

The bases for understanding of the NW Dinarides and Istria Peninsula tectonics

Osnove razumevanja tektonske zgradbe NW Dinaridov in polotoka Istre

Ladislav PLACER¹, Marko VRABEC² & Bogomir CELARC¹

¹Geološki zavod Slovenije, Dimičeva ul. 14, SI-1000 Ljubljana;
e-mail: ladislav.placer@geo-zs.si; bogomir.celarc@geo-zs.si

²Univerza v Ljubljani, Naravoslovnotehniška fakulteta, Aškerčeva 20, SI-1000 Ljubljana;
e-mail: mvrabec@ntfgeo.uni-lj.si

Prejeto / Received 24. 3. 2010; Sprejeto / Accepted 24. 5. 2010

Key words: Neogene and recent movements, Istria-Friuli Underthrust Zone, rigid indenter of Adria Microplate

Ključne besede: Neogenski in recentni premiki, Istrsko-Furlanska podrivna cona, trdno jedro Jadranske mikroplošče

Abstract

Thrust structure of the northeastern part of the External Dinarides is depended upon paleogeography of the **Adriatic–Dinaric Mesozoic Carbonate Platform**, which was in the southeast (in the recent position) composed of Dinaric and Adriatic segment with intermediate Budva Trough. In the northwest in the area of the present Slovenia, it represents uniform platform. In the northwestern continuation of the Budva Trough, shallow halftrough formed and more to the west, shallow Friuli Paleogene Basin came in to being, which separated so called Friuli Carbonate Platform from the central part of the carbonate platform. Area of Istria was separated from Adriatic segment with Kvarner Fault, originated already in the Mesozoic.

External Dinaric Thrust Belt formed in the final phase of the Dinarides overthrusting. It originated from Dinaric segment of the Mesozoic Carbonate Platform at the end of the Eocene and was thrust on the Adriatic segment of the Mesozoic Carbonate Platform. Whole process also triggered formation of the **External Dinaric Imbricate Belt** with Thrust Front of the External Dinarides against Adriatic–Apulian Foreland. Later also represents rigid indenter of the Adria Lithospheric Microplate (“Adria”), and External Dinaric Imbricate Belt represents its deformed margin, therefore we place it to the rigid indenter.

Segmentation of the “Adria” occurred in the Miocene or later. It roughly disintegrated in the Padan and Adriatic part along Kvarner Fault. During rotation of the Padan part in the counter clockwise sense, the corner part, representing Istria Peninsula, rotated and underthrust towards northeast under External Dinarides. As a result, **Istria–Friuli Underthrust Zone** formed, structurally conditioned with the position of the Friuli Paleogene Basin, and vast **Istria Pushed Area** between Southern Alps, Velebit Mts. and Želimlje Fault. This process is still active recently.

During Istria underthrusting and pushing in the northwest direction, Raša Fault and Thrust Front of the External Dinaric Thrust Belt bended, and as a consequence, strike-slip movements along those planes were hindered. From the tip of the Kvarner Bay towards Idrija and Ravne Faults in the Upper Soča Valley, conditions for formation of the en echelon strike-slip belt were set up. The strike-slip belt is defined with segment of the Raša Fault southeast from Ilirska Bistrica, seismically active area between Ilirska Bistrica – Hruševje stretch, Vipava Fault, Predjama Fault and northwestern part of the Idrija and Ravne Fault. Therefore we postulate, that a segment of the External Dinaric Thrust Belt Front and shear boundary between the tip of Kvarner Bay and Upper Soča Valley, with extended branches of the Idrija and Ravne Faults, represents new attached block of the Adria Microplate rigid indenter edge.

Izvleček

Narivna zgradba severozahodnega dela Zunanjih Dinaridov je pogojena s paleogeografsko podobo **Jadransko-dinarske mezozojske karbonatne platforme**, ki je bila na jugovzhodu v današnji legi zgrajena iz dinarskega in jadranskega segmenta platforme z vmesnim **Budvanskim jarkom**, na severozahodu na območju današnje Slovenije pa je tvorila enotno platformo. V podaljšku Budvanskega jarka proti severozahodu, se je v paleogenu izoblikoval plitek poljarek, zahodno od tod pa plitek **Furlanski paleogeni bazen**, ki je tedaj ločil t. i. Furlansko karbonatno platformo od osrednjega dela karbonatne platforme. Območje Istre je bilo od Jadranskega segmenta platforme ločeno s **Kvarnerskim prelomom**, ki je bil zasnovan že v mezozoiku.

V končni fazi krovnega narivanja Dinaridov je iz dinarskega segmenta mezozojske karbonatne platforme konec eocena nastal **Zunanjedinarski narivni pas**, ki se je narinil na jadranski segment mezozojske karbonatne platforme in izzval nastanek **Zunanjedinarskega naluskanega pasu** katerega čelo predstavlja **Narivno čelo Zunanjih Dinaridov** nasproti **Jadransko-apulijskemu predgorju**. Slednje predstavlja trdno jedro Jadranske litosferne mikroplošče (“Adrie”), Zunanjedinarski naluskani pas pa njeno deformirano obrobje in ga zato prištevamo k trdnemu jedru.

V miocenu ali pozneje je prišlo do segmentacije "Adrie". Ta je v grobem razpadla ob Kvarnerskem prelomu na padski in jadranski segment. Pri rotaciji padskega segmenta v nasprotni smeri urinega kazalca, se je njen vogalni del kjer leži polotok Istra, zasukal in se podrinil proti severovzhodu pod Zunanje Dinaride. Nastala je **Istrsko-furlanska podrivna cona**, ki je strukturno pogojena z lego Furlanskega paleogenskega bazena in obsežno **Istrsko potisno območje**, ki zajema prostor med Južnimi Alpami, Velebitom in Želimejskim prelomom. Ta proces je recentno aktiven.

Pri podirvanju in potiskanju Istre proti severovzhodu se je usločil Raški prelom in čelni nariv Zunanjedinarskega narivnega pasu, zaradi česar je bilo zmikanje ob teh ploskvah oteženo. Ustvarili so se pogoji za nastanek ešalonskega zmičnega pasu od vrha Kvarnerskega zaliva proti Idrijskemu in Ravenskemu prelomu v dolini zgornje Soče. Pas je definiran s segmentom Raškega preloma jugovzhodno od Ilirske Bistrice, pasom pogoste seizmične aktivnosti Ilirska Bistrica – Hruševje, Vipavskim prelomom, Predjamskim prelomim ter severozahodnim delom Idrijskega in Ravenskega preloma. Postavljamo domnevo, da predstavlja segment med Čelom Zunanjedinarskega narivnega pasu in strižno mejo med vrhom Kvarnerskega zaliva ter zgornjim Posočjem s podaljšanimi vejama Idrijskega in Ravenskega preloma proti zahodu nov priključeni blok mejnega pasu trdnega jedra Jadranske mikroplošče.

Introduction

The idea about tectonic structure of the north-western part of the External Dinarides is based on the data of structural mapping and hypothetic assumption of the Adria Microplate indenter underthrusting below External Dinarides (BLAŠKOVIĆ & ALJINOVIĆ, 1981; BLAŠKOVIĆ, 1991, 1998, 1999; Placer, 2002, 2005, 2007; Placer et al., 2004), on the analysis of repeated leveling line campaigns data (RIŽNAR et al., 2007) and GPS measurements (WEBER et al., 2010).

The question of structure of the northwestern part of Dinarides in hinterland of Trieste Bay, Istria Peninsula and Kvarner Bay (Fig. 1) is important for understanding the dynamics of tectonic processes and establishment of trace of north-eastern boundary of the rigid indenter of the Adria Lithospheric Microplate. It is also closely related with discussion on existence of a single or two Mesozoic carbonate platforms. The concept of a single platform has been recently maintained

by VELIĆ et al. (2002) and VLAHOVIĆ et al. (2005), and the term Adriatic Carbonate Platform was proposed, which also includes several intraplateform basins that assumed various positions in the evolution process of the platform. In structural sense, Budva Trough ($T_3 - K$) divides central and southern part of the platform into two segments. Two platforms, the Adriatic and the Dinaric one, with the interplatform Budva Trough, have been advocated by HERAK (1986, 1999), TARI (2002) and KORBAR (2009).

The analysis of the thrust structure of north-western part of Dinarides described in the present paper supports the assumption that the model by VELIĆ et al. (2002) and VLAHOVIĆ et al. (2005) more closely corresponds to the situation in the field, whereas Tari's model, although established in the central and southeastern part of the External Dinarides, provides an appropriate basis for structural and genetic presentation of problems. Since according to our research the Budva Trough was larger in size than believed by VLAHOVIĆ et al.

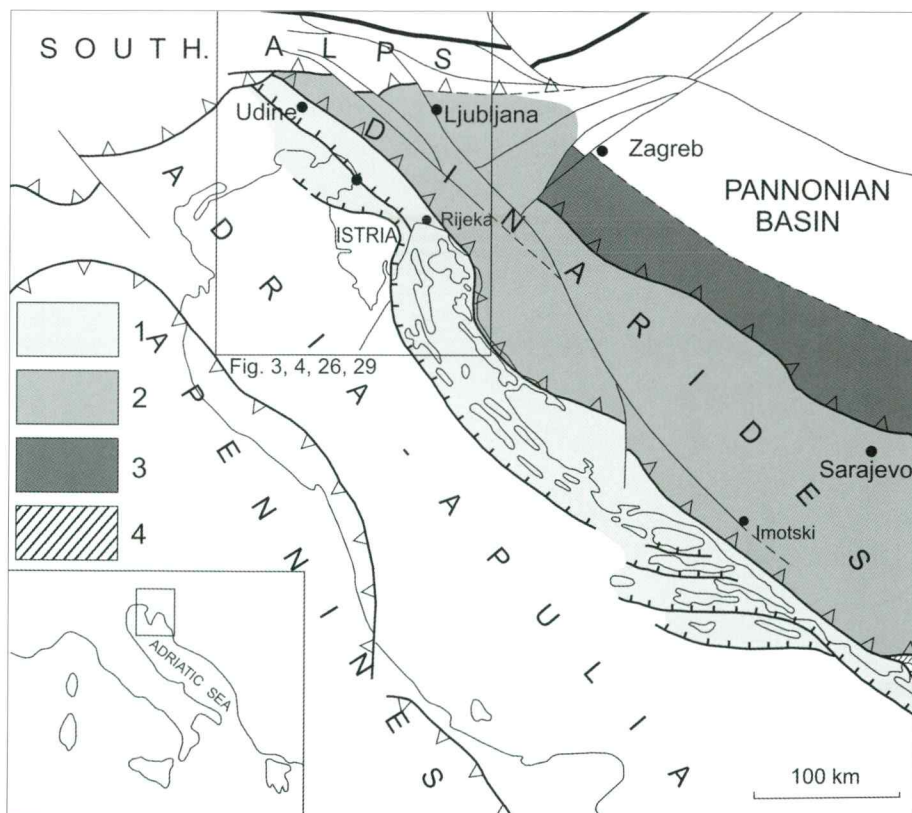


Fig. 1. Orientation sketch. Thrust subdivision of the Dinarides.
1. External Dinaric Imbricated Belt;
2. External Dinaric Thrust Belt;
3. Internal Dinaric Thrust Belt;
4. Budva Trough.

(2005), and had therefore a stronger influence on formation of the thrust structure, we believe it is more appropriate to use the term Adriatic-Dinaric Carbonate Platform (PAMIĆ et al., 1998) consisting of Adriatic and a Dinaric segment. Therefore we accordingly modified TARI'S (2002) structural terminology.

TARI (2002) subdivided the Dinaric thrust structure into the Eastern Thrust Belt and the Western Thrust Belt whose overthrusts verge toward SW. The Eastern Thrust Belt consists of rocks of the prerifting and rifting stages, and the most characteristic overthrust structure in it is the front nappe of ophiolitic melange. The latter is overthrust on the Western Thrust Belt whose northeastern part consists of Jurassic and Cretaceous flysch filling the pre-thrust basin of the Eastern Thrust Belt, and its central and southwestern parts comprise rocks of the Dinaric Mesozoic carbonate platform that comprises the foreland of the Eastern Thrust Belt. The southwestern boundary of the Western Thrust Belt is constituted by the Frontal Thrust of the Dinaric carbonate platform that passes along the Adriatic coast. Below the Frontal Thrust is underthrust the marginal part of the Adriatic Carbonate Platform, as a result of which the Imbricated belt of the Adriatic Carbonate Platform is formed. Rocks of the Budva Basin are covered by overthrusts of the Western Thrust Belt. The thrust structure of Dinarides progressed in time and space from northeast toward southwest. The Eastern Thrust Belt, however, started to form after the continental progressive convergence at the end of Jurassic, while the Frontal Thrust of the Western Thrust Belt ended its evolution in the Older Eocene. The imbricated belt of the Adriatic Carbonate Platform might have originated in the last thrusting stage of the Western Thrust Belt already, its evolution continued by underthrusting of the rigid indenter of the Adria Lithospheric Microplate under Dinarides in Oligocene, and has been still active in Pleistocene.

In the paper the classical structural subdivision into the Internal and External Dinarides, and their foreland is used (Fig. 1). TARI'S (2002) Eastern Thrust Belt is considered as the **Internal Dinaric Thrust Belt**, and Western Thrust Belt as the **External Dinaric Thrust Belt**. For southwestern boundary of the External Dinaric Thrust Belt it seems better to use the term **Frontal Zone of the External Dinaric Thrust Belt** than the term Frontal Thrust of the Western Thrust Belt, since it better corresponds to reality. Its trace is identical with the classic Overthrust of High Karst in the sense of HERAK (1999), PAMIĆ & HRVATOVIĆ (2003), PRELOGOVIĆ et al. (2004), and others. The **External Dinaric Imbricated Belt** is identical in its central and southeastern coastal part to Tari's Imbricated Belt of the Adriatic Carbonate Platform that represents in structural sense marginal part of the rigid indenter of Adria Lithospheric Microplate. The southwestern boundary of the External Dinaric Imbricated Belt is the **Thrust Front of External Dinarides**.

The overthrust model by KORBAR (2009) cannot be included into this concept, since his understanding of the size of the Dinaric and Adriatic segments of the Mesozoic Carbonate Platform differs from all previous ideas. Korbar included into the Dinaric segment also the central part of our External Dinaric Imbricated Belt, respectively of TARI'S Imbricated Belt of the Adriatic Platform between Istria and Brač which is a part of the Adriatic branch of the Adriatic-Dinaric Carbonate Platform, or a separate carbonate platform in previous models.

In the studied region, Paleozoic clastites and Upper Permian to Carnian bedded carbonates and clastites are exposed, followed by rocks of the Adriatic-Dinaric Carbonate Platform from Norian to Upper Cretaceous and Paleocene, and on the top by Upper Cretaceous and Tertiary marly calcareous and clastic rocks which are degradation products of the platform. The geometry of the thrust structure is controlled by the Budva intraplate troughs, and by two horizons of more ductile rocks which underlie and overlie the carbonate platform deposits (Fig. 2). The lower horizon is divided in External Dinarides in two levels, the lower one consisting of Carboniferous-Permian clastites, that include the Gröden (Val Gardena) Group (Fig. 2, b – dark grey shading), and the upper one composed of Upper Permian, Lower Triassic and Anisian layered carbonates and clastites, Ladinian and Carnian clastites (Fig. 2, a – light grey shading). This distinction is generally not feasible in the region of the Adriatic segment of carbonate platform owing to lack

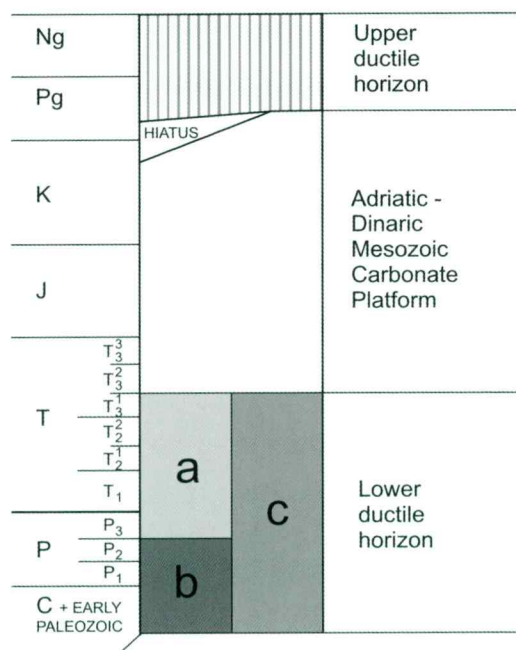


Fig. 2. Lithostratigraphic column.

Upper ductile horizon: flysch and molasse; Adriatic-Dinaric Mesozoic Carbonate Platform: Upper Triassic, Jurassic and Cretaceous carbonates; Lower ductile horizon: a – Upper level: Carnian clastites, Middle Triassic clastites and volcanic rocks, Anisian carbonates, Lower Triassic carbonates, marlstones and clastites and Permian carbonates; b – Lower level: Middle and Lower Permian clastites and carbonates and oldest clastites; c – Upper and Lower level undifferentiated.

of data; so the entire horizon is marked by grey shading (Fig. 2, c – grey shading). For the sake of better distinctness on the tectonic map in Fig. 3 only the lower level of the lower ductile horizon is drawn next to the upper ductile horizon (Fig. 2, b – dark grey shading).

In this article, the age of thrust deformations is based on the Eocene age of flysch in the southeastern part of the External Dinarides. New findings about Miocene age of flysch (MIKES et al., 2008) are not verified yet, so they were not taken in to the consideration.

The boundary with Southern Alps is considered in the present paper formally, without regard to the internal structure of the Southern Alps. The concept of the Southern Alpine Boundary is understood in the sense as presented by SLEJKO et al. (1986), CARULLI et al. (1990), NUSSBAUM (2000), MERLINI et al. (2002) and PERUZZA et al. (2002).

The rigid indenter of the Adria Microplate, abridged “Adria” in the quotation marks, will be used in the further text.

