 and 4):

a) The carbonate platforms and basins of the Adria: promontory of Chanell et al. (1979) or indenter of

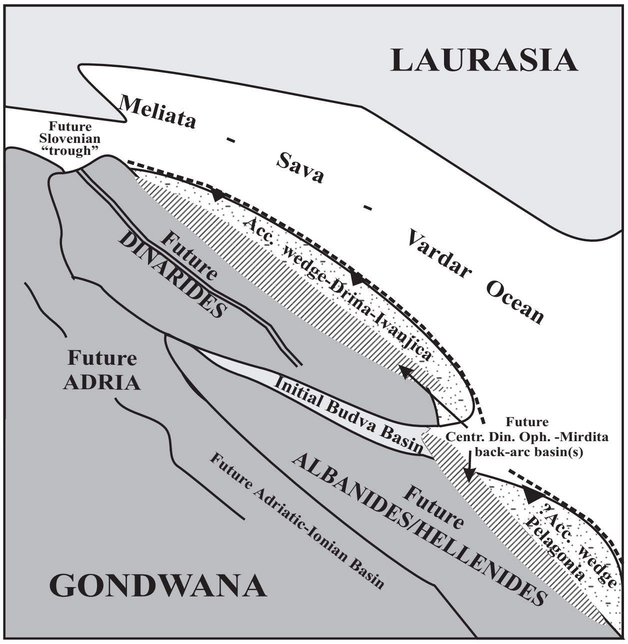

Fig. 2. Plate tectonic configuration towards the beginning fo the Triassic.

Ratschbacher et al. (1991).

b) The intra-platform Budva basin (since the Early Triassic) with the contiguous Krasta-Cukali and Pindos-Mirdita ocean (Robertson and Shallo, 2000; Nieuwland et al., 2001).

c) The Dinaridic carbonate platform, which formed an extension of the Apulian continental plate and was limited towards the NW by the intra-platform Slovenian basin since Late Triassic (Buser, 1987).

d) The Late Permian-Early Cretaceous Meliata-Sava-Vardar oceanic realm (Şengör et al., 1984; Yilmaz et al., 1996; Stampfli et al., 2001; Ziegler and Stampfli, 2001).

Convergence began in the late Jurassic and caused the progressive closure of the oceanic domains and deformation of the associated intraplatform basins mainly by SW-vergent thrusting. Eventually, shortening reached the carbonate platforms of the Adria, the marginal parts of which were imbricated and overthrust by the External Dinarides. Ongoing deformation is also documented by present day seismic activity (Kuk et al., 2000).

The present day architecture, the tectonic evolution and the paleogeography of the Dinarides have been the subject of numerous studies, mainly based on work carried out before the eighties (Kober, 1914; Kossmat, 1924; Petković, 1958; Aubouin, 1973; Grubić, 1980; Anđelković, 1982; Dimitrijević, 1982, Lawrence et al., 1995, and others). Major differences exist among the various authors mainly through the last century concerning the development of tectonic concepts, and, more recently, the differences in interpretation of tectonic, deposition and magmatism interactions.

In this paper we first present a regional cross section across the Dinarides and its foreland displaying the most important features of the chain (Fig. 3). This reconstruction is based not only on literature (inclusive of The Geological map of Yugoslavia (1967–1990), mapped at the scale of 1:25 000, and published with explanatory books at 1:100 000 scale) and own work but also on the knowledge accumulated at the Croatian Oil Company INA. We will make use of unpublished INA's technical reports, a set of regional sedimentary facies maps ranging from the Permian to the Paleogene (Tari and Gjurasek, 1990 – unpublished) and data acquired from about 100 deep exploratory wells in Pannonian Basin, Dinarides and Adriatic off-shore (Figs. 5 and 12). No comparable data set has been used hitherto in published articles. In the second part of the paper an evolutionary scheme for the Dinaridic orogen is presented. Obviously, a large amount of work will be needed in the coming years to lead to a deeper understanding of the kinematics and dynamics of the Dinarides.

2 The architecture of the Dinaridic belt

2.1 Eastern thrust belt, foredeep and foreland

The easternmost part of the Dinarides imaged along the section of Fig. 3 is formed by a double vergent nappe pile of Jurassic to Paleogene age named Eastern thrust belt. This is basically composed of SW vergent nappes involving pre-rift and rift-related stratigraphic units (Fig. 4). One of the most characteristic nappes is the Ophiolitic Melange. The ophiolite melange is composed of "pocket"-sized to "mountain"-sized blocks and boulders of oceanic crustal rocks and Paleozoic to Jurassic carbonates and clastics. Lherzolitic peridotites (Pamić, 1983) with underlying slices of mafic granulites, partly transformed to garnet amphibolites and intruded by doleritic dykes, are thrust onto an olistostrome melange which is composed of the slightly metamorphosed Paleozoic sediments, Permian to Liassic subgreywaqcke, red radiolarian chert, rare limestones of various facies and massive diabase and pillow lavas ("spilite"). Doleritic dikes do not occur in the melange (Lugović et al., 1991).

Westward prograding foredeep which is superimposed on the Dinaridic platform was filled with deposits composed of proximal "wild-flysch" Pogari foramtion (Pamić and Hrvatović, 2000) and Tithonian-Cretaceous turbidites and pelagites, known as "Bosnian flysch" (Aubouin, 1974), interpreted as a passive continental margin formations (Pamić, 1993).

The Dinaridic foreland was dominated by deposition of platform carbonates throughout Lower and Upper Cretaceous time.

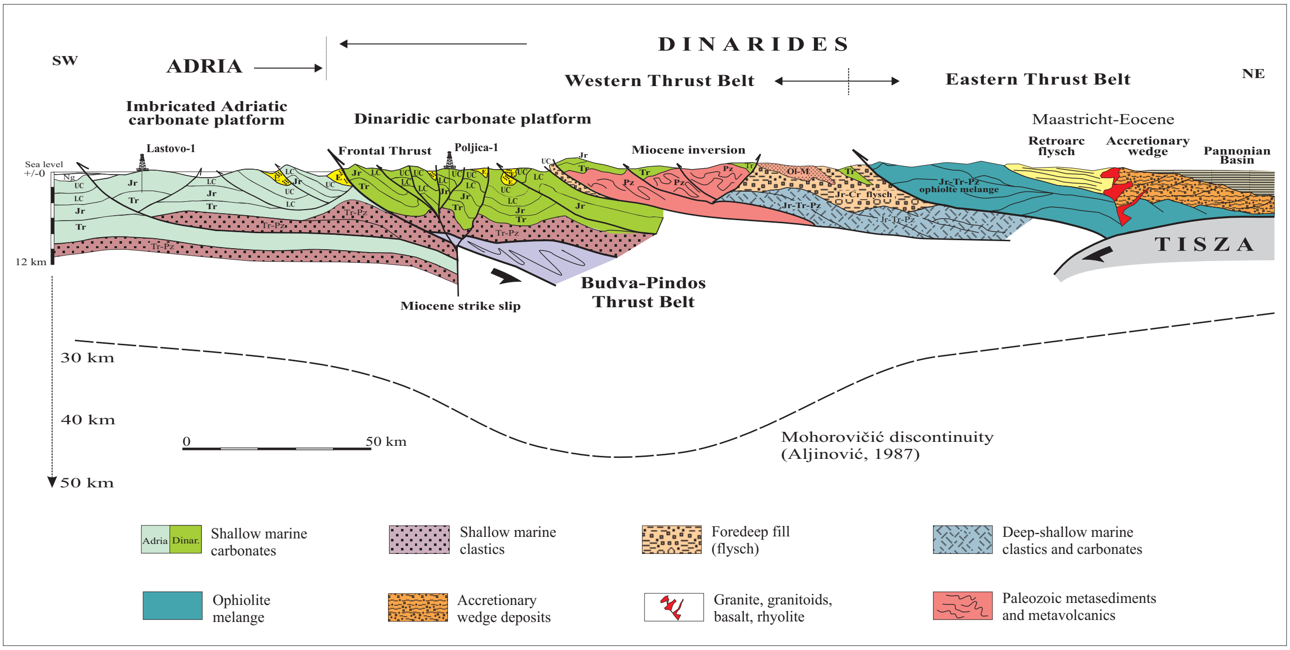

Fig. 3. Geological cross section. For the locations see Fig. 1.

2.2 Northern Dinarides Accretionary Wedge

The basement of the Southern Pannonian Basin beneath the Drava Depression and in Eastern Slavonija (Fig. 3 and 4) is a complex unit composed of pre-Alpine magmatic and metamorphic rocks (Pamić, 1997, 1998; Pamić et al., 1996; Balen and Pamić, 2000), Triassic dolomites and Jurassic and Cretaceous deep marine clastics and carbonates comparable with theTisza composite terranes described by Haas et al. (2000). The most common is a complex of poly-deformed olistostromes with a chaotic unsorted mixture of blocks of all sizes. Clasts predominantly consist of Cretaceous and Paleogene shallow to deep marine sediments, greywackes, pyroclastics, and boulders derived from the ophiolite melange of the Eastern thrust belt (Fig. 5). Fragments of the ophiolite melange, detached from the basement or eroded from the already uplifted Eastern thrust belt, are often incorporated into the accretionary prisms. Small outcrop of the “ophiolite melange” (Pamić and Tomljenović, 1998, 2000) are found on the northwestern slopes of the Mt. Medvednica.

This Accretionary wedge unit, which is exposed in restricted outcrops in the Zagorje-Mid-Transdanubian zone (Tomljenović, 2000) and in Slavonian Mountains (Pamić and Belak, 2000; Pamić et al., 2000), is here interpreted as representing remnants of the accretionary wedge which developed during the subduction of the Sava-Vardar ocean beneath the Dinarides platform. The accretionary wedge was compressionally further deformed during the Oligocene collision of Tisza with the Dinaridic platform. Accretionary wedge deposits (Fig. 9) are involved in generally North verging imbricates which were thrust over the ophiolite melange of the Eastern thrust belt (Fig. 8). This is evident on industrial seismic lines recorded in the Sava Depression (Fig. 7). In the eastern part of the Drava Depression, the accretionary wedge overlies various pre-Mesozoic metamorphics and Mesozoic rocks of Tisza affinity.

Possible remnants of the magmatic arc associated with the North Dinarides accretionary wedge were identified in the northern Bosnian mountains Motajica and Prosara, (Pamić, 1977, 1993, Tari and Pamić, 1998; Pamić and Lanphere, 1991; Pamić, 1998) as well as in Mts. Požeška and Moslavačka Gora within the South Pannonian Basin (Fig. 1). They are composed of granite, granitoids, basalts, alkali-feldspar rhyolites, volcanic breccia, agglomerate and tuff and are locally intruded by diabase and graniteporphyry veins. The age of this igneous complex is constrained by microflora assemblage from slates and low-grade phyllites of the Motajica and Prosara Mts. (Pantić and Jovanović, 1970) and is supported by radiometric ages of basalts and granitoids yielding Sr isochrons of 71.5 Ma and K-Ar age of 48.7–66.0 Ma (Pamić, 1997).

The area to the South of Accretionary Wedge in Northern Bosnia is formed by Upper Cretaceous to Paleogene flysch and flysch-like deposits. This Bosnian flysch was deposited in a retroarc setting and is composed of siliciclastics and subordinate carbonate turbidites of Maastrichtian to Early Oligocene age, alternating particularly during Paleocene and Eocene with shallow marine carbonates (Čičić, 1977; Jelaska, 1978; Čičić and Mojičević, 1984).

2.3 Western thrust belt, foredeep and foreland

This unit forms the bulk of the Dinarides as visible today. Three main zones are identified within the Western thrust belt, mainly defined by the rocks involved in thrusting: the