Tectonic structure

Interpretation of tectonic structure of Istria and its hinterland between Southern Alps and Velebit Mts. (Fig. 3) is based on data of the Basic Geologic Map of Yugoslavia of scale 1:100.000 (BUSER et al., 1967; BUSER, 1968, 1969, 1978, 1986, 1987; GRAD & FERJANČIČ, 1974, 1976; MAGAŠ, 1968; MAMUŽIĆ et al., 1969; PLENIČAR et al., 1969; PLENIČAR et al., 1973; POLŠAK, 1967; POLŠAK & ŠIKIĆ, 1973; PREMUR, 1983; SAVIĆ & DOZET, 1985; ŠIKIĆ et al., 1969; ŠIKIĆ et al., 1972; ŠUŠNJAR et al., 1970), of the compilation map Structural Model of Italy and Gravity Map, sheet 2 of scale 1 : 500.000 (BIGI et al., 1990) and Geologic Map of Friuli Venezia Giulia of scale 1 : 150.000 (CARULLI, 2006). In addition, all more important results from published works are considered (BIONDIĆ et al., 1997; BLAŠKOVIĆ, 1999; COLIZZA et al., 1989; CUCCHI et al., 1989a,b; ČAR & GOSPODARIČ, 1983/84; JURKOVŠEK et al., 1996; POLJAK & RIŽNAR, 1996; MARINČIĆ & MATIČEC, 1991; MATIČEC, 1994; MLAKAR, 1969; MLAKAR & PLACER, 2000; PERUZZA et al., 2002; PLACER & ČAR, 1997; PLACER, 1981, 1982, 1996, 2005, 2007, 2008a, 2008b; PONTON, 2002). This paper is also based on published data from structural mapping of the motorway section Divača – Koper across the Istria-Friuli Underthrust Zone in years 1999 – 2005, and Razdrto – Vipava, as well as the data from additional mapping of Razdrto – Senožeče road section, and of the seashore from Lazaret to Piran, and field inspections of key structural localities in the region between the Southern Alps and Velebit Mts.

Thrust structure of External Dinarides

In the northwestern part of Dinarides, with respect to age and genesis, there exist three thrust systems that verge toward southwest, and for which the reduction of space in SW-NE direc-

tion is characteristic. The three thrust systems are from northeast to southwest: 1. External Dinaric Thrust Belt with its frontal zone of complex structure, 2. External Dinaric Imbricated Belt with its distinct thrust front formed at overthrusting of Dinarides southwestwards, and 3. underthrusting of the “Adria” northeastwards.

Within the External Dinaric Imbricated Belt occurs the Istria-Friuli Underthrust Zone that formed in the younger stage of underthrusting of the “Adria”. The movements of Istria resulted in hinterland into the broad Istria Pushed Area that extends from Southern Alps to the Velebit Mountains. All mentioned thrust systems are underthrust under the Southern Alps. In this paper only the formal subdivision of the Southern Alpine Thrust Boundary is described.

In addition to the thrust deformations, there exist also the Dinaric NW-SE striking faults which are an important indicator of dynamics of the Dinarides.

In this article, the age of thrust deformations is based on the Eocene age of flysch in the southeastern part of the External Dinarides. New findings about Miocene age of flysch (MIKES et al., 2008) are not verified yet, so they were not taken in consideration

External Dinaric Thrust Belt

(Middle Eocene – Younger Eocene)

The External Dinaric Thrust Belt comprises nappes of the External Dinarides. Structurally highest is the Trnovo Nappe with two accompanying lower order structures, the Hrušica Nappe and the Sovič Thrust Block. These three units are associated in the Trnovo Thrust Series. Below it lies the Snežnik Thrust Unit that continues in the Vinodol Thrust Unit and the Velebit Thrust Unit. The latter three thrust units are conditionally associated in the “Velebit Thrust Series” in which, however, the relations between thrust units are not as clear as in the Trnovo Thrust Series.

Trnovo Thrust Series

Interpretation of the Trnovo Nappe is based on the data of the Basic Geologic Map (BUSER et al., 1967; BUSER, 1968, 1987) and works of MLAKAR (1969) and PLACER (1973, 1981, 1999, 2008b) that originated from study of the Idrija mercury deposit and Žirovski vrh uranium deposit respectively. Deep drilling at Cerkno (PLACER et al., 2000) confirmed the nappe structure with clear internal regularity. In the section across the Idrija deposit, the Trnovo Nappe is thrust for 32 km southwestward with respect to the Hrušica Nappe, and the Hrušica Nappe is shifted for 19 km with respect to the Sovič Thrust (PLACER, 1981). The length of shift has not been constructed for the Sovič Thrust, but is estimated to be in order of several kilometers. Thrusting directions toward southwest are proved by axes of hectometric and dekametric folds in all

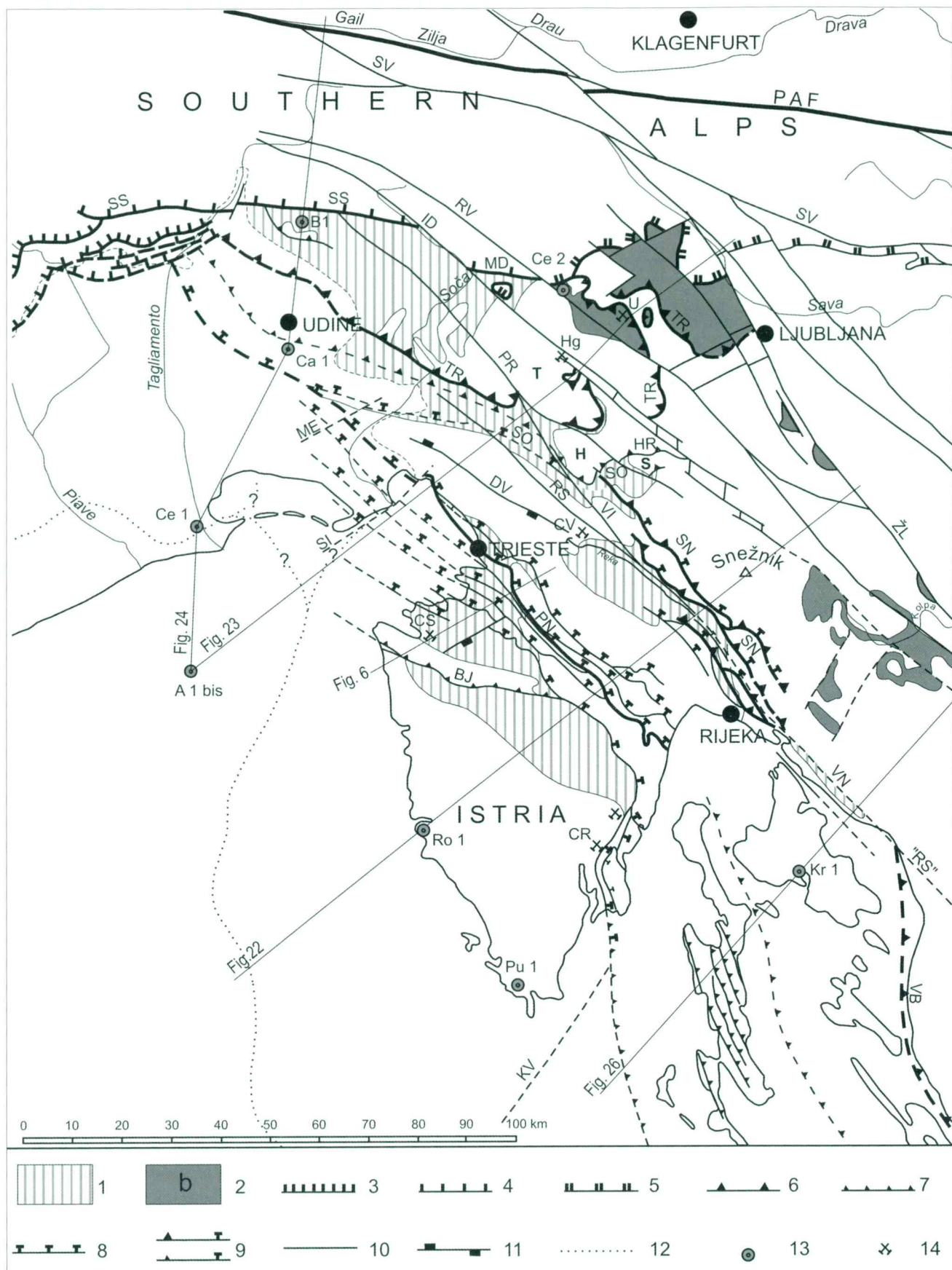


Fig. 3. **Tectonic sketch.** 1. Upper ductile horizon; 2. Lower ductile horizon southwest of the Želimlje fault; **b** – Middle and Lower Permian and Carboniferous clastites (Explanation on Fig. 2); *Boundary of underthrusting below the Southern Alps*: 3. Thrust Faults SW-NE, WSW-ESE; 4. Thrust Faults E-W west of the RV – Ravne Fault; SS – Staro selo Fault, MD – Modrej Fault; 5. Thrust Faults W-E east of the RV – Ravne Fault; *External Dinarides*: 6. Thrusts of the External Dinarides Thrust Belt: TR – Trnovo Nappe Fault, HR – Hrušica Nappe Fault, SČ – Sovič Thrust Fault, SN – Snežnik Thrust Fault Zone, VN – Vinodol Thrust Fault Zone, VB – Velebit Thrust Fault Zone; 7. Thrusts of the External Dinaric Imbricated Belt: BJ – Buje Thrust Fault; 8. The thrusts of the Istria-Friuli Underthrust Zone and Outside: PN – Palmanova Thrust Fault; 9. Reactivated thrust faults of the Istria Pushed Area; 10. *Faults*: SV – Sava Fault, ID – Idrija Fault, RV – Ravne Fault, ŽL – Želimlje Fault, PR – Predjama Fault, VI – Vipava Fault, RS – Raša Fault, SE – Sistiana (Sesljan) Fault, ME – Medea (Medeja) Fault, KV – Kvarner Fault, PAF – Periadriatic Fault Zone; 11. DV – Divača Pivot Fault; 12. Outside border of the carbonate platform; 13. *Boreholes*: A 1 bis – Amanda, Ce 1 – Cesarolo, Ca 1 Cargniacco, B 1 – Bernadia, Ce 2 – Cerkno, Ro 1 – Rovinj, Pu 1 – Pula, Kr 1 – Krk; 14. *Abandoned metal and coal mines*: Hg – Idrija (mercury), U – Žirovski vrh (uranium), CV – Vremski Britof (bituminous coal), CS – Sečovelje (bituminous coal), CR – Raša (bituminous coal).

of the three units, and rotation of macrolithons consisting of Triassic structural blocks in the Idrija mercury deposit (PLACER, 1982), and cleavage of microlithons in the Žirovski vrh uranium deposit (MLAKAR & PLACER, 2000) within the Trnovo Nappe, as well as direction of thrusting megalineation in the thrust plane of the Hrušica Nappe (PLACER, 1994/95).

The Trnovo Nappe consists of rocks of the Paleozoic and Triassic basement of the Adriatic-Dinaric Carbonate Platform, which are overlain by rocks of the carbonate platform aged from Upper Triassic to Upper Cretaceous. In the north-western part of the nappe Upper Cretaceous and Paleogene rocks were unconformably deposited in the mobile part of platform that dip toward NW, owing to which we suppose that the considered part of the Trnovo Nappe represents the north-western part of the Adriatic-Dinaric Carbonate Platform (in present orientation).

The relations in the Hrušica Nappe are different; there occur rocks of Mesozoic carbonate platform, on which the Paleogene beds of carbonate marly and flysch habitus are unconformably deposited.

The Trnovo Nappe is the oldest nappe unit of External Dinarides in the studied region. During the overthrusting toward southwest, it initiated the origin of the Hrušica Nappe, and subsequently the formation of the Sovič Thrust. With regard to its position in space, the Trnovo Nappe is unique, since in the studied area it is separated from the remaining External Dinarides nappe units. On the north it is cut by the Southern Alpine Boundary, and on the east by the Želimplje Fault which is the most important fault of the Ljubljana – Imotski Fault Zone (TARI, 2002, Miocene strike slip; PLACER, 2008b, Ljubljana – Imotski Fault Zone), and represents an important structural boundary of the External Dinarides. The Hrušica Nappe, after ČAR & GOSPODARIČ (1983/84), is clearly associated with nappe structure of the remaining part of the External Dinarides, its fault plane toward southeast being hidden in the fault zone of the Idrija Fault. The Sovič Thrust is a miniature pendant of the Hrušica Nappe (PLACER, 1996). The problem of connection of thrust planes of the Trnovo and Hrušica Thrust Nappes and of the Sovič Thrust Fault toward northwest consists in the fact, that the thrust planes visible in southeast owing to carbonates being overthrust on flysch, become extensively ramified where the thrusts are developed in flysch, as the joints develop into integral thrust planes. Since the problem of structural connecting in the field has not yet been accomplished, it is only indicated in the present paper (Fig. 3). Similar conditions in Istria (PLACER, 2007) could have been solved only by structural mapping which, however, has not yet been undertaken in the Vipava Valley area.

The main thrust plane of the Trnovo Nappe is gently folded in Dinaric direction in a wide frontal synform, and in a corresponding antiform in northeast, where it forms a tectonic half-window called the Poljane-Vrhnika belt. Both forms are indications of post-thrusting pressure in SW-NE

direction. The thrust boundary of Southern Alps that covers the mentioned folds is not folded.

The formation of the Trnovo Thrust Series could be temporally attributed to the time and space between the Internal Dinaric Thrust Belt, supposed to have started forming in Younger Jurassic, and its frontal zone, whose evolution might have been accomplished in Older Eocene (TARI, 2002). According to our opinion, however, it could have lasted, considering the age of the flysch beds in the Vipava Valley, to the end of Middle, or to the Younger Eocene.

Velebit Thrust Series

The region of the “Velebit Thrust Series” south-east of the Trnovo Thrust Series is not evaluated. Subdivision into the Velebit Nappe unit and the Vinodol and Snežnik thrust units is formal. The thrust front of this belt in northwest is covered with the thrust front of the Sovič or Hrušica Nappe fault.

Frontal Zone of the External Dinaric Thrust Belt (Younger Eocene)

The Frontal Zone of the External Dinaric Thrust Belt is an important structural element of the thrust structure of Dinarides. In hinterland of Kvarner and Istria to the Postojna Basin it is identical with frontal zones of the Velebit, Vinodol and Snežnik Thrust Faults, where it is covered with the Sovič or Hrušica Nappe fault. Two possible variants of its course from there towards northwest are found in the literature. According to the first one (HERAK 1999, PREMUR 1980, 2005), the frontal parts of the Snežnik Thrust Block and of Hrušica and Trnovo Nappe are connected with a single thrust zone, against which is supposed to lean the Hrušica and Trnovo Thrust Fault; whereas according to the second variant (BUSER et al., 1967; BUSER, 1968; PLACER, 1999, 2008b), the unique frontal zone has supposedly split into the Hrušica and Trnovo Thrust Faults. The first variant is based on sedimentological-paleontological research that resulted in the hypothesis of existence of two separated carbonate platforms, the Adriatic and the Dinaric one. The second variant is based on analysis of structural relationships and on the hypothesis that the differences in Upper Cretaceous, and later in Paleogene, are a result of formation of intraplateau troughs of Dinaric direction with specific environments (ŠRIBAR, 1995), which permitted the coexistence of various developments at relatively short distances. This could explain the differences in development on the opposite sides of the Snežnik Thrust Fault in the area of the Postojna Flysch Basin. During mapping of the Razdrto – Vipava motorway section and at a preliminary field inspection of the southeastern part of the Vipava Synclorium it has been found that the thrust planes of the Trnovo Nappe Series in their frontal part do not follow the regional dip of

nappe units toward northwest, because they were deformed during formation of the “Adria” unit.

The External Dinaric Imbricated Belt (Marginal belt of “Adria”) (Oligocene)

The External Dinaric Imbricated Belt (Fig. 4) in the region of Dalmatia and Kvarner is identical with the imbricated margin of Adriatic segment of the carbonate platform. In northeast it is bordered by the Frontal Zone of the External Dinaric Thrust Belt, and in southwest by the **Thrust Front of External Dinarides**. The latter represents the boundary of the imbricated margin of the “Adria” towards its solid core. The Thrust Front of External Dinarides lies in the middle Adriatic parallel to the Frontal Zone of External Dinaric Thrust Belt, whereas in the Istrian peninsula it is considerably displaced northeastwards, which resulted in a substantial shortening of the External Dinaric Imbricated Belt. The Buje Fault in Istria represents a relic of the Thrust Front of External Dinarides. The reason for deformation and narrowing of the imbricated belt is the Miocene and Post-Miocene separate underthrusting and displacement of Istria towards northeast. Towards northwest the belt widens again.

The External Dinaric Imbricated Belt in the Kvarner region and southeast from there, consists of folds and slices with characteristic lystric thrust planes hypothetically connected in depth with ductile horizons. The part of belt situated closer to Frontal Zone of the External Dinaric Thrusts is typically less imbricated. This part consists of folds in Ravni Kotari, on the islands of Pag, Rab and Krk, and in hinterland of Istria, the Bay of Trieste and in Friuli. In hinterland of Istria and Bay of Trieste the folds are referred to as the Kras-Notranjsko Folded Structure (PLACER, 2005). The latter comprises Anticlinorium of Čičarija and Trieste-Komen, Synclinorium of Brkini and Vipava, and the Ravnik Anticline. Characteristic for this group of folds is their en-echelon spatial arrangement. The southwestern half of the External Dinaric Imbricated Belt is more intensely imbricated in the Kvarner area, its structure being visible on the island of Cres. In Istria there are no visible proofs of lystric faults with the only exception of the Buzet Fault in the area of Northern Istria Structural Wedge.

Istria – Friuli Underthrust Zone (Miocene – Recent)

The Istria-Friuli Underthrust Zone is visible from Sestian in the Bay of Trieste to the eastern coast of Istria Peninsula along the Kvarner Bay (Fig. 4). The zone was defined during the mapping of the Kozina – Koper motorway section.

Formation of the Istria-Friuli Underthrust Zone, preliminarily called the Istria-Friuli block, was a result of separate underthrusting of a part

of the “Adria” northeastwards. Underthrusting is believed to have started in post-Miocene time, according to the Synthetic structural-kinematic map of Italy already in Oligocene (BIGI et al., 2000), and is probably still active at present. The recent activity of the zone is established in Istria (RIŽNAR et al., 2007), while its Paleocene and Pleistocene activity in Friuli is being proved (MERLINI et al., 2002). According to structural data, the southeastern boundary of separate underthrusting of the Istria-Friuli block is a transversal fault, or swarm of faults, that cuts the Adriatic segment of the carbonate platform. After GRANDIĆ et al. (1997b), this fault zone could have originated already in Middle Triassic, and has been reactivated later. It is called by KORBAR (2009) the Kvarner Fault Zone. It seems possible that the Kimmeridgian emersion and bauxite occurrences in Istria (VLAHOVIĆ et al., 2005) were a consequence of displacements along this zone. The role of this zone is explained in the following text.