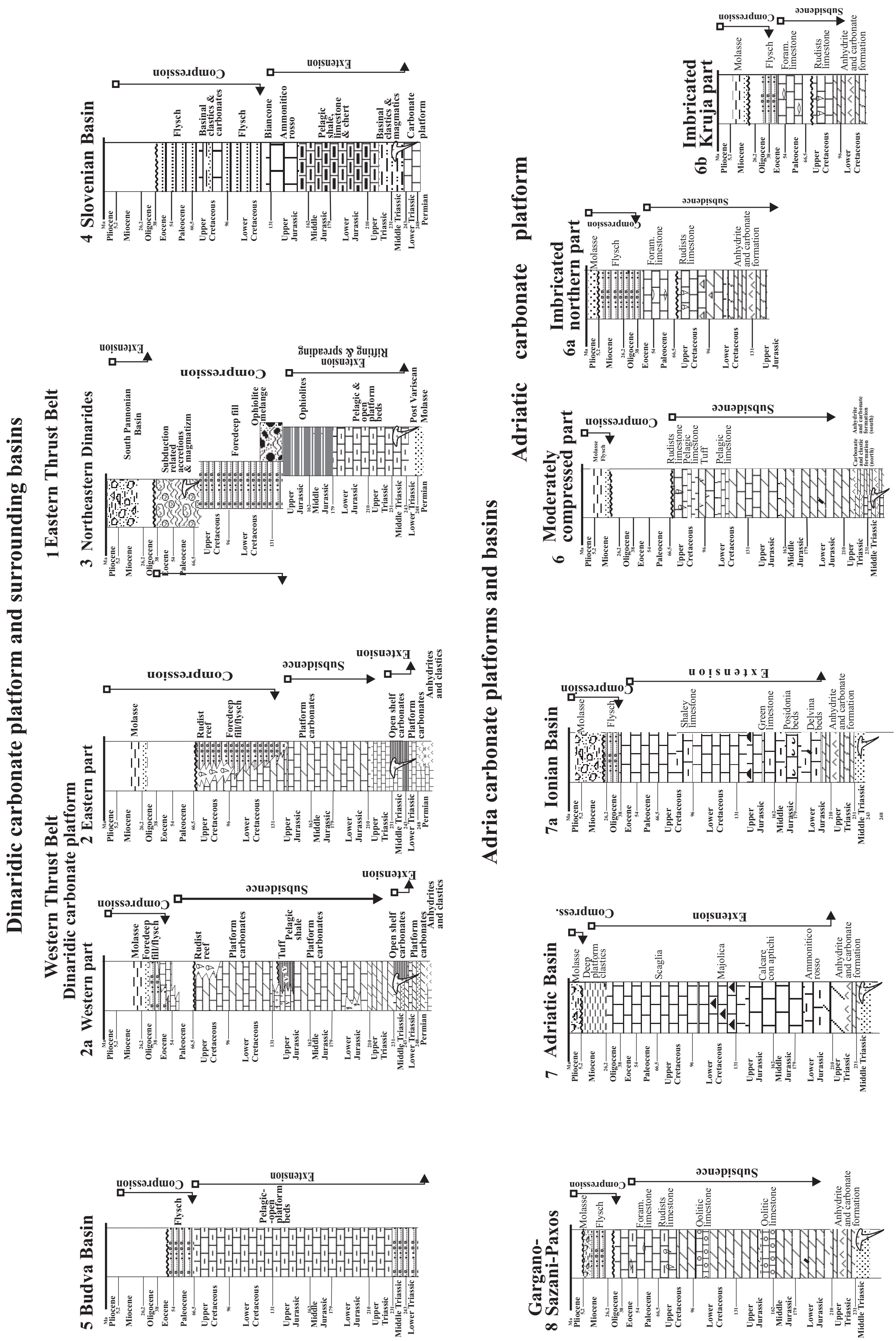

Fig. 4. Selected stratigraphic columns for the Dinarides and Adriatic tectonostratigraphic units. For the locations see Fig. 1.

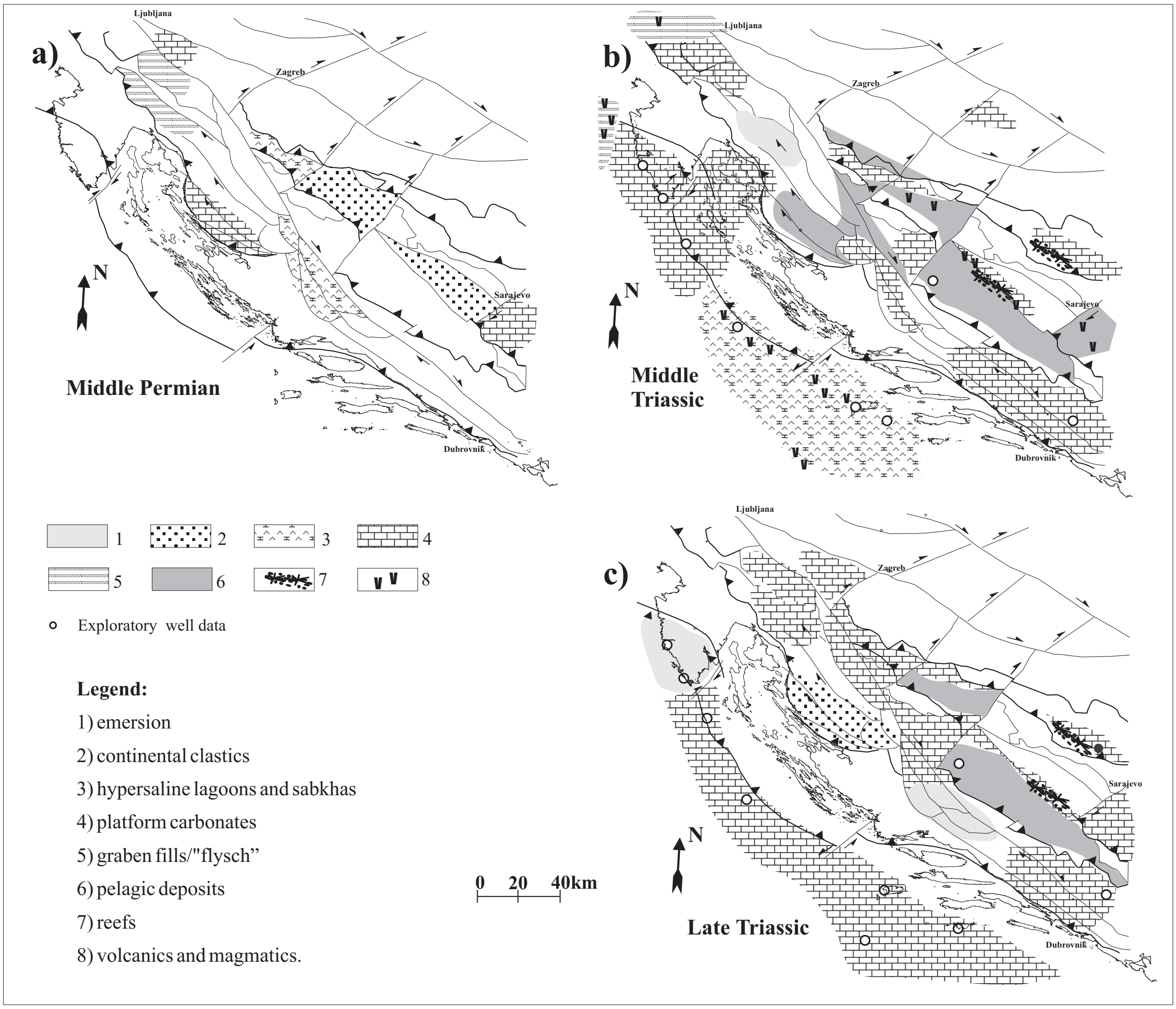

Fig. 5. Simplified Middle Permian to Late Triassic facies not palinspastically restored maps. 1) emersion; 2) continental clastics; 3) hypersaline lagoons and sabkhas; 4) platform carbonates; 5) graben fills/“flysch”; 6) pelagic deposits; 7) reefs; 8) volcanics and magmatics.

eastern one formed by Paleozoic rocks with reduced Mesozoic sedimentary cover, a central one where the bulk of the thrust sheets is formed by Mesozoic carbonates derived from the Dinaridic platform, and the western zone consisting of imbricates of the Adriatic carbonate platform. These zones were partly separated by two basinal units, the Lower Triassic to Middle Eocene Budva basin and the Lower Jurassic to Lower Miocene Adriatic and Ionian basin (further to the SW).

Mesozoic to Middle Eocene Dinaridic and Adriatic carbonate platforms and intervening basins were overlain by clastic deposited in the foredeep of the Western thrust belt. The onset flysch deposition becomes progressively younger from NE to SW. Flysch deposition commenced in southwestern Slovenia during the Early Eocene (Drobne and Pavlovec, 1991), in the ofshore parts of Dalmatia and Herzegovina during the Lutetian (Sakač et al., 1993) and in the present day coastal and island area during the Priabonian (Marjanac et al., 1998). Flysch deposits in the more external position of the Adriatic offshore, are dated the Oligocene and Miocene by well and seismic data (Tari-Kovačić et al., 1998; Tari-Kovačić, 1998).

The entire foreland and foredeep area of the Eastern thrust belt is strongly deformed by folding, faulting, thrusting.and erosion (Fig. 9). The structural style of the Dinaridic thrust belts depends on the polyphase tectonic shortening and the competence of the sedimentary units involved. The most important decollement horizons of the entire Dinarides are formed by the extensively developed Permian shales locally interbedded with gypsum, and by fine-grained clastics of Early and Middle Triassic age. The structural style of the Western thrust belt is dominated by competent carbonate rocks. Shortening started with ramping along deep decollements from the root zone with a southwestern tectonic transport direction. In this way, progressive in-sequence thrust propagation controlled the development of the Eastern and Western thrust belts. Fault-bend folds and folded thrust structures were reworked by footwall deformation and tear-

Cerna-1 well

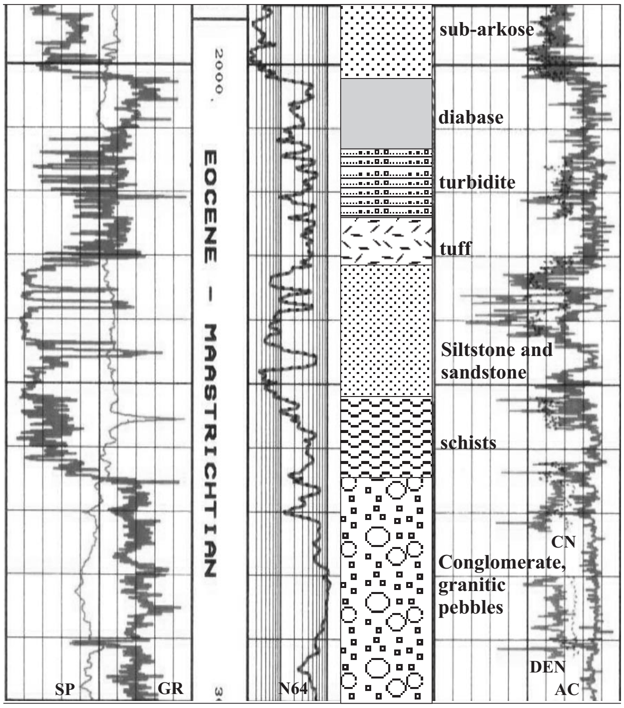

Fig. 6. Completion log of Cerna-1 well, interval 1900–3200 m.

fault related folds, resulting in the development of large southwest-verging, asymmetric folds with forelimb dips up to 80 degrees (Fig. 3).

3 An evolutionary scheme for the Dinaridic orogen

Following the Variscan orogeny, the realm of the future Apulian plate was placed along the north-eastern shelf of the Gondwana megacontinent (Yilmaz et al., 1996) toward the Paleotethys ocean. Şengör et al. (1984) proposed a continuation of the Paleotethys subduction beneath the eastern Apulian plate margin in Permian and Middle Triassic time.

Permian sediments in the Dinarides (Fig. 5) are coarse continental clastics in the central part of the chain passing to the NW and to the SE to marine areas with evaporites, shallow water carbonates and turbiditic deposits. Such differentiation could reflect the very initial stages of the future horst-graben paleogeomorphology. In the Dinarides, there seems to be no evidence documenting Permian rifting reported from the Austroalpine domain (Neubauer and Raumer, 1993). Clasts of diabase, meta-andesite and ignimbrites form few mm-sized lithoclasts within the Groeden sandstones of the Southern Alps in the northern Slovenia (Pamić et al., 2000) but are likely to be younger than Permian. The same holds for diabase dykes found in the same sandstones. Other diabase lithoclasts are found in tectonic breccias associated with Upper Permian carbonate clasts in nearby areas (Hinterlechner-Ravnik, 1965) suggesting a post-Permian age.

3.1 Extension: Early Triassic to Late Jurassic

The Dinaridic region as a part of Apulia was located to the S and W of the already existing Paleotethyan and continuated Mesozoic Tethyan ocean. Anisian to Paleocene basinal deposits of the Slovenian Basin (Buser, 1987) are considered to belong to that realm (Fig. 2).

To the west of the Dinaridic carbonate platfrom the Adria entity was found regarded as African promontory/indenter by Chanell et al. (1979) and Ratschbacher (1991). In this paper it is considered to be the integral part of the greater Apulia (Stampfli et al., 2001) as well as the Dinaridic carbonate platform. During the Mesozoic, the Adria was characterised by two semi-parallel rifted basins: the Budva Basin which formed in the Early Triassic (Fig. 2) and the Ionian Basin in which rifting started in Middle and Upper Triassic (Robertson and Shallo, 2000). In the Ionian Basin basinal deposition is documented by Early/Middle Jurassic "Posidonia" shale (Moorkens and Dohler, 1994; Nieuwland et al., 2001). Northwestward the Ionian Basin linked up with the Adriatic Basin (Fig. 4) that was bounded by the Gargano-Sazani platform in the west and by the Adriatic carbonate platform in the East. The Istria, Dalmatia and Kruja carbonate platforms present the integral parts of the unique Adriatic carbonate platform, previously considered as the separate units depending on their geographic positions, tectonic history and consequently different structural styles (Fig. 1). Rift related magmatism affected the area of Dinaridic and Adriatic platformsand it reached a climax in Ladinian to Carnian times (Fig. 4). Its cessation becomes younger from E to W.