The central structural element of the Istria-Friuli Underthrust Zone is the Palmanova Thrust Fault, locally named the Črni Kal Thrust Fault (PLACER, 2007), that is accompanied in the hanging wall and footwall limbs by several thrust faults. The section of the underthrust zone has been mapped in detail in the Kozina-Koper motorway segment (PLACER, 2007, Fig. 3), and is schematically shown in Fig. 6. The named thrust faults are shown on ground-plan in Fig. 5. In the hanging wall block the thrusts are arranged in the way, that the displacement along the highest, the Petrinje Thrust Fault, is the shortest (400–500 m horizontal displacement), and that it increases downward along the following thrusts. The displacement along the second thrust is around 1475 m, along the third one around 2900 m, while along the fourth, the Palmanova (Črni Kal) Thrust Fault the displacement in this profile is considerably larger, although it could not be reconstructed with sufficient accuracy. By extrapolation, allowing errors of up to 100%, it amounts to more than 10 km. The dip angle of the highest thrust fault varies between 35° and 30°, and of others from 25° to 20°. Traces of thrust faults in the hanging wall block can be followed on surface from Sistiana (Sestian) northwest of Trieste to Mt. Učka just next to the Kvarner Bay, where even tectonic windows and outliers occur, indicating the nappe character of overthrusts in the area (ŠIKIĆ et al., 1969, 1972). Hence it follows that displacements increase toward southeast. The plane of the Palmanova Thrust Fault in the Mt. Učka area is subhorizontal, while east of the ridge, passing parallel to the seashore and forming the core of a monocline, it gets together with beds tilted downwards. As a result of rotation the fault trace strikes approximately north-south, consequently different than in the case if the beds had retained the Dinaric NW-SE direction.

The position of thrust faults in the footwall side is different. Their dip angle decreases toward southwest from 25°–30° for the Palmanova Thrust Fault, to 10°–20° for the Buzet Thrust Fault, and

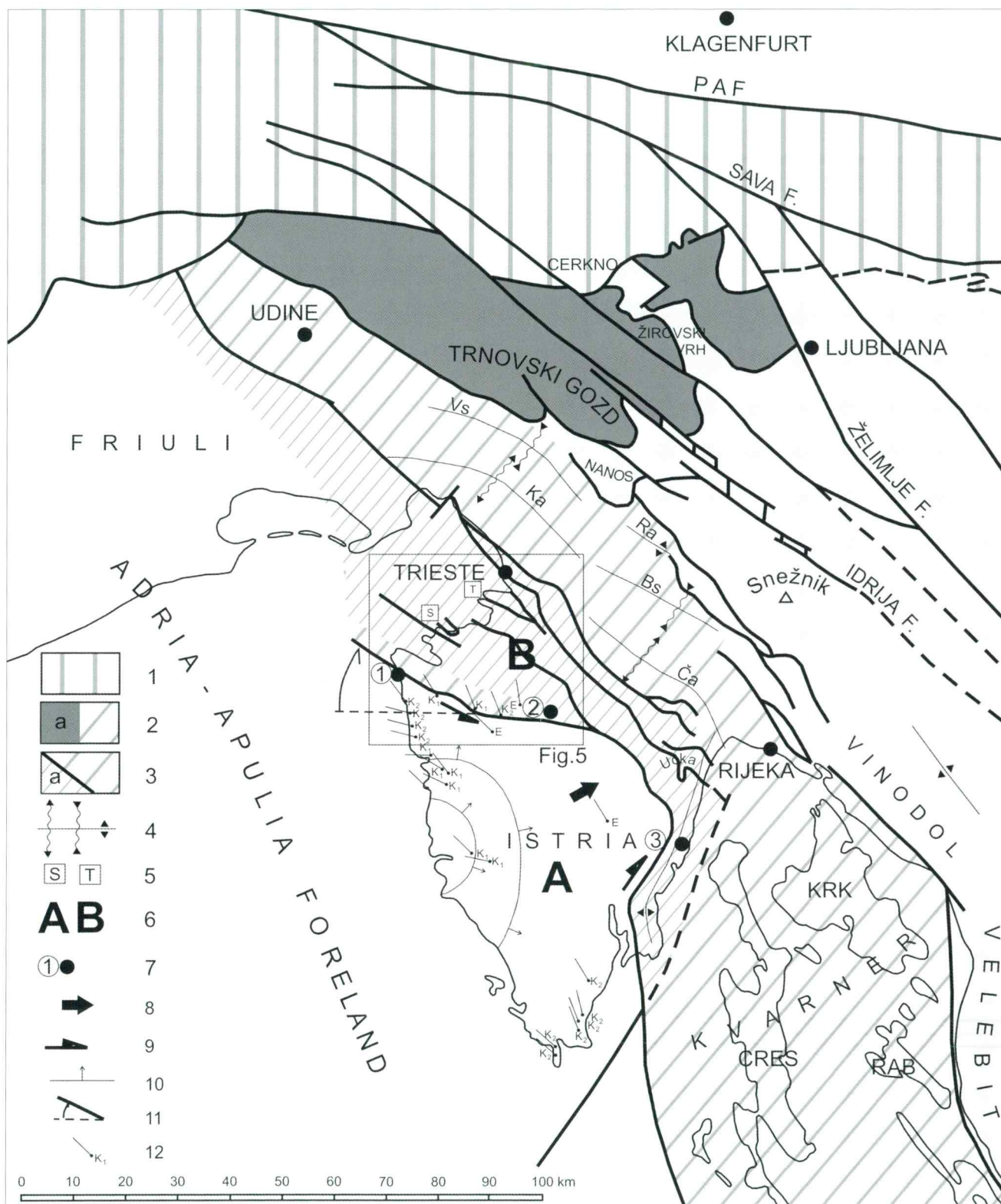


Fig. 4. Subdivision of thrusts.

1. Southern Alps;
2. External Dinaric Thrust Belt: a - Trnovo Nappe;
3. External Dinaric Imbricated Belt: a - Istria-Friuli Underthrust Zone;
4. Kras-Notranjsko Folded Structure (Vs - Vipava Synclinorium, Ra - Ravnik Anticline, Ka - Trieste (Trst) - Komen Anticlinorium, Bs - Barka Synclinorium, Ča - Čičarija Anticlinorium);
5. S - Strunjan Structure, T - Tinjan Structure;
6. A - Southern Istria Structural Wedge, B - Northern Istria Structural Wedge;
7. Measuring sites: (1) - Zambratija, (2) - Mlun, (3) - Vidikovac;
8. Direction of the maximal underthrusting and pushing;
9. Direction of movements in flanks of the Southern Istria Structural Wedge;
10. Dip of beds;
11. Rotation of western part of the Buje Anticline;
12. Direction of paleomagnetic pole, stratigraphic age of sample.

nal ridge. In the southeastern part, at the eastern Istria coast, the thrust faults of the External Dinaric Imbricated Belt from the Kvarner area obliquely lean on the frontal thrust plane, while in the northwestern part they are radially dispersed between the Buje Fault and the Palmanova Thrust Fault. Their continuation northwest of Istria is hypothetical, and it is based on data of the Cesarolo 1 (CATI et al., 1989) and Cargnacco 1 (VENTURINI, 2002) boreholes. The Buje Fault is of expressively hybrid structure which reflects its disproportionate transformation from the Frontal Thrust Fault of External Dinarides, which has a characteristic listric shape (MATIČEC, 1994) at Zambratija, into a gently dipping thrust fault in the narrowed part of underthrust zone at Račice. The transformation is recognized by the observation, that at Zambratija

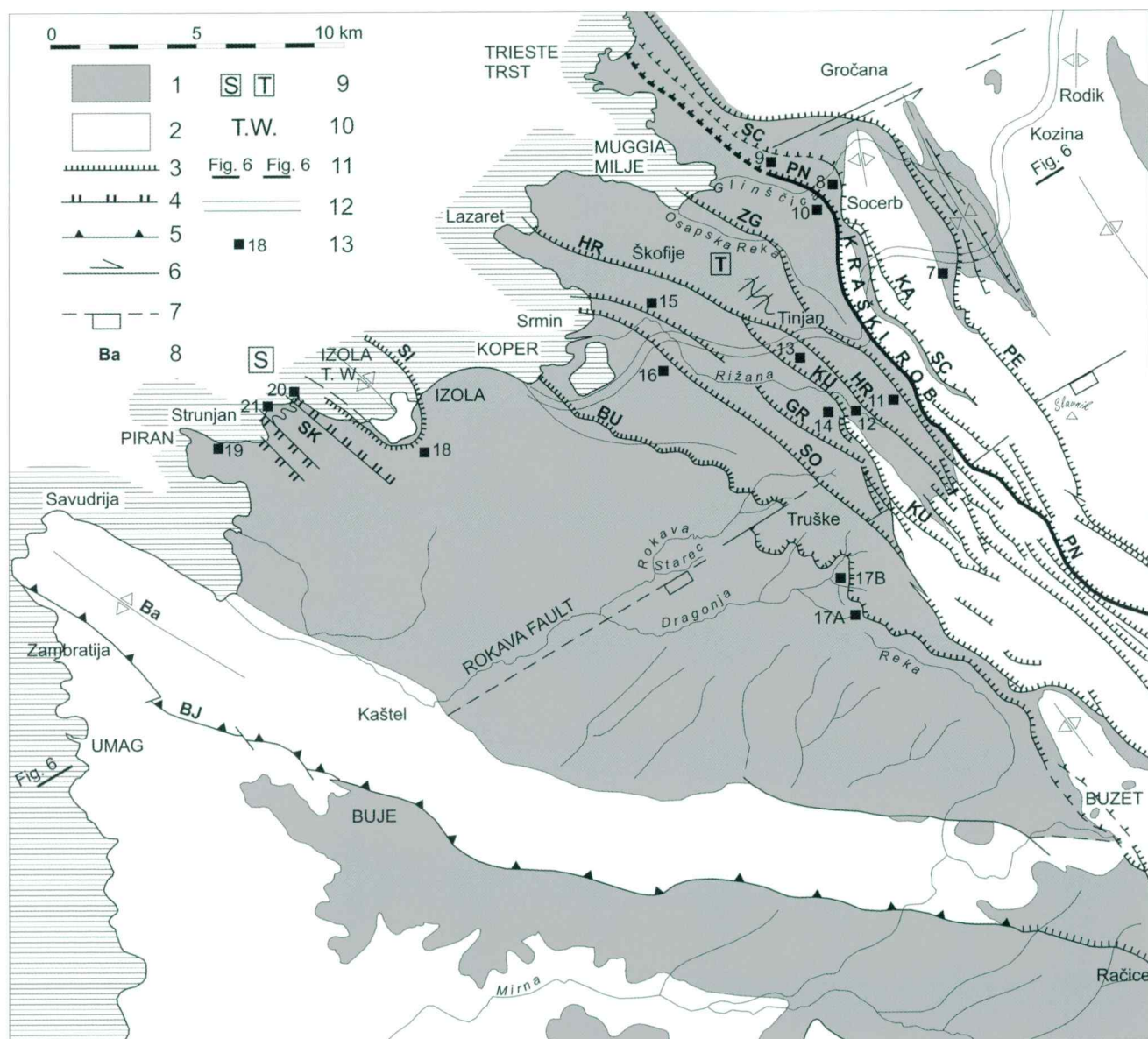


Fig. 5. **Istria-Friuli Underthrust Zone.** 1. Upper ductile horizon: flysch; 2. Platform carbonates; 3. Thrust faults: PE – Petrinje Thrust Fault, KA – Kastelec Thrust Fault, SC – Socerb Thrust Fault, PN – Palmanova Thrust Fault (local Črni Kal Thrust Fault), ZG – Zanigrad Thrust Fault, HR – Hrastovlje Thrust Fault, KU – Kubed Thrust Fault, GR – Gračišče Thrust Fault, SO – Sočerga Thrust Fault, BU – Buzet Thrust Fault, SI – Simon Thrust Fault; 4. Secondary thrust faults of the Strunjan Structure: SK – Sv. Križ Thrust Fault; 5. Thrust Front of External Dinarides: BJ – Buje Fault; 6. Strike-slip fault; 7. Normal fault; 8. Ba – Buje Anticline; 9. S – Strunjan Structure, T – Tinjan Structure; 10. Izola Tectonic Window; 11. Fig. 6 – Fig. 6 – Synthetic profile Umag – Kozina on Fig. 6: 12. Motorway.

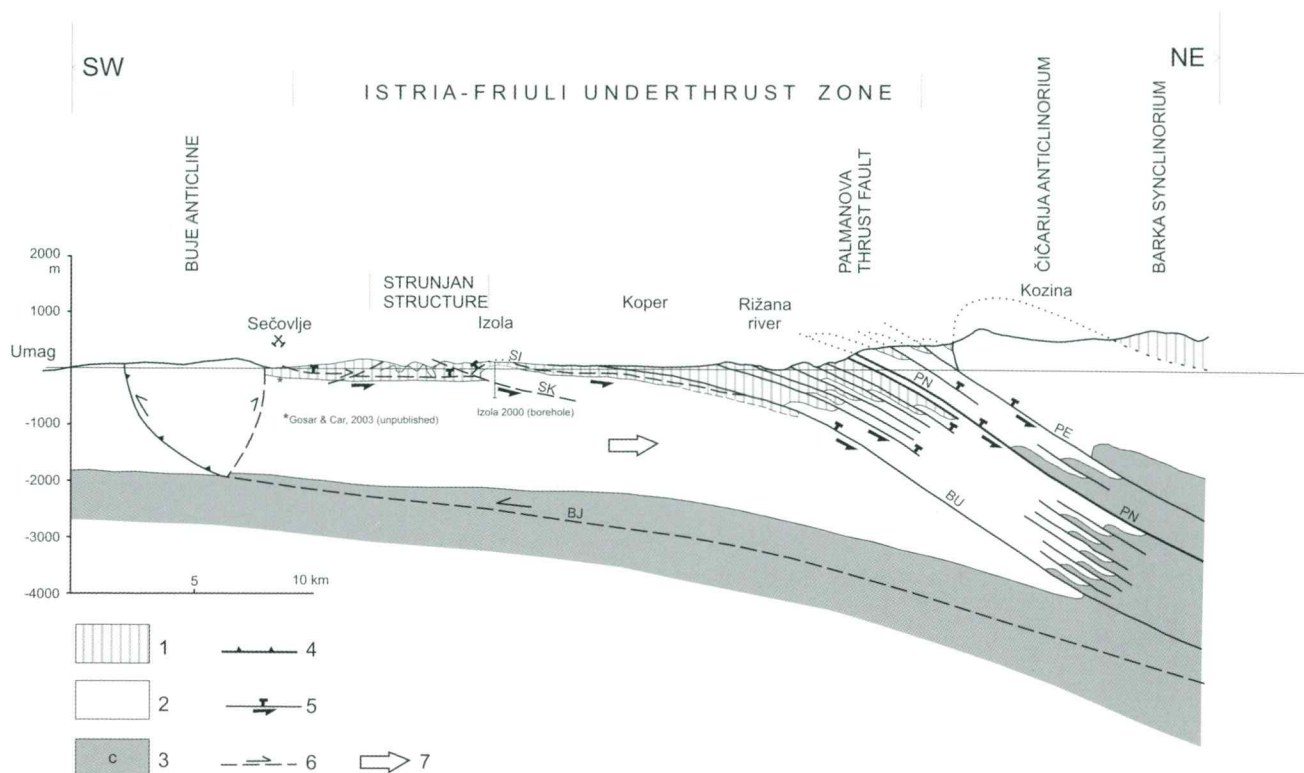


Fig. 6. **Synthetic profile** Umag – Kozina across the Istria-Friuli Underthrust Zone. See Fig. 3 and Fig. 5 for position of the profile: 1. Upper ductile horizon: flysch; 2. Carbonate platform; 3. Lower ductile horizon: c – Carnian and older beds, explanation in Fig. 2; 4. Thrust Front of External Dinarides: BJ – Buje Fault; 5. Thrust faults of the Istria-Friuli Underthrust Zone, underthrust direction: PE – Petrinje Thrust Fault, PN – Palmanova Thrust Fault (local Črni Kal Thrust Fault), BU – Buzet Thrust Fault, SI – Simon Thrust Fault; 6. Thrust faults of the Strunjan Structure: thrust direction: SK – Sv. Križ Thrust Fault; 7. Push direction.

it has properties of a strike-slip fault with measured subhorizontal slickensides and indications of transpression towards the east above Račice, and where it turns toward southeast it acts as a typical gentle thrust fault with a vast sequence of overturned flysch beds in the footwall. Between the two extremes occur intermediate forms, although the strike-slip component is observable at Istarske Toplice, and even farther eastward. Transformation has occurred only east of there.

The Strunjan Structure (PLACER, 2005) is a secondary element within the Istria-Friuli Underthrust Zone (Figs. 4, 5 and 6). It formed due of the clockwise rotation of western branch of the Savudrija Anticline crest as a result of pushing, and not of underthrusting. By rotation of the western part of the Savudrija Anticline crest the symmetric Strunjan Structure formed with several overthrusts directed to northeast, and a single one to southwest (Sv. Križ Thrust). The Izola Anticline with a tectonic window was formed as a result of anticlinal bending of the hanging wall side of the Sv. Križ Thrust.

Thrust faults of the Istria-Friuli Underthrust Zone have been documented by reconnaissance (Fig. 5) and by photographs in figures, from the highest Petrinje Thrust Fault (Fig. 7) and Socerb Thrust Fault (Fig. 8), Palmanova (Figs. 9 and 10), Zanigrad (Fig. 11), Hrastovlje (Figs. 12 and 13), Kubed (Fig. 14), Gračišče (Fig. 15), Sočerga (Fig. 16), Buzet (Fig. 17) and Simon Thrust Fault (Fig. 18), and the probable tectonical intralayer slips in the Piran Cliff (Fig. 19). The deformations

of the Strunjan Structure indicated the Sv. Križ Thrust Fault (Fig. 20) and the folds in its core (Fig. 21).

Istria is divided by the Buje Fault into two wedge-shaped structural blocks. The block between this fault and the southeastern branch of the Thrust Front of External Dinarides at the Istria east coast is the **Southern Istria Structural Wedge** (A in Fig. 4), and the block between the Buje Fault and the Palmanova Thrust Fault the **Northern Istria Structural Wedge** (B in Fig. 4). The underthrusting mechanism is reflected in dynamics of these two structural wedges. The tip of the Southern Istria Structural Wedge is directed to northeast, and its symmetral coincides with direction of maximum of the underthrusting. We presume that due to the shift in direction of the tip the wedge became laterally compressed and gently folded (the South Istria Anticline). Because of gentle dip of beds, the true direction of its axis is difficult to determine. The direction of displacement of the South Istria Structural Wedge is consequently controlled by its lateral boundaries.