Quite different tectonics were taking place in the East where the development of a back arc basin began associated with the long-lasting SW-ward subduction of the Paleotethys-Tethys (Sava-Vardar) ocean (Şengör et al., 1984) or as a site of lithologies of the future Inner Dinaridic Ophiolite Belt, recently interpreted by Ziwegler and Stampfli (2001) as Maliak Back arc basin. Neritic, pelagic, and magmatic deposits (Fig. 10a) developed along the northeastern margin of the Apulian plate (Eastern Dinarides). Deposition was fault-controlled and sedimentation patterns demonstrate a strong differentiation between shelf (platform carbonates) and slope/graben (Lawrence et al., 1995). Rocks belonging to the area form the Central Dinaridic Ophiolite Belt (Pamić, 1982; Lugović, 1991; Halamić, 1998). The composition of magmatic rocks (basalts, andesites, and dacites together with gabbro, diorite, granosyenite and granite of toleiitic and calc-alkaline affinity indicate a rift-induced magmatism with prominent crustal contamination (Pamić et al., 1998). Rift-related magmatism (Pamić, 1982; Trubelja et al., 2000) migrated westward through Anisian and Norian times. The rifting was followed by sea-floor spreading and opening of the Maliak(?) ocean (Ziegler and Stampfli, 2001), future Central Dinaride Ophiolite Belt, under the back-arc conditions along the eastern Apulian margin, namely in an upper plate position with respect to the ongoing subduction of the Tethys beneath Apulia (Dinarides). The age of spreading (157 Ma) is dated by K-Ar mineral age of amphibolites associated with

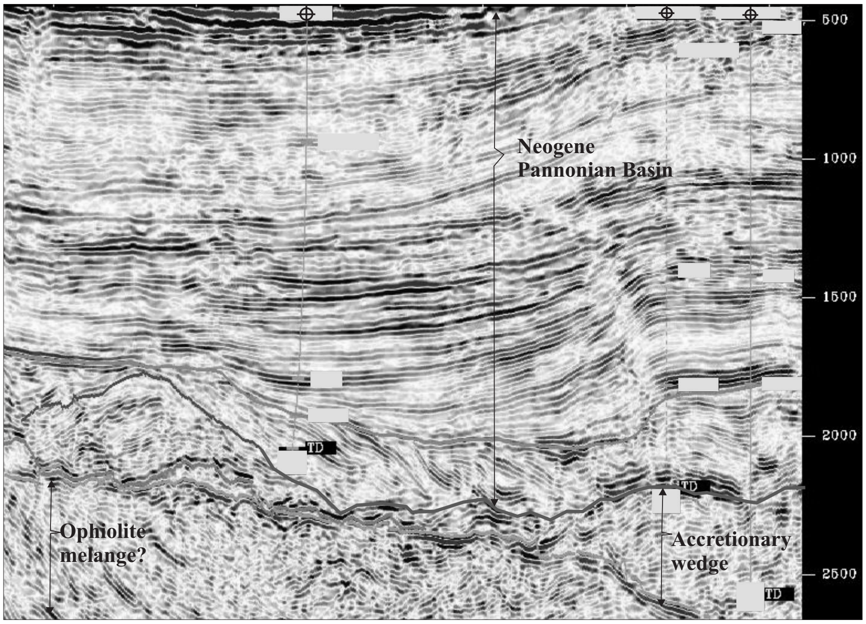

Fig. 7. 3D Seismic line "a" across the western part of the Sava Depression. For the locations see Fig. 1. Published with permission INA-Naftaplin.

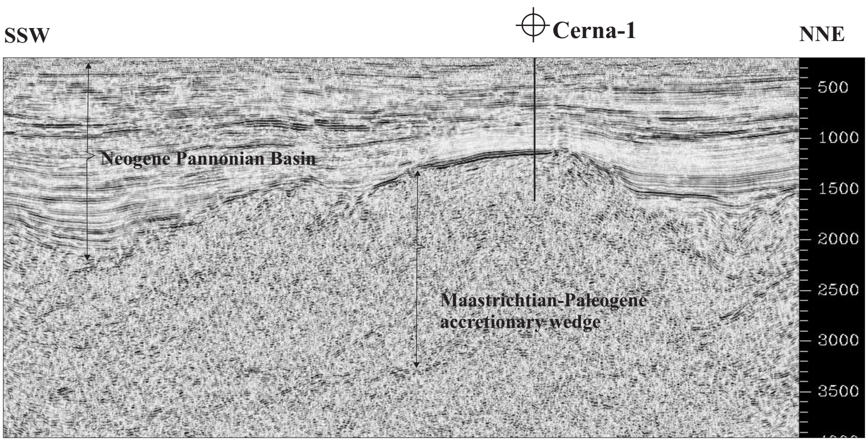

Fig. 8. 2D Seismic line "b" accros the eastern part of the Sava Depression. For the locations see Fig. 1. Published with permission INA-Naftaplin.

peridotites (Lanphere and Pamić, 1992) and Sm-Nd isochron age of the lherzolites of 136$\pm$15 Ma (Lugović et al., 1991), suggesting Middle/Late Jurassic age of the ophiolites.

Indirect evidence suggests that the rifting domain was associated to the NE with an active margin and, therefore, that it had a back-arc setting (e.g. Şengör et al., 1984). Some indications are:

1) The presence of oceanic rock types such as ophiolite, amphibolite, graywacke, shale, chert and radiolarite and limestone clasts within the ophiolite mélange of the Central Dinaride Ophiolite Belt (Fig. 10c) (Lugović et al., 1991; Halamić, 1998).

2) The same melange contains huge blocks of Paleozoic rocks and coarse-grained and reddish granite clasts of most likely Permian age, derived from a Variscan basement and post-Variscan molasse series (Hrvatović, 2000; Pamić and Jurković; 2001). Those blocks are here interpreted as olistolithes, which were tectonically transported toward the basin centres during back-arc basin spreading.

During the Late Jurassic orogenic cycle all these lithologies were incorporated into the Eastern thrust belt (Fig. 10b) and partly redeposited in the foredeep basin (Fig. 11) as Tithonian/Early Cretaceous Pogari breccia (Pamić and Hrvatović, 2000) as the basal formations of the foredeep fill.

Processes taking place in the area were probably similar to the ones observed in Tertiary back-arc basins in the Tyrrhenian Sea (Pepe et al., 2000; Faccenna et al., 1996) and in the Aegean Sea (Mascle and Chaumillon, 1996; Armijo, 1996; Lyon-Caen, 1996; Gautier et al., 1996). Middle Triassic rift-related magmatism is indeed quite common all over the Dinarides (Fig. 4). Large amounts of fine- to coarse-grained clastics were deposited in grabens during Early Triassic to Late Jurassic-Kimmeridgian times (Figs. 4 and 5).

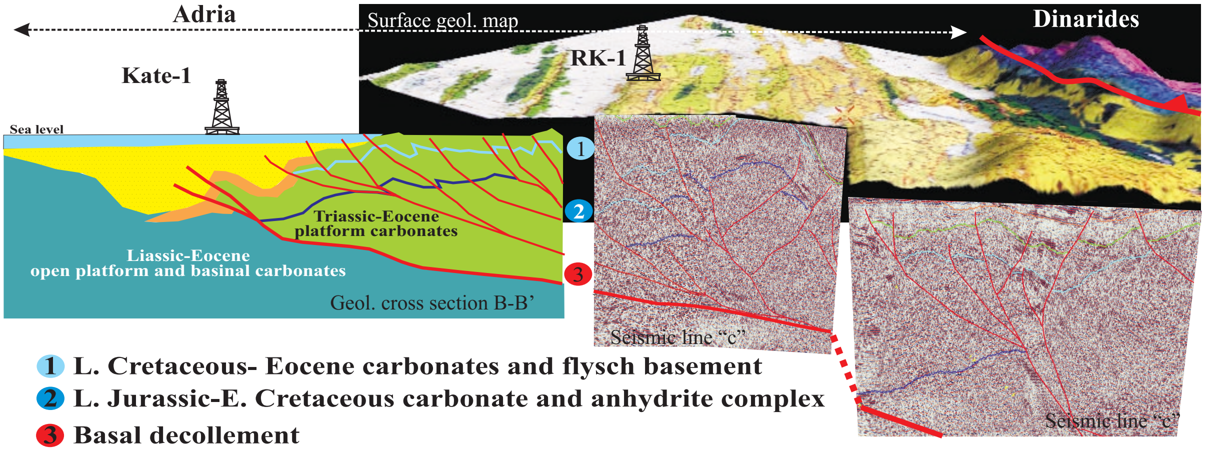

Fig. 9. Geological display showing position of 2D Seismic line "c" accros the part of the imbricate Adria carbonate platform. For the locations see Fig. 1. Published with permission INA-Naftaplin.

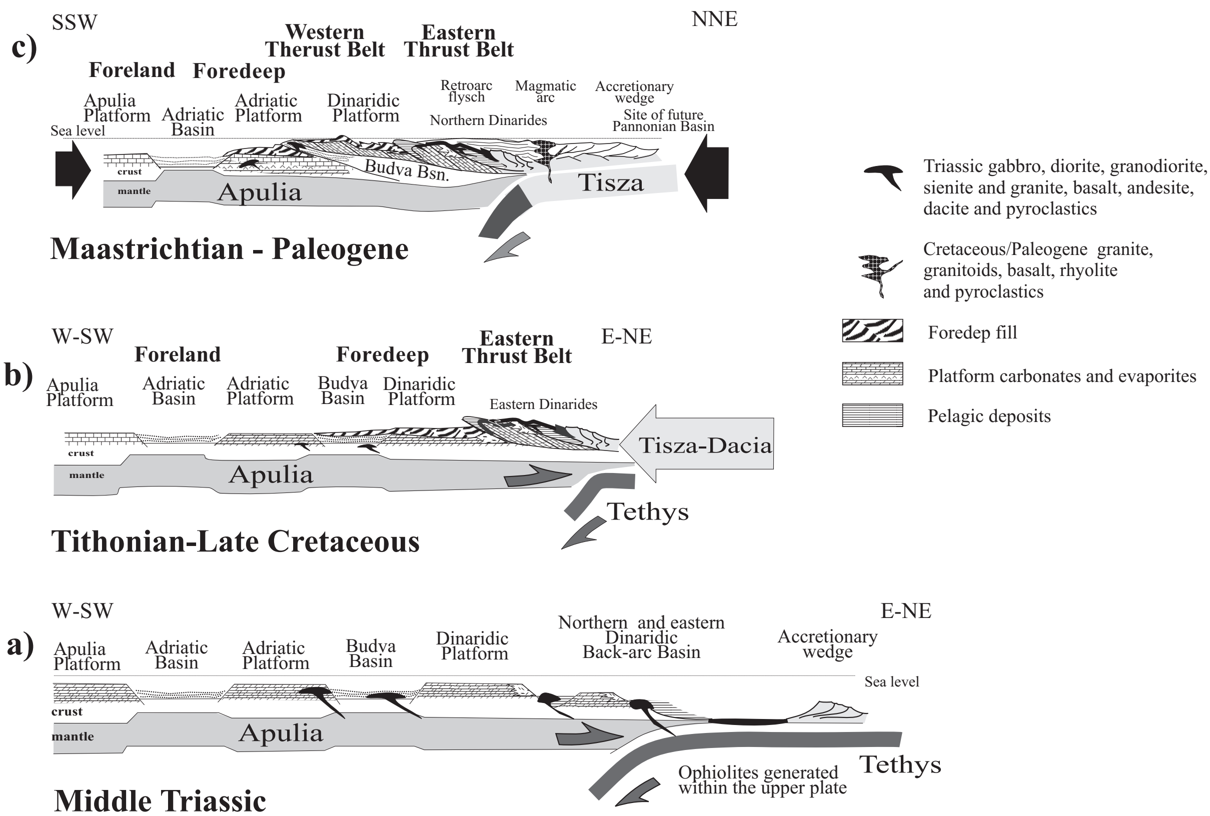

Fig. 10. Triassic to Paleogene evolutionary diagram for Dinarides.

3.2 Contraction: Late Jurassic to present day

3.2.1 Late Jurassic to Late Cretaceous

Late Jurassic to Late Cretaceous tectonics were characterized by the convergence between Apulia in the SW and Getia/Dacia and Tisza to the NE (Fig. 10b). Convergence was accommodated by the Vardar ocean subduction towards the SW and was associated with the development of the Eastern thrust belt and their westerly placed foredeep. Little deformation took place in the foreland area, i.e. on the Dinaridic carbonate platform, apart from a partial emersion at the Jurassic-Cretaceous boundary or Oxfordian-Kimmeridgian pelagic "Lemeš" trough episode (Lawrence et al., 1995). The areas affected by Triassic extensional tectonics in the central part of the Adria domain also remained undisturbed, as recognised on seismic sections at the depths below 3.0 sec, (>8 km).