Kinematics of the South Istria Structural Wedge has been established after the microstructural analysis in the Buje Fault and in the east coast of Istria. Point 1 is located within the core of the Zambratija Fault that belongs to the wider zone of the Buje fault. Here sinistral strike-slip displacements occur along NW-SE to WNW-ESE striking planes with steep NE to NNE dip, indicating compression in the W-E direction. The Zambratija

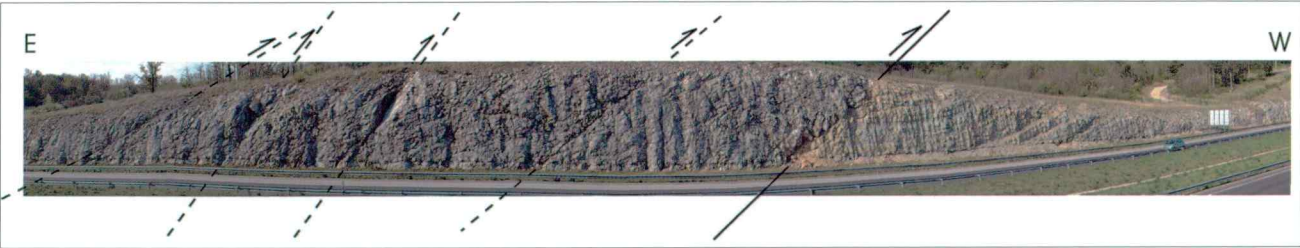


Fig. 7. **Petrinje Thrust Fault**, diagonal transverse section of footwall block of the fault zone. Southern face of highway cut east of the Kastelec tunnel near Petrinje. Small thrust of Eocene Transitional marly limestone on the Transitional marlstone, and other small thrusts. View from north to south.



Fig. 8. **Socerb Thrust Fault**, diagonal transverse section. View from Čelo hill opposite to Dolina (S. Dorligo della Valle) near Boljunec village towards Socerb castle and thrust of the Eocene Alveoline – nummulitid limestone on flysch. Inclination of the thrust plane about 20°. View from northwest to southeast.

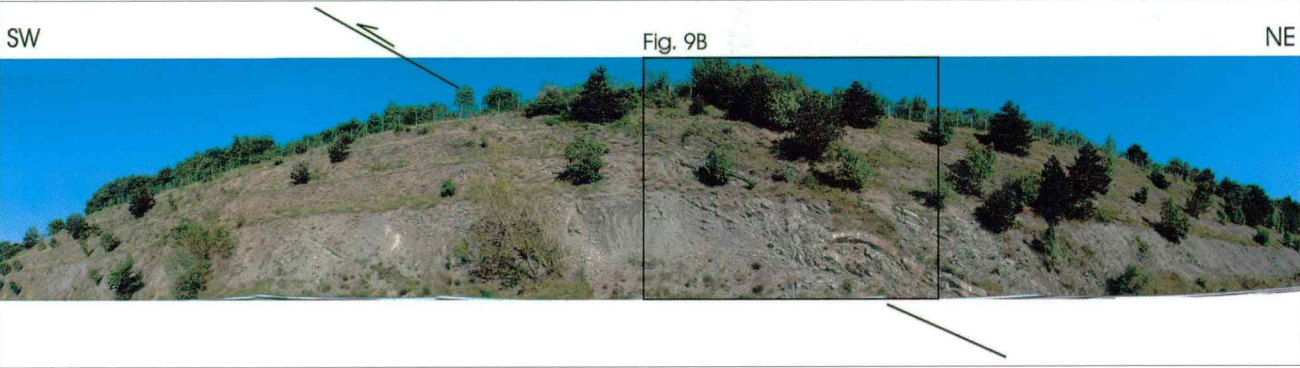


Fig. 9. **Palmanova Thrust Fault**, transverse section.

A – NW face of the highway cut under Čelo hill opposite to Dolina (S. Dorligo della Valle) village. Thrust fault together with large part of thrust zone in hanging- and footwall is visible.

B – Detail of main thrust plane in the thrust zone. View from southeast to northwest.



Fig. 10. **Palmanova Thrust Fault** (locally Črni Kal Thrust Fault), diagonal transverse section of part of the fault zone. Overturned folds in the ravine under Prebeng (Prebenico) village. View from east to west.

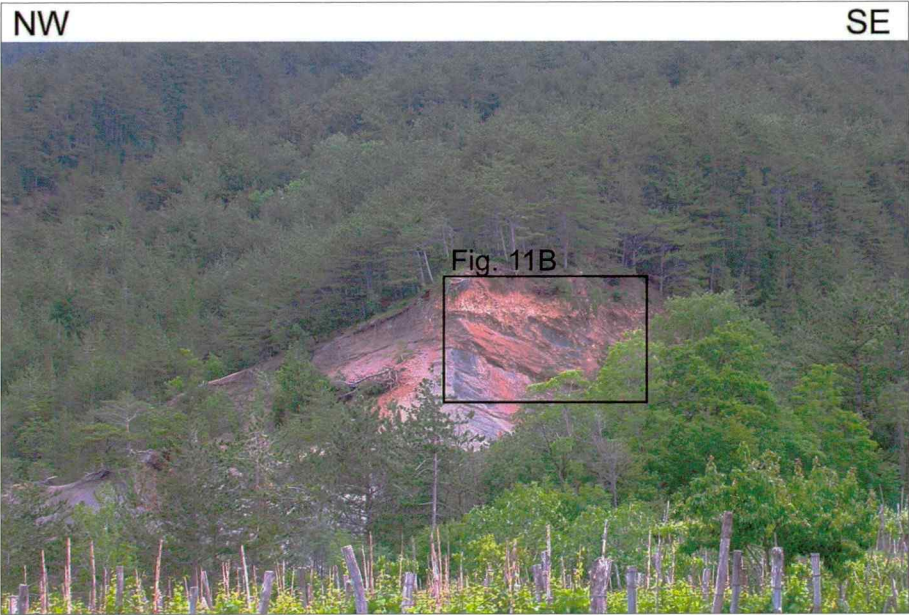


Fig. 11A. **Zanigrad Thrust Fault**. View on the fault zone over the Predloka village under Črni Kal village, longitudinal section. View from southwest to northeast.



Fig. 11B – Fault zone detail, transverse section. View from southeast to northwest.

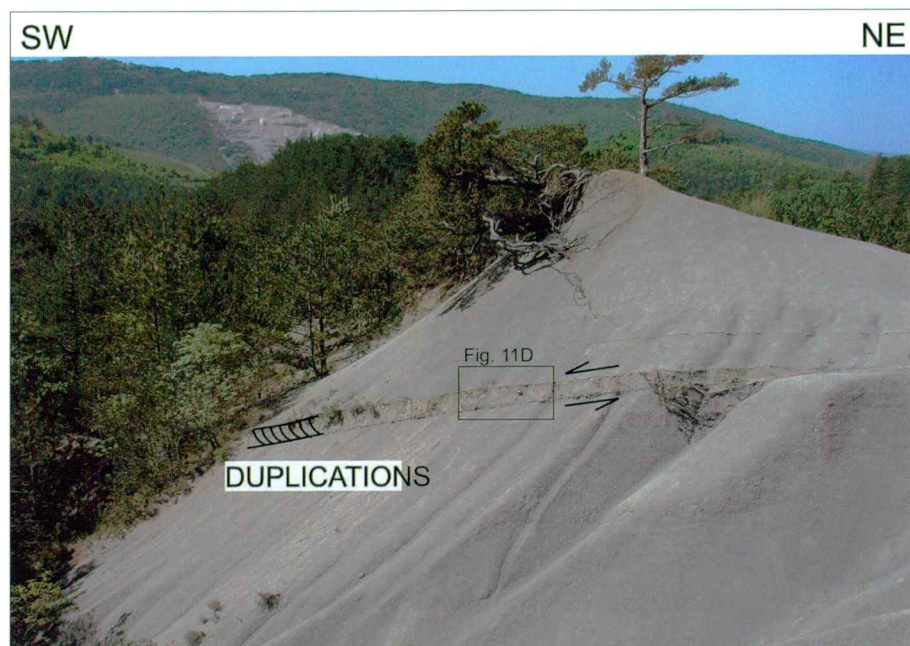


Fig. 11C – Duplications in the footwall block, transverse section. View from southeast to northwest.

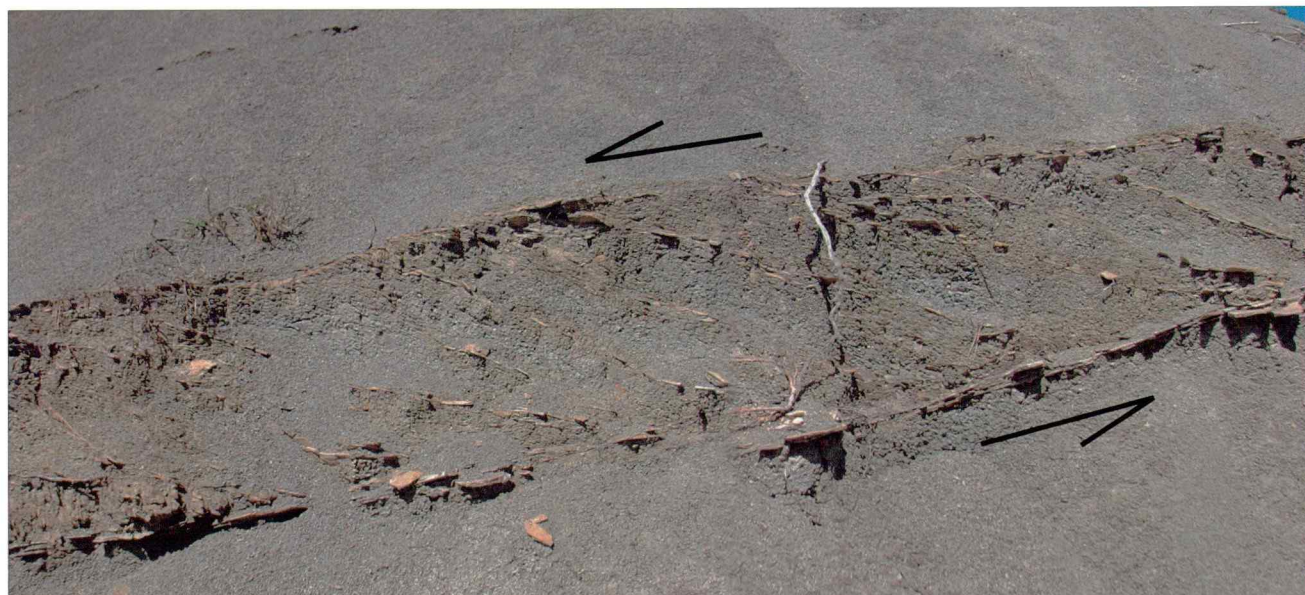


Fig. 11D – Detail.

fault is parallel to the Buje fault, hence a similar displacement along the latter is presumed. At the southern road to Veliki Mlun (point 2) similar oblique sinistral displacements occur along sub-vertical joint planes of W-E strike, which indicate compression in the WSW-ENE direction. These displacements can also be applied to the Buje Fault. These on sinistral displacements along the Buje Fault are also supported by data of MARTON (1987), who mentions extreme counterclockwise rotation in the southern side of the fault.

Important for confirmation of kinematics of the Southern Istrian Structural Wedge is the Vidikovac outcrop (point 3) which is situated outside of the fault zones. Dextral strike-slip activity parallel with the eastern edge of the Southern Istria Structural Wedge appears in joints, striking parallel with the coastline and gently dipping to the ESE.

Conditions in the area of Northern Istria Structural Wedge are different. Here we present indi-

cations of the compression in SW-NE direction (Strunjan Structure – S), and lateral extension toward NW (Tinjan Structure – T) (PLACER, 2005). Which structures are pre-recent and which recent could be determined only by future structural measurements. Data by WEBER et al. (2010) about recent displacements give just a general trend.

Secondary folding of thrust planes and repeated weak thrusting are common characteristics of the Istria-Friuli Underthrust Zone. The intensity of this process is modest, but its presence in Istria is a general phenomenon which is in some places the reason for an essentially steeper dip (more than 25°) to northeast of thrust planes; in other places the dip is subhorizontal, and somewhere even pointing to the southwest (Figs. 11C and 11D). The underthrusting of the Istria-Friuli block was evidently a polyphase process.

Important from the standpoint of underthrusting mechanism of the Istria-Friuli block is the

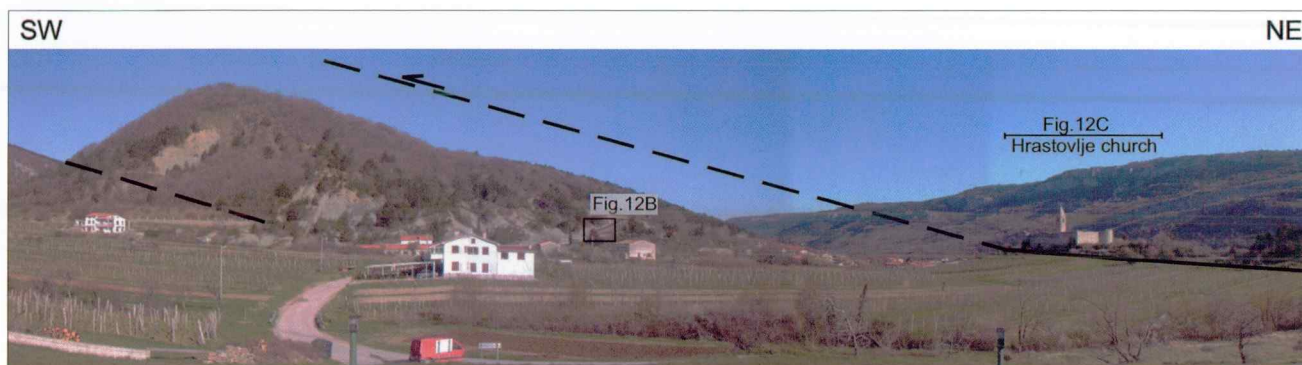


Fig. 12A. **Hrastovlje Thrust Fault**, transverse section.

View on southeast slopes of the Vrh hill above Hrastovlje village, which is completely positioned in the thrust zone. View from southeast to northwest.



Fig. 12B. Detail of the fault zone in the marlstones.

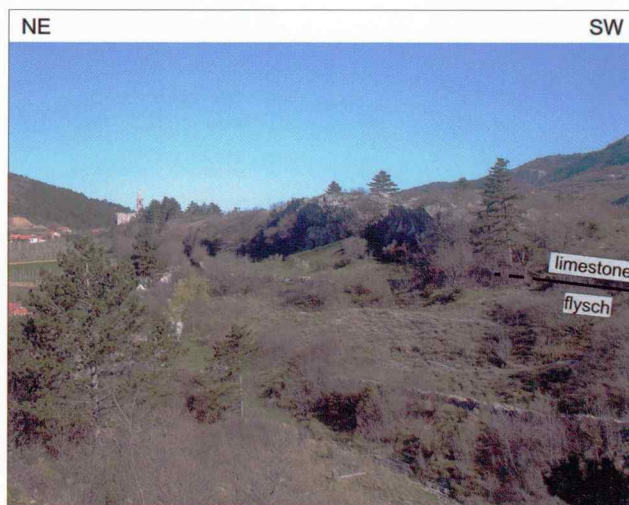


Fig. 12C. View to the principal fault plane, Alveoline – nummulitid limestone thrust on flysch.



Fig. 13. **Hrastovlje Thrust Fault**, transversal section of part of the fault zone. Cut face behind hunter cabin in Kortine settlement. Fault zone in sandstones and siltstones. View from southeast to northwest.

question of trace, structure and age of the Palmanova Thrust Fault in its continuation towards northwest, under sediments of the Friuli Plain. Competent data on this are furnished by VENTURINI (2002), MERLINI et al. (2002), PERUZZA et al. (2002) and FANTONI et al. (2002). It follows from records of the Cargnacco 1 borehole and from seismic profiles that the Palmanova Thrust Fault continues under the alluvium deposits of the Friuli Plains to the Southern Alpine Thrust Boundary. Its morphologic expression under alluvial deposits of the Friuli Lowland and the width of the thrust zone diminish in the northwestern direction, as manifested in profiles across Istria (Fig. 22), over the

Kras edge (Fig. 6), Sistiana (Sesljan) (Fig. 23) and across the Southern Alpine Thrust Boundary (Fig. 24). Considered in the latter profile are the data of cross-section across the Cargnacco 1 borehole – Ca 1 on Fig. 3 (MERLINI et al. 2002, Fig. 3B) and profile between Gemona (Gumin) and Udine (Videm) (FANTONI et al. 2002, Fig. 5; MERLINI et al., 2002, Fig. 3A). According to these data, the Palmanova Thrust Fault should have been still active in Pliocene and Pleistocene. The seismic profiles of MERLINI et al. indicate that in the Cargnacco 1 profile and to the northwest of there no other thrust faults are present southwest of the Palmanova Thrust Fault.



Fig. 14. **Kubed Thrust Fault**, diagonal transversal section of part of the fault zone. South slopes of Ivačevac hill (226m). Fault zone; in the lower part in marlstones, in the upper part in sandstones and siltstones. View from south to north.

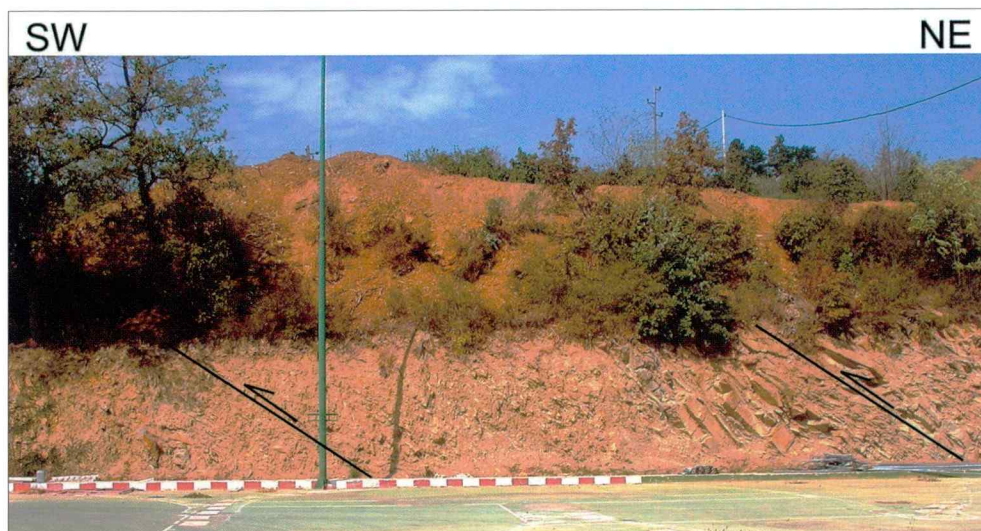


Fig. 15. **Gračišće Thrust Fault**, diagonal transversal section of part of the fault zone. Excavation of playground behind tavern in the Valmarin settlement. Fault zone in sandstone and siltstone beds. View from southeast to northwest.