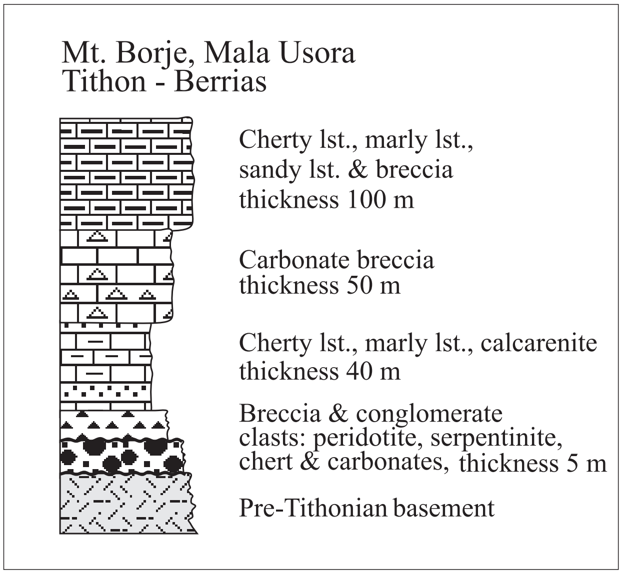

Fig. 11. Basal part of the Late Jurassic-Cretaceous foredeep overstep sequences in front of the Eastern thrust belt, Central Bosnia.

3.2.2 Late Cretaceous and Paleogene

During Late Cretaceous to Paleogene times convergence and associated subduction of the Vardar ocean under the Apulian plate continued. The most important event was the Late Cretaceous continent-to-continent collision of Tisza and Apulia. Continental collision of the Apulia and either Tisza (Balla, 1987) or Dacia (Csontos, 1995) first occurred along the present day position of the "eastern" margin of the Dinaridic platform and led to the formation of the Eastern thrust belt (Fig. 10b). As a consequence, a) a new, E- to N-vergent accretionary wedge developed and b) shortening in the Eastern thrust belt was deactivated and deformation progagated towards the SW affecting the Dinaridic Platforms, the Budva Basin and parts of the Adriatic Platform.

Thrusting propagated from the Eastern thrust belt to the west during Late Cretaceous and Eocene times and was associated with progressive westward overstepping and migration of the foredeep basin sequences over the platform carbonates of the Dinaridic platform forming the foreland of the Eastern thrust belt. At the end of the Senonian, the Eastern thrust belt was completely uplifted whereas shortening continued in the Western thrust belt through Maastrichtian-Oligocene, Miocene and Pliocene-Pleistocene compressional events.

In the eastern part of the domain (Fig. 10c) the Eastern thrust belt was mainly deactivated and a new accretionary wedge developed to the E, probably with a NE vergence. A magmatic arc was also activated. These features are presently buried underneath the Pannonian basin. Upper Cretaceous-Paleogene accretionary wedge deposits were recognised in oil wells and seismic interpretation of the basement of the South Pannonian Basin in Croatia (Tari and Pamić, 1998) and Serbia (Čanović and Kemenci, 1988, 1999). Coeval flysch-like deposits (Jelaska, 1978) of the retroarc area in the northern Bosnia belong to the same tectonic event. Upper Cretaceous-Paleogene west-east trending remnants of the magmatic arc are exposed to the surface in the mountains Prosara, Motajica, Požeška Gora, Papuk, Cer and Bukulja following the southern margin of Pannonian Basin (Tari and Pamić, 1998).

The complicated petrological and sedimentological composition of Cuisian (restricted to Slovenia and Eastern Herzegovina) and Lutethian-Priabonian flysch deposits were apparently sourced from two different source areas:

– uplifted and eroded Jurassic-Cretaceous foredeep fill of the Eastern thrust belt giving predominantly siliciclastic flysch sequences;

– and from the Western thrust belt as the source of predominantly carbonate clastics. The geometry of the Late Eocene foredeep can be hardly re cognised in the NW part, in the area from the Bay of Trieste and in the northwestern Istrian peninsula due to a strong shortening.

The central and western parts of the area began to be affected by shortening which led to the Eocene formation of the SW-vergent Western thrust belt. The Dinaridic Platform and the adjacent Budva Basin were burried by foredeep deposits during the Middle and Upper Eocene (Fig. 12b) (Tari-Kovačić and Mrinjek, 1994; Tari-Kovačić et al., 1998; Drobne et al., 2000) and then, during Oligocene/Early Miocene overthrust by the Dinaridic thrust belt. The SW-ward thrus propagation caused a general exhumation and emersion of the Dinaridic platform domain. However, south of Dubrovnik and further southwards in Montenegro, Albania and Greece the Budva basin was not involved in shortening until the Early Miocene.

Further to the SW in Adriatic offshore, highs and lows, most likely horst and graben extensional structures, were developed within the Adriatic platform during Cenomanian and Turonian (Fig. 12), i.e. during the initial stages of thrusting in the NE (Grandić et al., 1997).

3.2.3 Oligocene to Early Miocene

During the Oligocene and Miocene Adria continued to underthrust the Dinarides and Southern Alps. Cretaceous-Paleogene carbonate and flysch deposits were detached from their substratum and were imbricated in front of the Western thrust belt, which in turn was affected by back-thrusting and tectonic inversion. During the Oligocene progressive underthrusting of the Adria Early Cretaceous-Eocene carbonates and Late Eocene flysch deposits were detached at the level of Jurassic and Early Cretaceous anhydrites and thrust back southwestward over the western margin of the Adriatic carbonate platform. These imbricate structures (accretions) in front of the Western thrust belt were as generally accepted opinion considered to belong to the Dinaridic carbonate platform (Lawrence et al., 1995). However, the stratigraphic record evidences their Adriatic carbonate platform affinity (Fig. 3).