Fig. 16. **Sočerga Thrust Fault**, transversal section of part of the fault zone (in building pit). Excavation in Pobegi village. Fault zone in sandstone and siltstone beds.

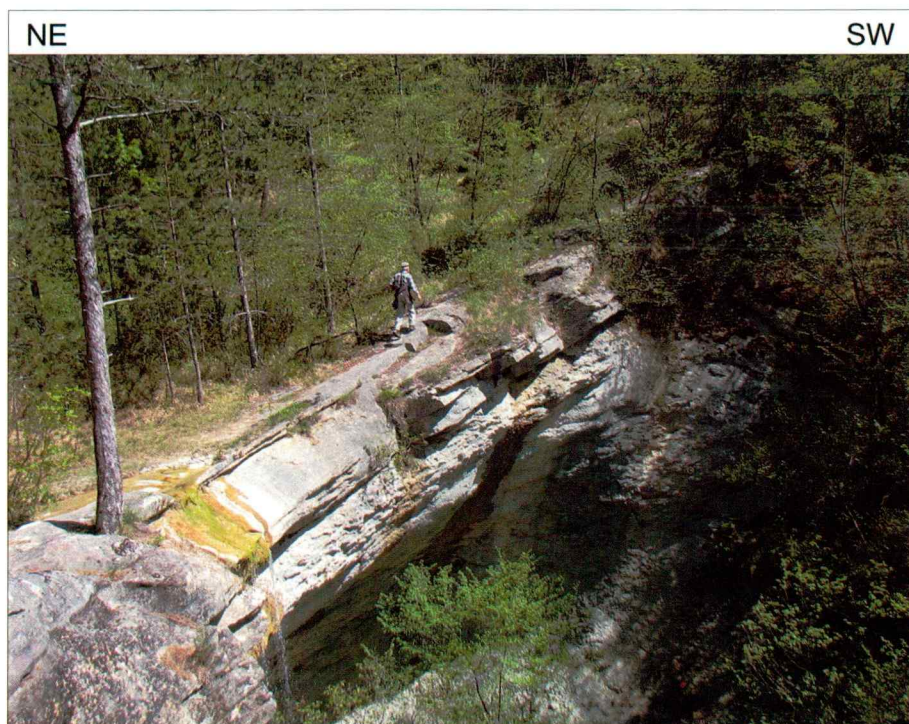


Fig. 17A. **Buzet Thrust Fault.** Waterfall on the Stranica creek south from Trebeše village. View on inverse calcarenite megabeds in the footwall block of thrust. View from northwest to southeast.



Fig. 17B. Part of the fault zone along Dragonja River north of Trebeše village. View from west to east.

The Kras edge originated by underthrusting of the southeastern part of the Istria-Friuli block. As underthrusting experienced its maximum intensity in the southeast, the maximum uplift affected the southeastern part of the Čičarija Anticlinorium, to an elevation of 1394 m a.s.l. (Mt. Učka), whereas northwestwards the territory gradually lowers to a few tens of meters a.s.l. at the Soča

River, where the Trieste-Komen Anticlinorium “sinks” under alluvial deposits of the Friuli Lowland. The morphologically elevated thrust front, however, continues also below these deposits.

With increasing underthrusting intensity towards southeast, all to Mt. Učka, arises the question of transition of the Istria-Friuli Underthrust Zone into structures of the External Dinaric Imbricated Belt in the Kvarner area. Genesis of the transition structure is schematically shown in Fig. 25. We assume that before the separate displacement of the Istria-Friuli block northeastward the External Dinaric Imbricated Belt was not deformed, and that its strike was NW-SE oriented. The displacement of Istria to northeast was indubitably associated with dextral slip along the Kvarner Fault Zone, and with the slight counterclockwise rotation of the Istria-Friuli block. Judging from interpretation by GRANDIĆ et al. (1997a, 1997b, 2004), the Kvarner Fault Zone after reactivation never cut and displaced the frontal thrust of the External Dinaric Imbricated Belt, but it extended northeastwards below the separating plane of the imbricated structure. There formed the broader dextral strike-slip fault zone due to which an extensive S structure was generated, which is manifested in the Kvarner area, with clockwise rotation of islands of Susak, Cres, Lošinj and partly Krk, and, on the other side of the Kvarner Fault Zone, as pushing and underthrusting which were most intense in the tip of the Southern Istrian Structural Wedge. This is the reason for occurrence of elements of nappe structure in Mt. Učka (Fig. 3). The distinct difference in internal structure between the underthrust belt in Istria that consists of gentle dipping thrust faults with elements of nappe structure in Mt. Učka area (Figs. 6, 22) and the imbricated structure of Kvarner with characteristic listric thrust faults (Fig. 26) illustrates the im-



Fig. 18. **Simon Thrust Fault**, transversal section of part of the fault zone.

A – Road cut above Izola in direction of the Šared village. Thrust zone is almost parallel to bedding in the marlstones. View from northwest to southeast.

B – Detail.

portance of the Kvarner Fault Zone. The structure in this profile has been summarized from data of surface mapping and from deep drillings published for Kvarner by ĐURASEK et al. (1981), and for the Dalmatia region by TARI (2002) and GRANDIĆ et al. (2004). DEL BEN et al. (1991) presumed at the eastern Istrian coast and in part inland northwest of Rijeka a transtensional fault which they named the Istrian Fault. KORBAR (2009) presumes the existence of a similar fault which he named the Kvarner Fault Zone. On land, however, ŠIKIĆ et al. (1972) and MATIČEC (1994) were not able to find proofs for its existence.

The Palmanova Thrust Fault cannot be connected in eastern Istria with the deformed Thrust Front of External Dinarides. The fault passes across Učka to the Kvarner area, where according to our hypothesis its continuation could not be expected.

Reactivation of the transversal Kvarner Fault Zone and displacement of the Istria-Friuli block, combined with underthrusting is the expression of a more radical differentiation of the “Adria” into the Padan and Adriatic parts, the same as in WEBER et al. (2010).

The Istria Pushed Area (Miocene - Recent)

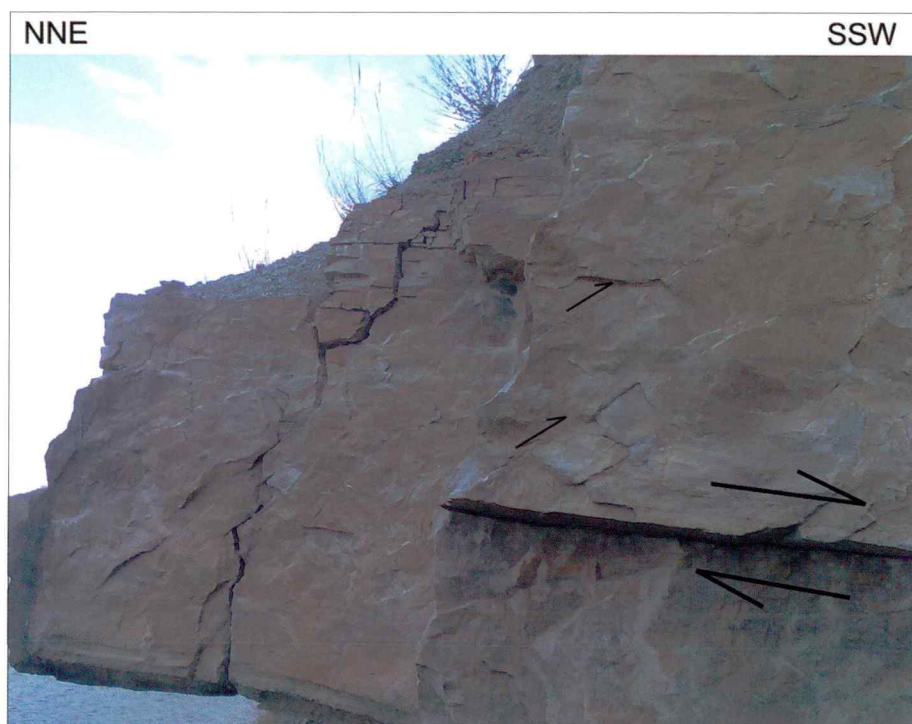
The displacement of the Istria-Friuli block northeastwards created next to the Istria-Friuli Underthrust Zone also a wide, northeastwards pushed area whose boundary could not be precisely determined. It comprises in general the External Dinarides from the Southern Alps to Velebit Mts. and Mali Kvarner, and can be tracked in the direction of the push all to the Želimplje Fault. We named it the **Istria Pushed Area** (Fig. 27). The most conspicuous is the lateral bending of older structures toward NE, and consequences of the push are manifested also by secondary underthrusting below the Istria-Friuli Underthrust Zone. Pushing and underthrusting was polyphase, the two processes having taken place, and are still taking place, in parallel and alternatively. This mechanism is a object of future investigations. The present state of displacements is described in a treatise about the recent movements of the “Adria” (WEBER et al. 2010).

Effects of push are subdivided here into:
1. Bending of the oldest structures toward NE,
2. Secondary underthrusting outside of the Istria-



Fig. 19. Interbedding movements in subhorizontal beds near Piran.

A – Limestone block with system joints, which are bent due to internal rotation. It was triggered by bedding-plane slides. Tectonical movement or synsedimentary slides.



B – Oriented shear joints in sandy marlstone bed of the cliff east of Piran.

Friuli Underthrust Zone, 3. Special effects, and 4. Disintegration of the Istria-Friuli block.

1. The bended structures are developed in three areas: **A.** In the core of the push area, the south-eastern part of the Čičarija Anticlinorium and of Brkini Synclinorium was moved farthest northeastward. Both units are bent owing to their position in the prolongation of bisector of the Southern Istrian Structural Wedge (Fig. 27). Less perceptibly bent is the thrust plane of the Snežnik Thrust Fault and the dinaric-striking Raša Fault. The bending is clearly expressed on the digital elevation model of Istria (Fig. 28A, B).

B. The most prominent in the northwestern side of the pushed area is the bending of the north-western part of the Trieste-Komen Anticlinorium and Vipava Synclinorium.

C. In the southeastern side of the pushed area occurs a perceptible clockwise rotation of the Kvarner islands Susak, Cres and Lošinj what is being interpreted as a consequence of rotation at the dextral strike-slip Kvarner Fault Zone.

2. Secondary underthrusting at existing thrust planes is the most explicit in continuation of the Southern Istria Structural Wedge axis. After data of the Basic Geologic Map (Šikić et al., 1972) the



Fig. 20. **Sv. Križ Thrust Fault, part of the Strunjan Structure.** Cliff above Sv. Križ Bay near the Strunjan village.

density of reverse faults is here significantly increased. Especially illustrative is the Snežnik Thrust Fault southeast of the Pivka structure which shows in this segment the characteristics of the nappe structure (Fig. 3). Here recumbent folds can be found and erosion windows in overturned beds (PLENIČAR, 1959). Underthrusting is manifested in the area of the Snežnik Thrust Fault in addition to the mentioned nappe geometry also in the way how the axes of folds of the Ravnik Anticline and Brkini Synclinorium obliquely lean to

the front of the Snežnik Thrust. The same was recognized also by PREMUR (2005). This means that in the apical part of the Southern Istria Pushed Area the Southern Istria Structural Wedge is pushed under the Snežnik Thrust Unit.

Important for comparison are conditions along the northeastern coast of Kvarner, where BLAŠKOVIĆ (1999) mentions underthrusting along the Vinodol Thrust Fault. The described structures do not have characteristics of nappe structure as observed along the Snežnik Thrust Fault, but suggest a different mechanism of shortening. This is shown in Fig. 26. Shortening due to clockwise rotation of the Kvarner islands is here compensated by extensive anticlinal arching of the External Dinaric Thrust Belt in the Gorski Kotar area, where as consequence also Paleozoic beds are exposed. On the island of Krk in the zone of maximum compression occur also folds of NE vergence.

3. In addition to pushing and underthrusting also other effects associated with one process or the other are observable, and having specific kinematics owing to various reasons. Three effects should be mentioned, the Divača Fault, blind valleys of Matarsko podolje, and the Ljubljana Moor.

A. The Divača Fault is a pivot fault with its southwestern side rotated in the way to uplift its southeastern part (JURKOVŠEK et al. 1996). The southwestern block situated closer to Istria is thus uplifted, or in the kinematic sense, moved to the underthrust block that experienced a larger displacement. The Divača Fault was consequently reactivated in the stage of asymmetric underthrusting of the Istria-Friuli block, its southwestern side having a similar symmetry as the Kras edge which is the highest uplifted in southeast (Mt. Učka, 1264 m).

B. The blind valleys in Matarsko podolje are developed in axis of the Southern Istria Structural Wedge in two or three levels (MIHEVC, 1994, 2007).

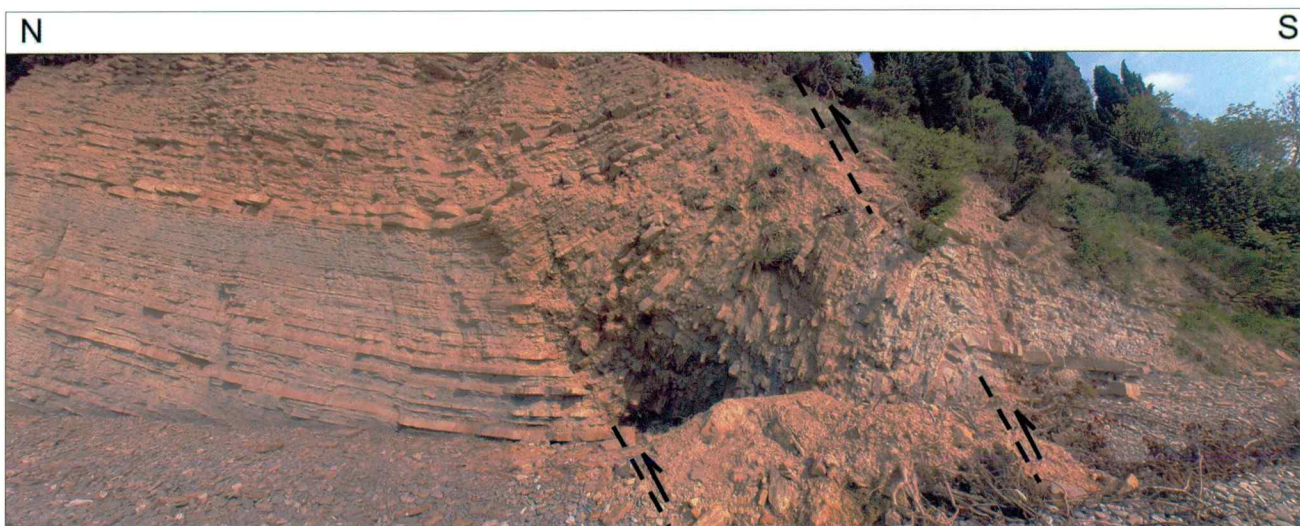


Fig. 21. **Folded core of the Strunjan Structure** (see Fig. 6), diagonal transversal section. The cliff face in Strunjan village north of the Stjuža Bay. The fold verges in direction opposite to vergence of the Sv. Križ Thrust. View from west to east.

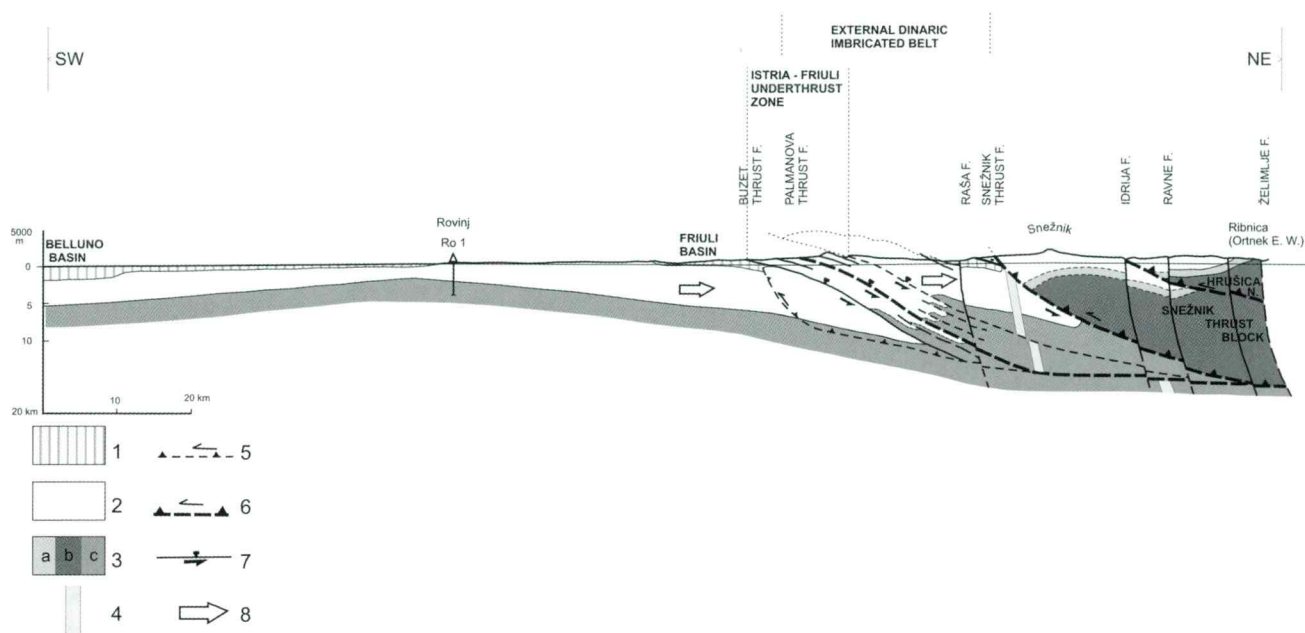


Fig. 22. **Profile** Rovinj – Mount Snežnik – Ribnica (Ortnek). Position of the profile in Fig. 3: 1. Upper ductile horizon: flysch; 2. Carbonate platform; 3. Lower ductile horizon: **a** – Upper level: Carnian clastites, Middle Triassic clastites and vulcanites, Anisian carbonates, Lower Triassic carbonates, marlstones and clastites and Upper Permian carbonates; **b** – Lower level: Middle and Lower Permian clastites and Carboniferous, and older clastites; **c** – Upper and Lower level; 4. Hypothetic fault structure in Adriatic – Dinaric Mesozoic Carbonate Platform in the continuation of the Budva Trough, see Fig. 29; 5. Thrust faults of External Dinaric Imbricated Belt, Thrust Front of External Dinarides; 6. Thrust fault of External Dinaric Thrust Belt, thrust direction; 7. Thrust fault of Istria – Friuli Underthrust Zone, underthrust direction; 8. Push direction.

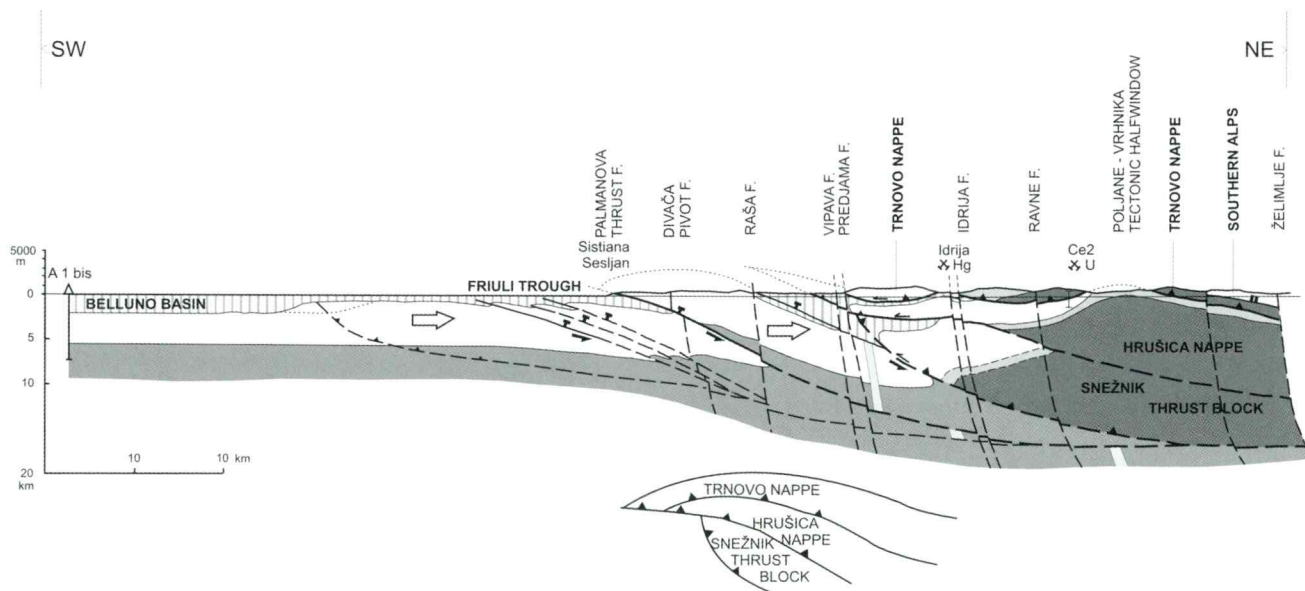


Fig. 23. **Profile** boreholes Amanda-1 bis – Sistiana (Sesljan) village – Idrija Hg ore deposit – Žirovski vrh U ore deposit. Position of profile in Fig. 3 (Explanation in Fig. 22).

C. The Ljubljana Moor formed, and is still forming, as a result of expressing of the Ljubljana Wedge (PLACER, 2008b, 2009) between the Želumlje Fault, and the faults of the series which comprises the Ravne, Sovodenj, Borovnica and Ravnik Faults. The regional frame for the expressing mechanism is the tension state within the Istria Pushed Area.

4. During underthrusting the Istria–Friuli block disintegrated into three segments separated by three transversal faults. The most important is the bordering Kvarner Fault Zone. The second, Sistiana (Sesljan) Fault, passes across the Sistiana

inlet (CARULLI, 2006), and the third one is the hypothetical fault along the Middle Soča (Isonzo) Valley between Solkan and Turriaco (Turjak), the Medea Fault. The result of the Kvarner Fault Zone has been discussed already. The fault across the Sistiana inlet was recognized on Slovenian territory as a fracture zone connecting the areas of arching of the Trieste–Komen Anticlinorium and Vipava Synclinorium, and can be followed to the Bela Valley between Trnovski gozd and Nanos. The fault evidently continues also under the sea, and is connected with the paleogeographic boundary between Istria and Friuli Platform. With regard to intense arching of the Trieste–Komen Anticlinorium

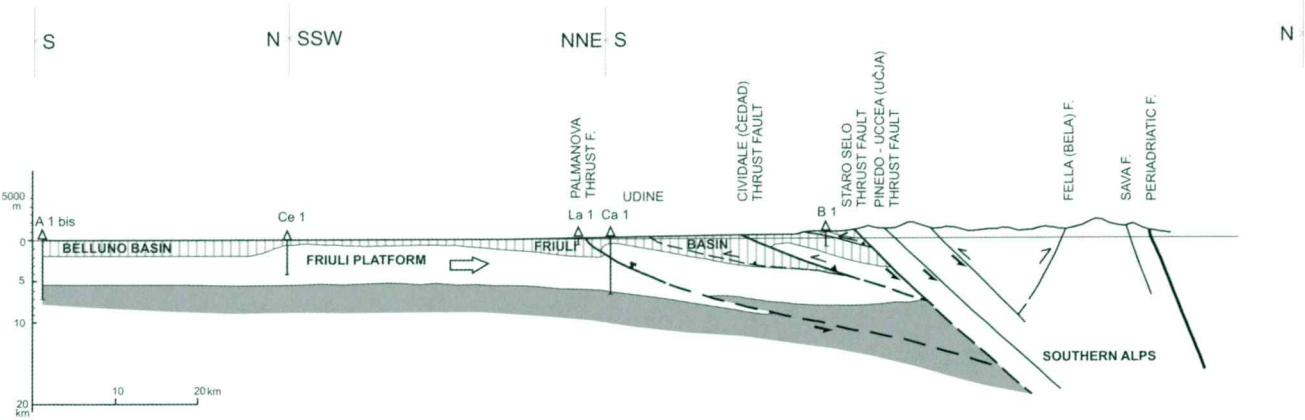


Fig. 24. **Profile** borehole Amanda (A1 bis) – Cesarolo (Ce1) – Cargniacco (Ca1) – Bernadia (B1) – Staro selo Fault – Periadriatic Fault Zone. Position of profile in Fig. 3 (Explanation on Fig. 22).

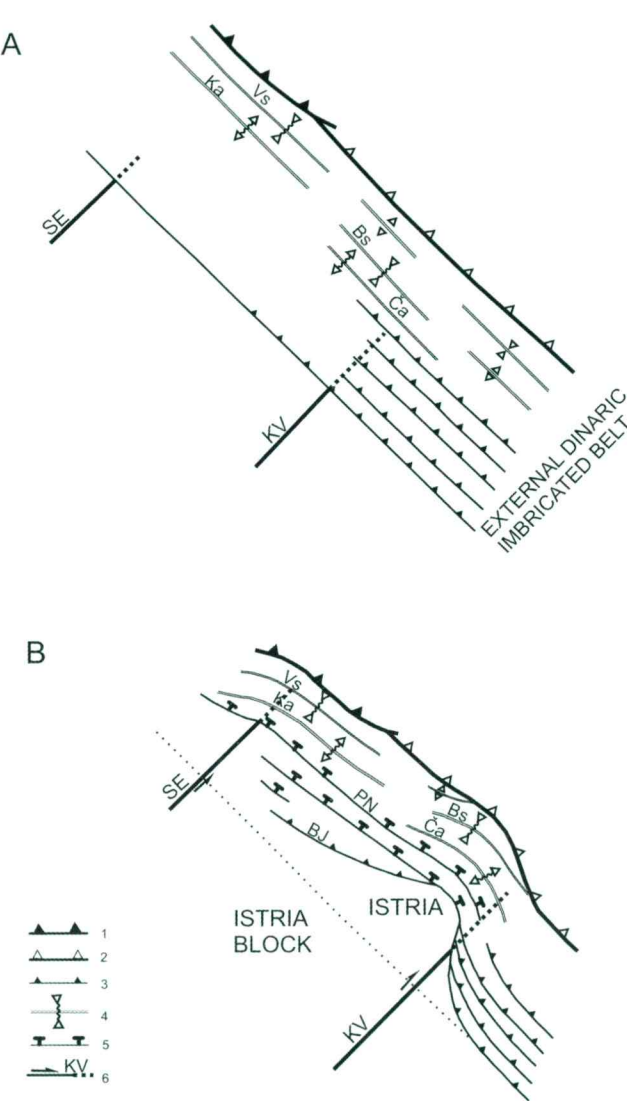


Fig 25. **Kynematic model** of Istria – Friuli Underthrust Zone. **A** Position before underthrusting; **B** Position after underthrusting. 1. Frontal Zone of External Dinaric Thrust Belt, Trnovo Thrust Series; 2. Frontal Zone of the External Dinaric Thrust Belt, Velebit Thrust Series; 3. Thrust faults of the External Dinaric Imbricated Belt: BJ – Buje Fault; 4. Folds of External Dinaric Imbricated Belt: Vs – Vipava Synclinorium, Ka – Trieste (Trst) – Kras Anticlinorium, Bs – Brkini Synclinorium, Ca – Čičarija Anticlinorium; 5. Thrust faults of Istria-Friuli Underthrust Zone: PN – Palmanova Thrust Fault; 6. Faults of stable part of the carbonate platform: KV – Kvarner Fault, SE – Sistiana (Sesljan) Fault, covered fault.

rium and Vipava Synclinorium we presume the origin of deformation being located in the disintegrated platform, underthrust below the overthrust block of the Palmanova Thrust Fault. Indications for existence of the fault along the Middle Soča (Isonzo) Valley are the orientation of the valley and anomalies of the thrust structure on the Medea Hill (CARULLI, 2006).

Boundary of underthrusting below
the Southern Alps
(Miocene – Recent)

Underthrusting of Dinarides under Southern Alps is a complex process that started in Miocene, and is still active at present in the frame of “Adria”. The complexity of its evolution is witnessed by present structure of the Southern Alpine Thrust Front (Fig. 3) which is divided in the W-E direction in three segments each with distinct characteristics.

The first segment of this boundary between the Želimlje and Ravne Faults consists of a gentle thrust fault which dips 20°-30° to southwest and is interrupted in several places by a younger steep fault of transversal dinaric strike. Position and dip of the thrust fault plane was determined during investigations of the Knap polymetallic deposit. Along the thrust plane outcrop Paleozoic clastic rocks of the Trnovo Nappe, and Triassic rocks in footwall of the Trnovo Nappe underthrust below Mesozoic rocks of the Southern Alps, belonging to the Slovenian Basin (BUSER, 1989).

The second segment of boundary west of the Ravne Fault is a fault of W-E strike and 40°-50° dip north. Between the Ravne Fault and Idrija Fault it is named the Modrej Fault (BUSER, 1986). It is displaced to northwest at the Idrija Fault and continues as the Staro selo Fault of the same strike and dip. West of the Tagliamento River Valley, in front of Gemona, in the W-E direction two thrust faults pass (NICOLICH et al., 2004). South of the Modrej Fault in the Trnovo Nappe the Ponikve Tectonic Klippe is situated, consisting of rocks of the Slovenian Basin and therefore belonging to the Southern Alps. Its thrust plane is subhorizontal, and therefore we compare it with the bordering thrust plane east of the Ravne Fault.

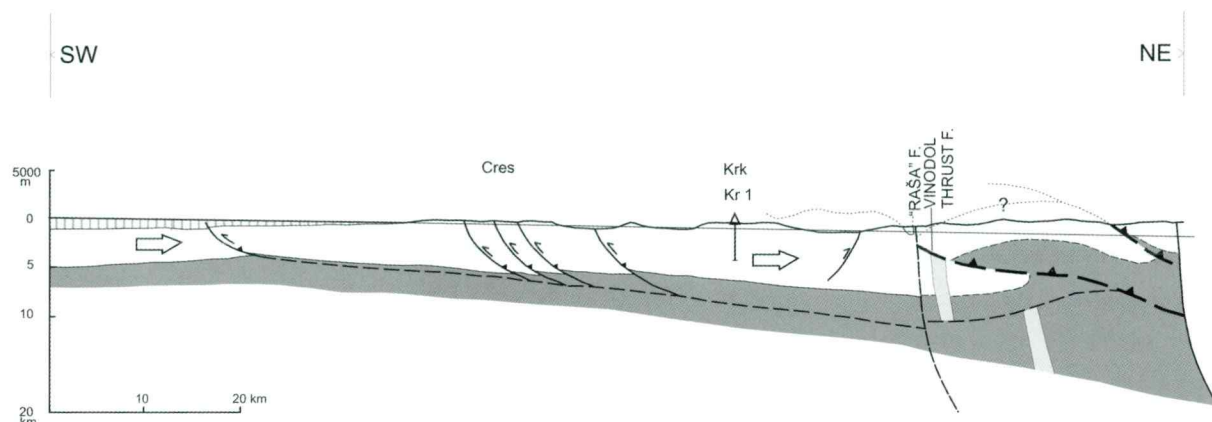


Fig. 26. **Profile Kvarner – Gorski Kotar.** Position of profile in Fig. 3 (Explanation in Fig. 22).

On relationships in third segment of the boundary south and southwest of Tagliamento River Valley, the authors of recent publications disagree (NUSSBAUM, 2000; PERUZZA et al., 2002; NICOLICH et al., 2004), and no reliable interpretation is available. Important is, however, that according to NICOLICH et al. (2004), the WSW-ENE striking Barcis Thrust Fault leans on the W-E striking thrust fault west of Tagliamento River. The same is presumed also for the SW-NE striking Bassano Thrust Fault. It is indicative that both thrust faults lean on the W-E thrust fault in the continuation of the Raša Fault. Relation of other

SW-NE striking thrust faults southeast of the Bassano Thrust Fault is not clear. We presume that differences in interpretation are associated with recent displacements. Important for explanation of dynamics, however, is the fact that the dip angle of the Barcis and Bassano Thrust Faults is around 30° as estimated on profile in NICOLICH et al. (2004), which is significantly less than dip of the Staro selo Fault. The roles of N-S striking sinistral strike-slip faults in the Tagliamento River Valley are not considered here.

The different characteristics of the Southern Alpine Thrust Front in the area between the Želimplje

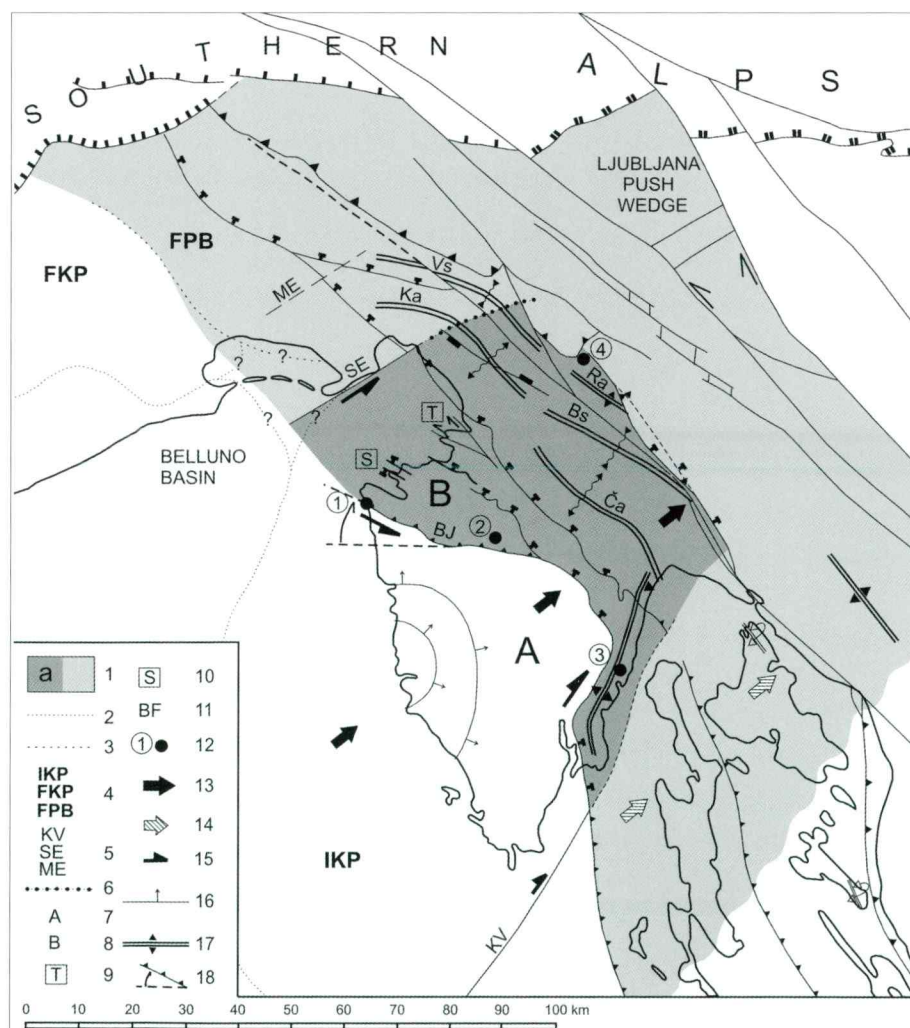


Fig. 27. **Istrian Pushed Area.**

1. Istrian Pushed Area: a – Initial area; 2. External edge of carbonate platform; 3. Platform edge towards internal Paleogene basin; 4. Units of Adriatic - Dinaric Carbonate Platform: IKP – Istria part of carbonate platform, FKP – Friuli Carbonate Platform, FPB – Friuli Paleogene Basin; 5. Faults: KV – Kvarner Fault, SE – Sistiana (Sesljan) Fault, ME – Medea (Medeja) Fault; 6. Zone Sistiana (Sesljan) village – Bela brook, the boundary belt between Istria and Friuli structural block; 7. A – Southern Istria Structural Wedge; 8. B – Northern Istria Structural Wedge; 9. T – Tinjan lateral push wedge; 10. S – Strunjan compressive structure; 11. BJ – Buje Fault; 12. Location of microstructural analyses: (1) – Zambratija, (2) – Mlun, (3) – Vidikovac, (4) – Ubelsko; 13. Direction of maximal underthrusting and pushing; 14. Direction of pushing on Kvarner area; 15. Direction of strike-sliping; 16. Dip of beds; 17. Kras – Notranjsko Folded Structure (Ra – Ravnik Anticline, Ča – Čičarija Anticlinorium, Ka – Trieste (Trst) – Komen Anticlinorium, Vs – Vipava Synclinorium, Bs – Brkini Synclinorium); 18. Rotation of western flank of the Buje Anticline.