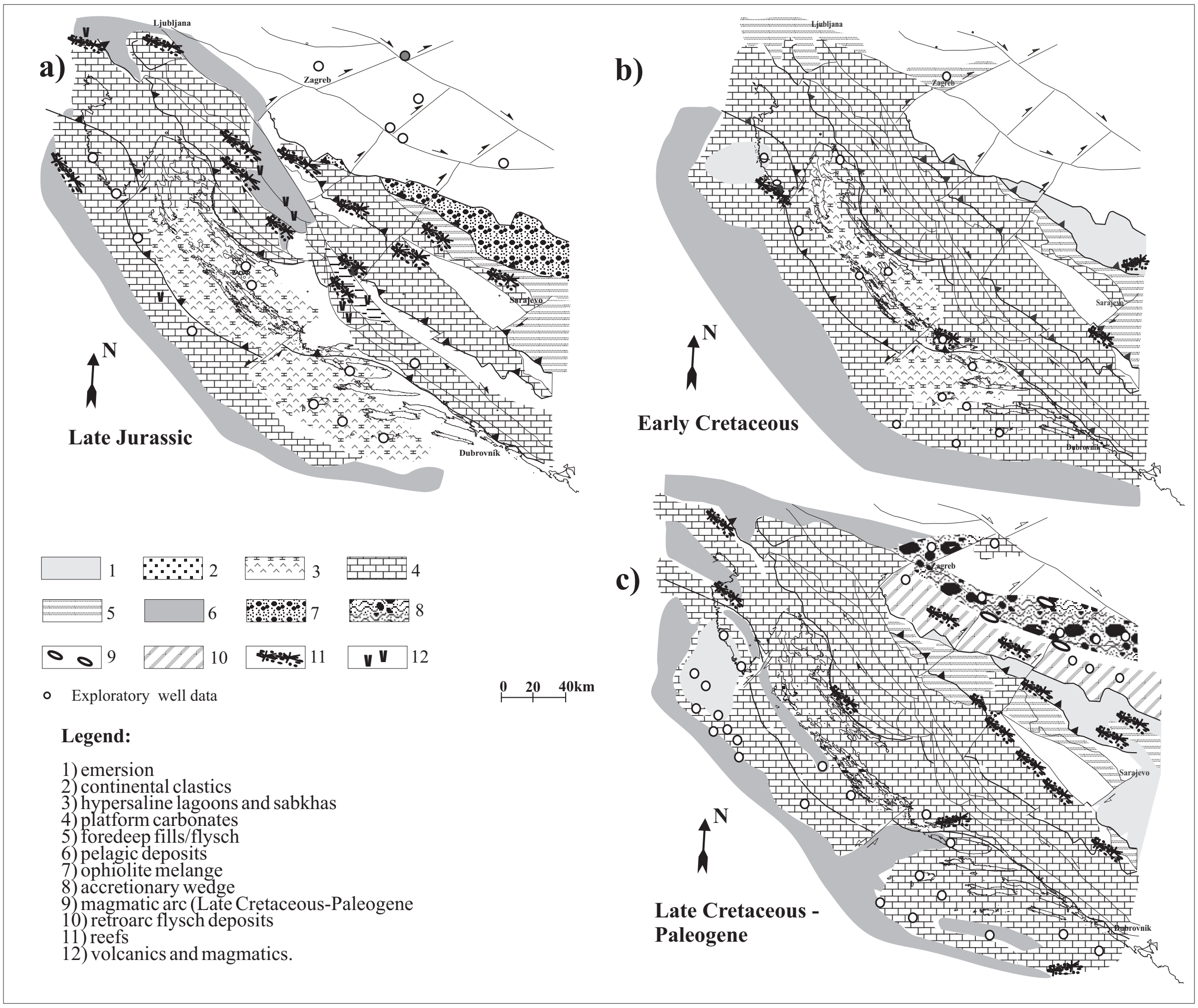

Fig. 12. Simplified Late Jurassic to Maastrichtian-Paleogene facies not palinspastically restored maps. 1) emersion; 2) continental clastics; 3) hypersaline lagoons and sabkhas; 4) platform carbonates; foredeep fills/flysch; 6) pelagic deposits; 7) ophiolite melange; 8) accretionary wedge; 9) magmatic arc (Late Cretaceous-Paleogene; 10) retroarc flysch deposits; 11) reefs; 12) volcanics and magmatics.

A continuous belt of the imbricated Cretaceous and Paleogene deposits developed along the eastern Adriatic coast from Bay of Trieste until the town of Split during the Oligocene, and further southward until the town of Dubrovnik during the Miocene and after. The width of this belt and the size of it structures was controlled by the presence and the depth (between 2000 and 6000 m) of the Jurassic-Early Cretaceous anhydrite decollement (Figs. 3 and 9).

The amount of shortening within the Adria and, consequently, the Dinarides decreases towards the South. In the central coastal area (Fig. 9) the style of the Adria detached- and flip-back-imbricated structures is controlled by the position of the major decollement..

3.2.4 Miocene to Pleistocene

Three main deformation episodes affected the area in Miocene to Pleistocene times.

In the NE domain extension associated with the development of the Pannonian basin affected the Eastern thrust belt causing its subsidence (Figs. 7 and 8). As a result, the entire accretionary wedge is overlain now by the thick sedimentary fill of the Pannonian Basin.

In the SW domain underthrusting of Adria continued. The Adriatic offshore was occupied during the Pliocene and Pleistocene by the Apennine foredeep. Its sedimentary fill overlies gently structured Mesozoic and Tertiary sequences of the Adriatic carbonate platform and the Adriatic-Ionian Basin. In Montenegro, the pelagic deposits of the Budva Basin were thrust over the Adriatic (Kruja) carbonate platform, which is almost undisturbed in South Adriatic offshore. Further southward in Albania, the Kruja carbonate platform and Ionian basin deposits were strongly shortened during Aquitanian, and again during the Tortonian, Messinain and post-Pliocene.

The third major event affecting the Dinaride edifice was the activation of strike slip faults. Two sets are distinguished, in NE-SW and NW-SE direction, both with a dextral sense of movement (Fig. 1). The first seems to be older than the second.

The NE-SW trending system, probably of Early Miocene age, is related to extension in the Pannonian Basin. Clear examples are the Early Miocene NE-SW striking Zagreb-Zemplin and NNE-SSW striking Danube-Drina strike-slip faults. Later W-E directed Miocene to Pliocene Sava and Drava strike-slip fault systems are the result of accommodation processes within Pannonian Basin, related to Carpathians, Alps and Dinarides interaction.

The NW-SE trending system within Western thrust belt and Adria results from N-ward movement of the Adriatic block. Subduction of the Ionian and Aegean oceanic lithosphere under the Hellenides and Albanides, that started in Early Miocene (Avigad et al., 1996), push and indented Adria with the Southern Alps. At the same time Adria continued to underthrust the Dinarides to the east, and started to underthrust the Apennines on the west. In the zones of the oblique-slip motions the main fault zones are marked by the systems of transpressional flower structures and transtensional pull-apart basins, exampled by the structures along the Sava and Drava depressions. In the Dinarides large transpressional features (Fig. 1) and restricted pull-apart basins/karst valleys developed. For instance, the Paleozoic Mid-Bosnian Schist Mountains (Fig. 3) are interpreted as being uplifted in conjunction with the Miocene inversion of the hanging wall related to the back thrusting on the leading edge of the Western thrust belt.

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