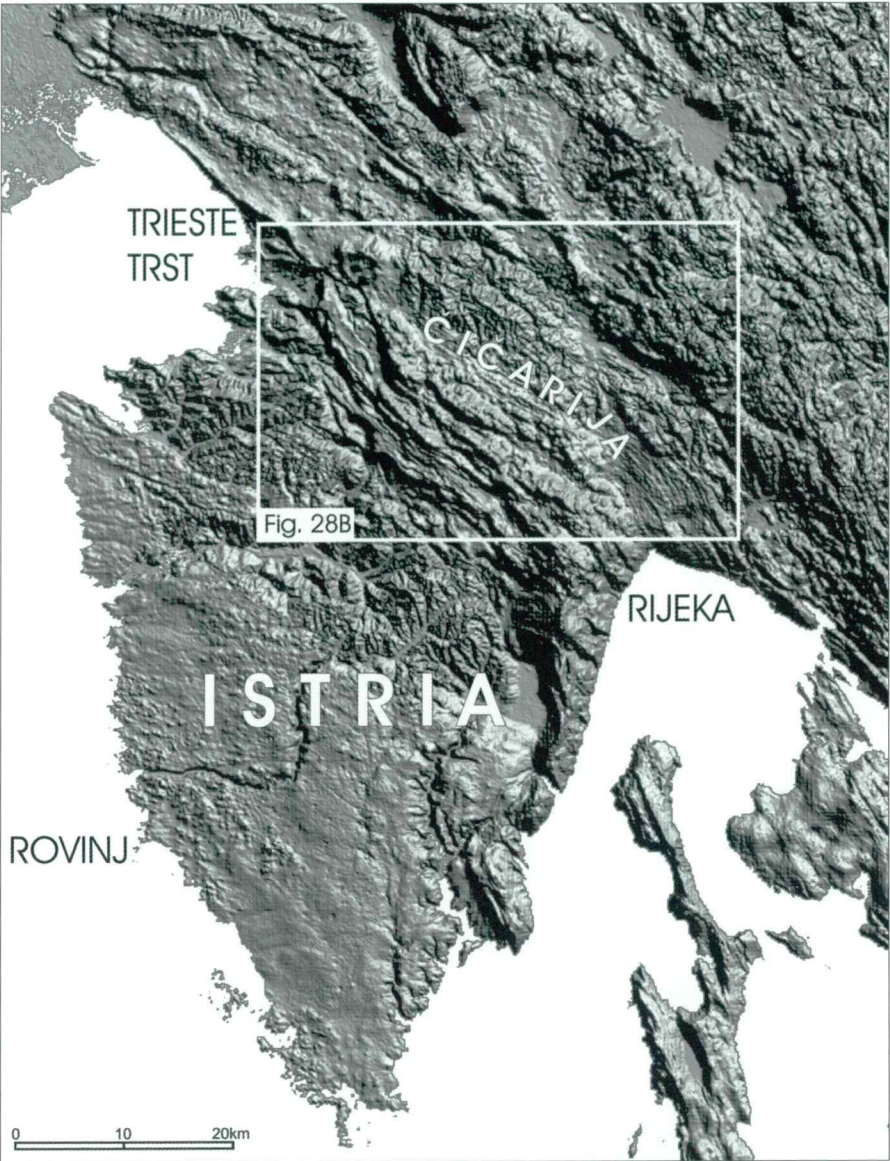
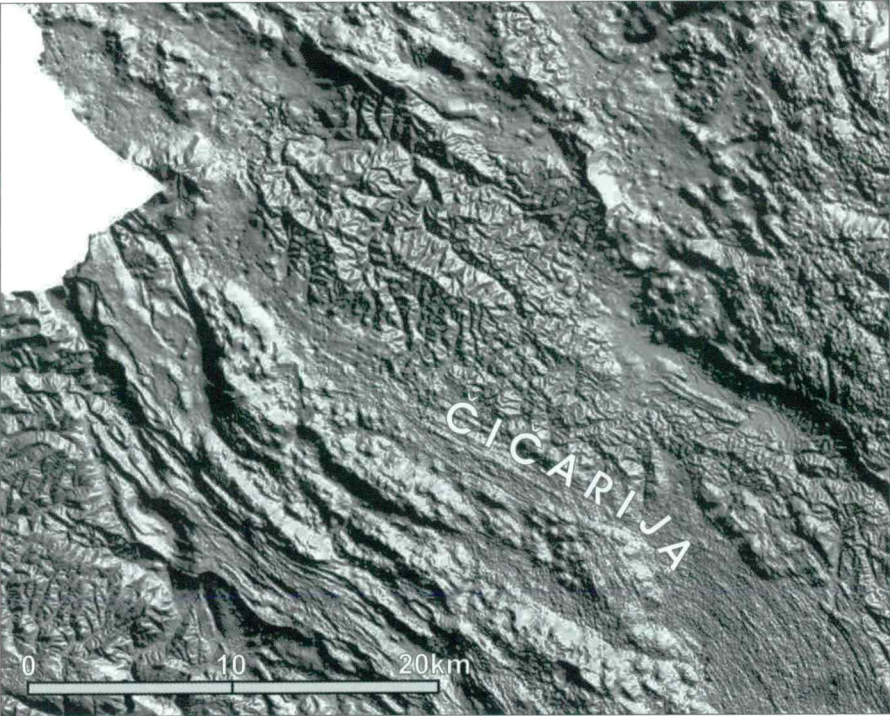


Fig. 28. **Digital elevation model of Istria.**

A Deformation of southern Čičarija hills in continuation of Southern Istria Structural Wedge (see Fig. 27);



B Detail with bent structure of Čičarija.

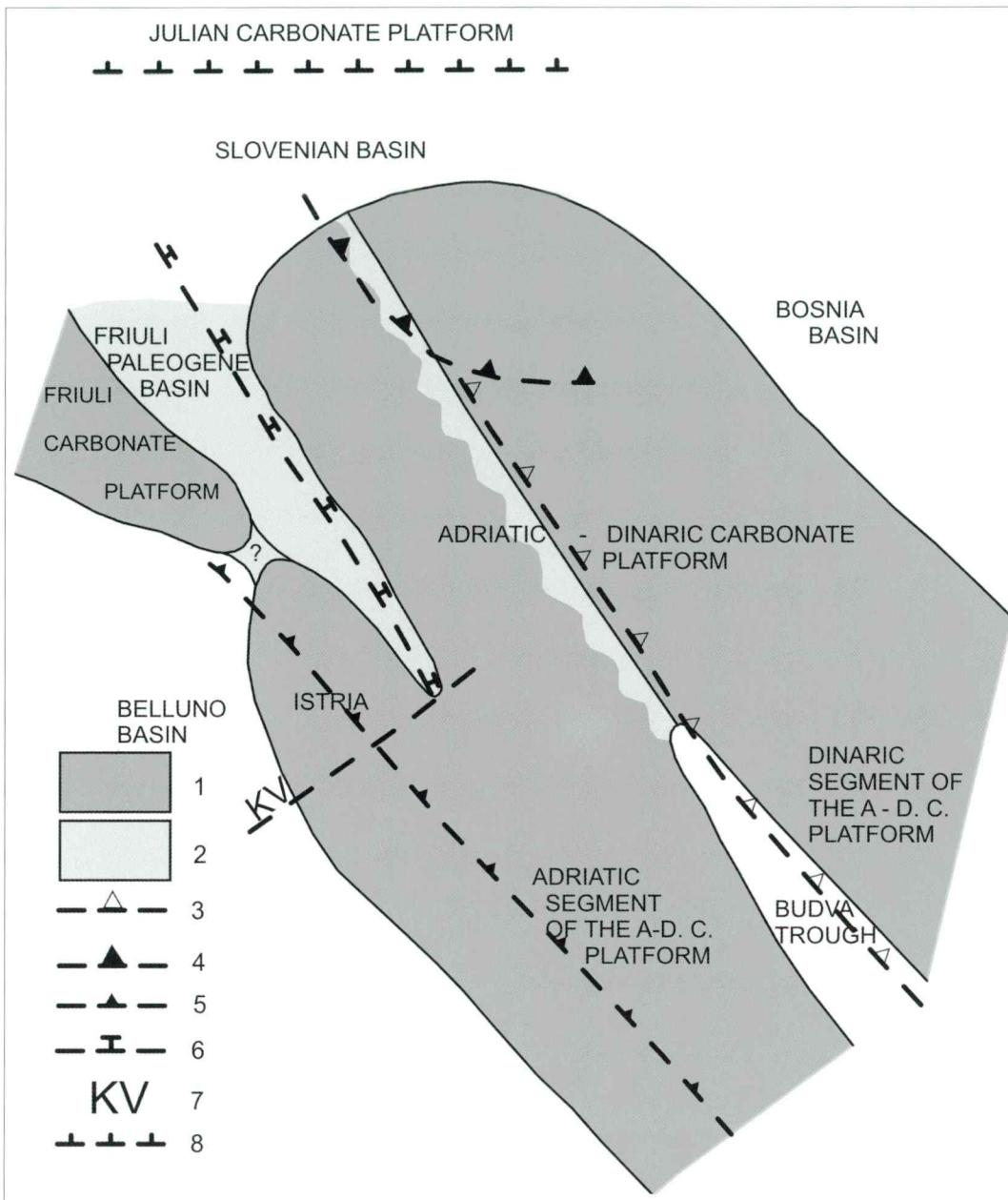


Fig. 29. **Paleogeographic model** of Adriatic - Dinaric Carbonate Platform; paleogeographic predisposition of External Dinarides tectonic model. 1. Carbonate platform; 2. Paleogene basin or trough; 3. Predisposition of Frontal Zone of External Dinaric Thrust Belt, "Veletit Thrust Series"; 4. Predisposition of Frontal Zone of External Dinaric Thrust Belt, Trnovo Thrust Series; 5. Predisposition of Trust Front of External Dinarides; 6. Predisposition of Istria - Friuli Underthrust Zone; 7. KV - Kvarner Fault; 8. Predisposition of boundary of underthrusting below the Southern Alps.

Fault and west of Tagliamento River are an indication of different stages of its evolution.

The relation between the Southern Alps, External Dinarides and Adriatic-Apulian foreland is schematically presented in Fig. 24.

NW-SE faults

The network of NW-SE striking dinaric faults in the study area of northwestern Dinarides is presented schematically. The basic data sources for this system are Basic Geologic Maps and papers by BUSER (1976), VRABEC (1994), JURKOVŠEK et al. (1996) and PLACER (2008a, b).

In general, three groups of faults that evolved in the course of geologic history from various

stress fields and specific conditions are important. The first group comprises the Ljubljana - Imotski Fault Zone (TARL, 2002, Miocene strike slip; PLACER, 2008b, Ljubljana - Imotski Fault Zone) of which is most important the Želimlje Fault, the second is a fault zone of the Idrija Fault, and the third is a group of faults southwest of the Idrija Fault, with the more important Predjama, Vipava, Raša and Divača Faults.

The Želimlje Fault represents an important structural boundary. Its importance is based on the differences in thrust structure of the Dinarides southwest and northwest of this fault zone (PLACER, 2008b).

The Idrija Fault has been relatively well studied. Two kilometers of dextral displacement of the mercury deposit at Idrija along this fault has been determined by MLAKAR (1964) and PLACER

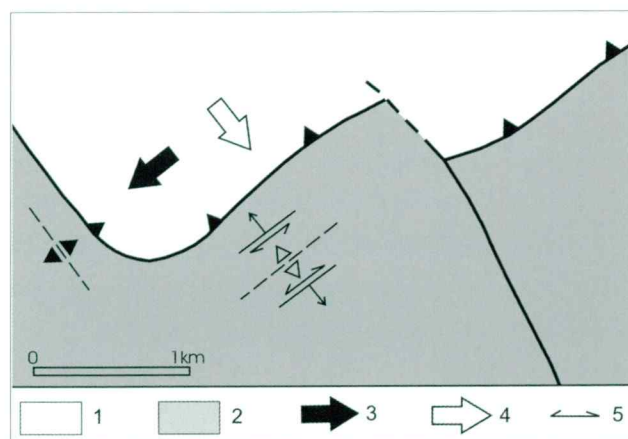


Fig. 30. Secondary thrusting of Hrušica nappe toward SE. Location 4 on Fig. 27. 1. Hrušica nappe; 2. Upper ductile horizon, flysch; 3. Thrusting direction of Hrušica nappe, Upper Eocene – Lower Oligocene; 4. Direction of secondary thrusting, Pliocene – Quaternary; 5. Horizontal interbed slipping.

(1982). Genesis of karst poljes southeast of Idrija was investigated by POLJAK (1986) and VRABEC (1994). The displacement of the Southern Alpine Thrust Front, however, was not reconstructed to a more precise detail because of impossibility of determining the intersections of the Modrej and Staro selo Faults with the Idrija Fault. The estimate of the horizontal displacement is about 10 km. The wider fault zone of the Idrija Fault comprises a number of parallel faults, of which the Ravne Fault is the most important. The Sovodnje, Borovnica and Ravnik Faults are arranged in an echelon series between the Ravne and the Želimlje Faults. Farther southeast they lean on the Želimlje Fault, respectively the Ljubljana – Imotski Fault zone also the Idrija Fault (PLACER, 2008b). In 1998 (ZUPANČIČ et al., 2001) and 2004 (VIDRIH & RIBIČIČ, 2004) occurred earthquakes with horizontal focal displacement at the Ravne Fault.

For understanding the dynamics of the considered region also the Predjama, Vipava, Raša and Divača Faults are important. These faults were variously deformed after the disintegration of the “Adria” into the Padan and Adriatic parts, and formation of the Istria Pushed Area. From the temporal succession and type of these deformations, the deformation model for the northeastern corner of the “Adria” will have to be constructed.

Discussion

On the basis of the above presented structure of the northwestern part of External Dinarides the following should be underlined:

Adriatic-Dinaric Mesozoic Carbonate Platform (Fig. 29). The initial structure of the thrust and nappe structure of External Dinarides is the paleogeography of the Mesozoic Carbonate Platform and its internal structure. With regard to the present structural relations in northwestern part of External Dinarides, the most suitable is the conservative concept of an Adriatic-Dinaric

Mesozoic Carbonate Platform consisting of a Dinaric and an Adriatic segment of the platform, between which the Budva Trough is situated. In northwest these segments have to merge into a single carbonate platform. In prolongation of the Budva Trough, the existence of a shallow Paleogene trough, or semi-trough, is not excluded. Istria and Friuli are parts of the Adriatic-Dinaric Carbonate Platform. They are separated from its central part by shallow Friulan Paleogene Basin. Friuli is separated from Istria by a shallow Paleogene passage. Istria is separated from the Adriatic segment of the Adriatic –Dinaric Carbonate Platform by a fault zone originating according to GRANDIĆ (1997b) most probably already in the Middle Triassic, and having been later reactivated as the Kvarner Fault Zone.

Differences in development of the Upper Triassic, Upper Cretaceous and Paleogene beds on the carbonate platform are a consequence of its incipient disintegration to Dinaric striking troughs and horsts (ŠRIBAR, 1995), and smaller shallow basins with a more or less continuous sedimentation in subsided parts, and various levels of erosion in the uplifted parts. Therefore differences in the upper part of platform cannot be used for establishing large tectonic displacements without objective material proofs for them. Also the differences in development between the Adriatic and Dinaric segment of platform cannot serve as a realistic base for extreme mobilistic explanations, but rather as stimulation for careful structural mapping of the contact areas. In this light the ideas of HERAK (1999), TARI (2002) and KORBAR (2009) should be considered.

2. Nappe structure of External Dinarides (Figs. 27 and 29). External Dinarides were formed in thrust processes in Paleocene and Eocene, and in the underthrusting stage of the “Adria” from Miocene on. The External Dinaric Thrust Belt developed predominantly from the Dinaric segment of platform and its prolongation toward northwest, where the Dinaric and Adriatic segments of platform were merged, which is the reason for existence of two areas of different internal geometry. In northwest, where the platform is uniform, the southwestern part of the External Dinaric Thrust Belt consists of the Trnovo Thrust Series, known from the analysis of nappe structure of the Idrija area and its wider surroundings. All mentioned units in it, the Trnovo and Hrušica Nappes and the Sovič Thrust Unit, have an identical geometry. Towards southeast, where the External Dinaric Thrust Belt consists of the Dinaric platform segments, extend from northwest to southeast the Snežnik, and Vinodol and Velebit Thrust Units. According to the structural data, inferred from situation on the surface, the extent of displacement increases from the Snežnik Thrust Unit southeastwards, and therefore we facultatively speak of the “Velebit Thrust Series”. The Trnovo Thrust Series covers the “Velebit Thrust Series”, so that the Frontal Zone of the External Dinaric Thrust Belt comprises the Frontal Zone of the “Velebit Thrust Series”, which is

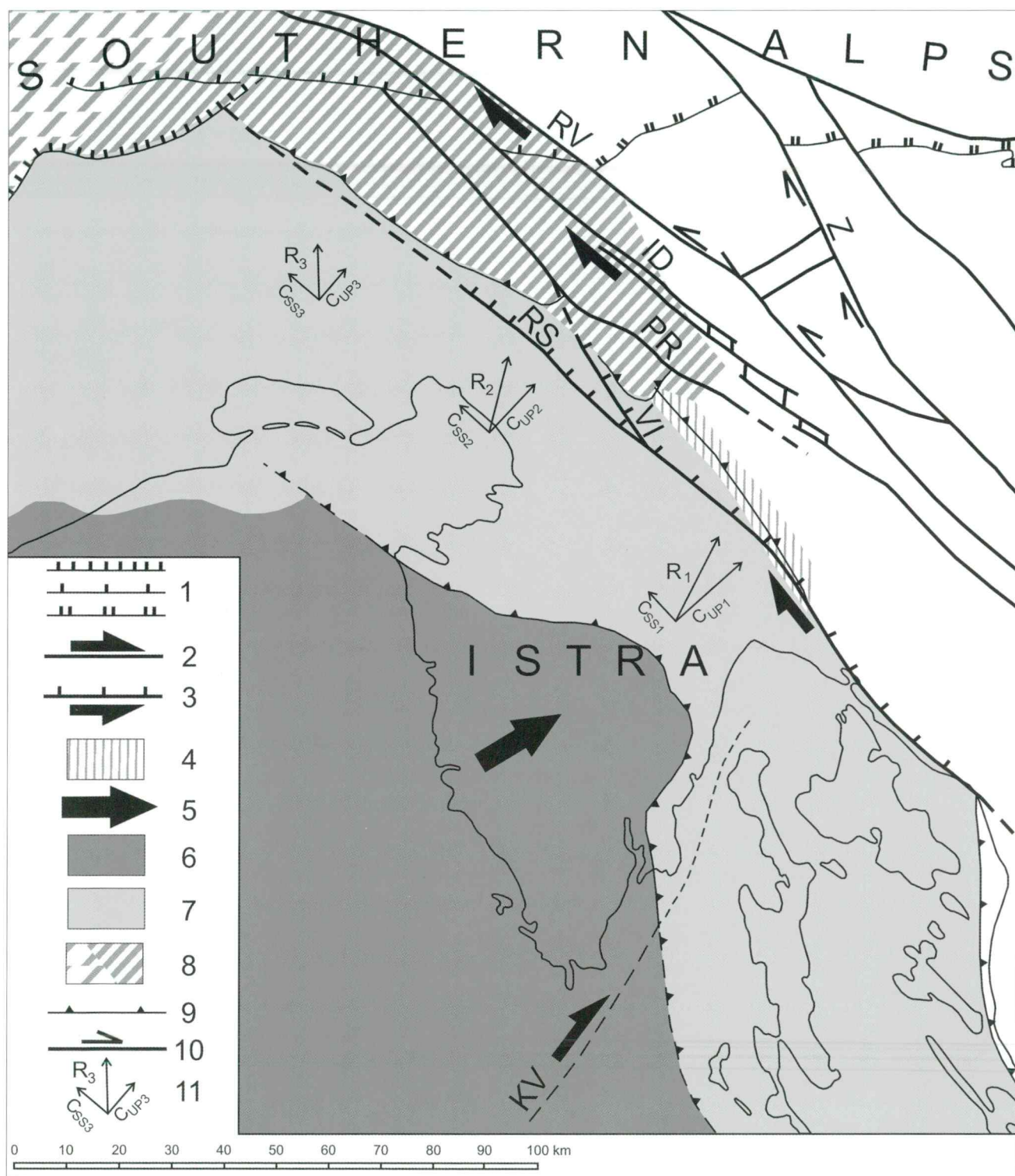


Fig. 31. **Recent dynamic model.** 1. Thrust faults of Southalpine Thrust Boundary; 2. Important strike-slip faults; 3. Transpressive faults; 4. Seismic active zone Ilirska Bistrica – Hruševje; 5. Direction of relative movement of Southern Istria Structural Wedge; 6. “Adria”; 7. Imbricated margin of “Adria”; 8. Neotectonic-recent segment incorporated in external edge of margin of “Adria”; 9. Thrust Front of External Dinarides; 10. Border faults of Ljubljana Wedge; 11. R_1, R_2, R_3 —relative vectors of resultant movements, C_{SS} —strike slip component of displacement ($C_{SS1} \approx C_{SS2} \approx C_{SS3}$), C_{UP} —sum of underthrusting and pushing displacement component ($C_{UP1} > C_{UP2} > C_{UP3}$).

linear, and the Frontal Zone of the Trnovo Thrust Series, which is, owing to the northwest regional dip of the units, segmented according to fronts of individual thrust and nappe units.

The External Dinaric Thrust Belt is overthrust in southeast, in the area of the “Velebit Thrust Series”, across the Budva Trough on the north-eastern margin of the Adriatic platform segment

which became therefore folded and partly imbricated. In northwest, where the platform segments are joined, predominate en echelon arranged folds of the Kras-Notranjsko Folded Structure.

Decreasing of displacements in front of the “Velebit Thrust Series” towards northwest is connected with pinching out of the Budva Trough. The difference in development of Cretaceous and

Paleogene between the Snežnik Thrust Unit and its basement is connected with structural differentiation of the platform and the resulting consequences.

3. Underthrusting below Southern Alps caused beside formation of the Southern Alpine Thrust Boundary also existence of the accompanied structures in Dinarides. They are well defined in the ductile formations of the lower and upper detachment horizon. Folds in the W-E direction in the Permocarboniferous clastites of the Trnovo Nappe are observable in the lower and folds in the SW-NE direction in the flysch of the upper detachment horizon under southeastern or left flank of the Hrušica Nappe near Ubeljsko (point 4 in Figs. 27 and 31). W-E directed folds are positioned east from Idria Fault and were formed in the first phase of the post-Sarmatian underthrusting. Younger, SW-NE directed folds are positioned west from Idria Fault. They formed as consequence of the contemporaneous lateral movement along Idria Fault and underthrusting below Southern Alps. Gentle secondary thrusting of the Trnovo and Hrušica Nappe in the southeast direction is also the effect of the above mentioned folding. PREMUR (1980) believed that Trnovo and Hrušica Nappes, as they are treated in our article, were secondary thrust to the south, and arguments this with W-E directed folds. He didn't discuss the extent of thrusting.

4. The Istria-Friuli Underthrust Zone (Figs. 4 and 25) and the **Istria Pushed Area** (Fig. 27) are two phenomena that in sense of dynamics cannot be separated. Both phenomena are connected with formation of the "Adria" and its separation by the Kvarner Fault Zone into the Padan and Adriatic part. The movements started in Miocene. Already during the first displacement stage the dextral strike-slip movements along the Kvarner Fault Zone had to occur, and underthrusting under the frontal part of the Snežnik Thrust Fault, as evidenced by dipping of the Ravnik Anticline and Brkini Synclinorium axis under the Snežnik Thrust Unit. Underthrusting resulted also in deformation of the front of the Hrušica and Trnovo Nappes. We see the reasons for such interpretations in the lateral displacement between beds of the secondary fold (point 4 in Fig. 27, detail in Fig. 31). We presume that the Istria-Friuli Underthrust Zone started forming at a time when further underthrusting below the Snežnik Thrust Unit was not possible any more. It developed after the weakened part of platform in the place of the Friulan Paleogene Basin. In principle the Istria-Friuli Underthrust Zone accepted the displacements that were not possible any more in hinterland of Istria in the Frontal Zone of the External Dinaric Thrust Belt. Extensive underthrusting below the Snežnik Thrust Unit was probably limited to a narrow space between the apical part of the Southern Istrian Structural Wedge and the Kvarner Fault Zone in the depth. The limited capability for underthrusting below the Snežnik thrust block is associated with the unique platform.

The effect of push, expressed in deformation of the frontal part of Hrušica and Trnovo Nappes, can be recognized by disability of reconstructing the thrust planes of the both nappe units in flysch according to principles of expected geometry of the overthrust units.

Formation of the Istria-Friuli Underthrust Zone and of Istrian Pushed Area was a polyphase process. The polyphase character can be observed e.g. in internal structure of the Istria – Friuli Underthrust Zone, in which alternate phases of underthrusting and folding, and also in relation between the Dinaric striking faults and laterally deformed arcuate structures, as in continuation of the Southern Istrian Structural Wedge in which the Raša Fault and Čičarija Synclinorium are arched, whereas the fault itself together with the Trieste-Komen Anticlinorium and Vipava Synclinorium are not arched, etc.

5. "Adria" (Fig. 30). If accepting the hypothesis that the original structure of the rigid indenter of "Adria" has been the Adriatic segment of the Adriatic – Dinaric Mesozoic Carbonate Platform, it could be deduced from interpretation of the present structure of the External Dinarides that the boundary of the "Adria" is identical with the Frontal Zone of the External Dinaric Thrust Belt. However, this impression is only apparent, more acceptable seems the hypothesis that the original structure of the rigid indenter of microplate is identical with the lithologic boundary of the northeastern margin of the Adriatic segment of carbonate platform in the depth, which in places coincides spatially with the Frontal Zone, and with fault deformations that have arisen along this boundary. In northwestern part of External Dinarides, where the Adriatic and the Dinaric segment of carbonate platform should have been joined, the original structure should have been subjected to other criteria. We presume on the basis of deformation geometry at least two principal phases of evolution of northwestern boundary of the "Adria", accompanied with interphase events as sketched under point 3. Two phases are presumed with respect to segmentation of underthrusting boundary of the External Dinarides under Southern Alps west of the Ravne Fault, which is attributed to the broader zone of the Idrija Fault (Fig. 3). It is subdivided into the Modrež Fault, respectively Staro selo steep Thrust Fault of W-E strike, and a zone of gently inclined thrust faults striking ENE-WSW to NE-SW west of Tagliamento that lean on the W-E striking faults. The area of the intersecting line of SW (WSW)-NE (ENE) and W-E striking thrust faults lies, at least theoretically, in the structural prolongation of the Budva Trough below the Trnovo Thrust Series. The area of actual displacements along the Ravne Fault, respectively the broader fault zone of the Idrija Fault, lies on the trace of a wider zone of echelon arranged dinaric, NW-SE striking faults, that passes from tip of the Kvarner Bay to central Soča River area. The zone is defined by the Raša Fault at the segment from eastern Kvarner coast

to the Ilirska Bistrica, active seismic zone Rupa – Postojna, Predjama Fault and the northwestern section of the Idrija and Ravne Faults. The connection between Kvarner and central Soča River area seems to be of a younger date. It formed after deformation of the Raša Fault in prolongation of the tip of Southern Istria Structural Wedge. Formation of this zone is conspicuously indicated by the linear arrangement of earthquake hypocenters in the Ilirska Bistrica – Hruševje zone. The mentioned boundaries of the “Adria”, older and younger, reflect the subrecent and recent fragmentation process of northeastern part of the “Adria”. The mechanism of this process is suggested by results of GPS measurements in the considered area (WEBER et al., 2010) that was generated by separate rotation of the Padan part of the “Adria” in whose edge Istria is situated opposite to the southern or Adriatic part. The rotation generates pushing of Southern Istria Structural Wedge northeastwards and strike-slip along faults of an echelon zone between Kvarner and the central Soča River area. Recent displacements along the Črni Kal Thrust Fault (RIŽNAR et al., 2007) indicate integral displacement of smaller structural blocks that will have to be determined by measurements. Such blocks are in addition to the Southern Istria Structural Wedge also the Northern Istria Structural Wedge, the Istrian block with respect to the Friulan block, etc..

An idea about incorporation of the new segment of the crust in the “Adria” opens the question about its northern boundary. It is positioned in the western continuation of the Idrija or Ravne Fault respectively. From this point of view, the South Alpine Thrust Front Boundary west from Idrija Fault and original NW boundary of the “Adria” in the structural continuation of the Budva trough under the Hrušica and Trnovo nappe plain has to be newly defined.

The kinematics of the eastern part of the Padan segment of the “Adria” is represented with resultant vectors of single parts of its boundary belt movements. According to the most intensive underthrusting and pushing in the Istria and gradual declining to the northwest, which is represented on the profiles across Istria (Fig. 22, C_{UP1} component), across Trieste – Karst Plateau (Fig. 23, C_{UP2} component) and Friuli (Fig. 24, C_{UP3} component), the relation between relative components of the underthrusting and pushing is as follows: $C_{UP1} > C_{UP2} > C_{UP3}$. If we presume that the component of displacement owing to the strike slip in the north-eastern direction (C_{SS}) is roughly the same in the whole area, then $C_{SS1} = C_{SS2} = C_{SS3}$. Relative resultant movements R_1 , R_2 and R_3 are therefore distorted in the counter-clockwise direction as deduced from reduced movements based on the GPS measurements (WEBER et al. 2010).

References

- BIGI, G., CONSENTINO, D., PAROTTO, M., SARTORI, R. & SCANDONE, P. 1990: Structural Model of Italy and Gravity Map, 1: 500.000. Sheet 2, Edit.: BIGI et al., Consiglio Nazionale delle Ricerche, 1990 (1983).
- BIGI, G., CASTELLARIN, A., CATALANO, R., COLI, M., COSENTINO, D., DAL PIAZ, G. V., LENTINI, F., PAROTTO, M., PATACCA, E., PRATURLON, A., SALVINI, F., SARTORI, R., SCANDONE, P. & VAL, B. 2000: Syntetic Structural – Kinematic Map of Italy, 1 : 2.000.000. Edit.: BIGI et al., Consiglio Nazionale delle Ricerche, 2000 (1989).
- BIONDIĆ, B., DUKARIĆ, F., KUHTA, M. & BIONDIĆ, R. 1997: Hydrogeological Exploration of the Rječina River Spring in the Dinaric Karst. Geol. Croat. (Zagreb) 50/2: 279–288.
- BLAŠKOVIĆ, I. & ALJANOVIĆ, B. 1981: Mikrotektonski elementi kao osnova za model tektonske građe šireg područja Kvarnera (Microtectonic elements as a basis for tectonic model of the broader Kvarner area). Simp. Kompleksna naftno-geološka problematika podmorja i priobalnih djelova Jadranskog mora, Split, Zbornik radova (Proceedings), 87–100, Zagreb.
- BLAŠKOVIĆ, I. 1991: Rasporod uzdužnih, reversnih i normalnih rasjeda i konstrukcija oblika i dubina ploha podvlačenja (Disposition of the longitudinal, reverse and normal faults and the construction of the forms and depths of the underthrusting surfaces). Geol. vjesnik (Zagreb) 44: 247–256.
- BLAŠKOVIĆ, I. 1998: The Two Stages of Structural Formation of the Coastal Belt of the External Dinarides. Geol. Croat. (Zagreb) 51/1: 75–89.
- BLAŠKOVIĆ, I. 1999: Tectonics of Part of the Vinodol Valley with in the Model of the Continental Crust Subduction. Geol. Croat. (Zagreb) 52/2: 153–189.
- BUSER, S., GRAD, K. & PLENIČAR, M. 1967: Osnovna geološka karta Jugoslavije 1:100.000, list Postojna (Basic geological map of Yugoslavia, sheet Postojna). Savezni geološki zavod, Beograd.
- BUSER, S. 1968: Osnovna geološka karta Jugoslavije 1 : 100.000, list Gorica (Basic geological map of Yugoslavia, sheet Gorica). Savezni geološki zavod, Beograd.
- BUSER, S. 1969: Osnovna geološka karta Jugoslavije 1 : 100.000, list Ribnica (Basic geological map of Yugoslavia, sheet Ribnica). Savezni geološki zavod, Beograd.
- BUSER, S. 1976: Tektonska zgradba južnozahodne Slovenije (Tektonischer Aufbau Südwest-Sloveniens). 8. jugosl. Geol. kongres, Bled 1974, 3: 45–57, Ljubljana.
- BUSER, S. 1978: Osnovna geološka karta Jugoslavije 1 : 100.000, list Celje (Basic geological map of Yugoslavia, sheet Celja). Savezni geološki zavod, Beograd.
- BUSER, S. 1986: Osnovna geološka karta Jugoslavije 1 : 100.000, tolmač lista Tolmin in Videm (Udine) (Basic geological map of Yugoslavia, guidebook for sheet Tolmin in Videm (Udine). Savezni geološki zavod, Beograd.

- BUSER, S. 1987: Osnovna geološka karta Jugoslavije 1 : 100.000, list Tolmin in Videm (Udine) (Basic geological map of Yugoslavia, sheet Tolmin in Videm (Udine)). Savezni geološki zavod, Beograd.
- BUSER, S. 1989: Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian basin (NW Yugoslavia). *Mem. Soc. Geol. It. (Roma)* 40 (1987): 313–320.
- CARULLI, G. B., NICOLICH, R., REBEZ, A. & SLEJKO, D. 1990: Seismotectonics of the Northwest External Dinarides. *Tectonophysics*, 179: 11–25.
- CARULLI, G. B. 2006: Carta geologica del Friuli Venezia Giulia 1:150.000 (Geological map of the Friuli Venezia Giulia 1 : 150.000). Edit.: Carulli, Università degli studi di Trieste, Università degli studi di Udine, Firenze.
- CATI, A., SARTORIO, D. & VENTURINI, S. 1989: Carbonate platforms in the subsurface of the northern Adriatic area. *Mem. Soc. Geol. It. (Roma)* 40 (1987): 295–308.
- COLIZZA, E., COSTA, R., CUCCHI, F., KNEZAUREK, G., PIRINI RADRIZZANI, G., PUGLIESE, N., ULCIGRAI, P. & ZUCCHI STOLFA, M. L. 1989: The geology of the San Pelagio area (Karst of Trieste, Italy). *Mem. Soc. Geol. It. (Roma)* 40 (1987): 45–51.
- CUCCHI, F., PIRINI RADRIZZANI, C. & PUGLIESE, N. 1989a: The carbonate stratigraphic sequence of the Karst of Trieste (Italy). *Mem. Soc. Geol. It. (Roma)* 40 (1987): 35–44.
- CUCCHI, F., VAIA, F. & FINOCCHIARO, F. 1989b: The geology of T. Rosandra valley (Karst of Trieste, Italy). *Mem. Soc. Geol. It. (Roma)* 40 (1987): 67–72.
- ČAR, J. & GOSPODARIČ, R. 1983/84: O geologiji krša med Postojno, Planino in Cerknico (About geology of karst among Postojna, Planina and Cerknica). *Acta carsologica (Ljubljana)* 12: 91–105.
- DEL BEN, A., FINETTI, I., REBEZ, A. & SLEJKO, D. 1991: Seismicity and seismotectonics at the Alps-Dinarides contact. *Bollettino di Geofisica Teorica ed Applicata* 33/130–131: 155–176.
- DURASEK, N., FRANK, G., JENKO, K., KUŽINA, K. & TONČIĆ-GREGL, R. 1981: Prilog poznavanju naftno-geoloških odnosa u sjeverozapadnom dijelu jadranskog podmorja (Contribution to the understanding of oil-geological relations in NW Adriatic area). *Simp. Kompleksna naftno-geološka problematika podmorja i priobalnih djelova Jadranskog mora, Split, Zbornik radova (Proceedings)*, Zagreb: 201–213.
- FANTONI, R., CATELLANI, D., MERLINI, S., ROGLEDI, S. & VENTURINI, S. 2002: La registrazione degli eventi deformativi cenozoici nell'avampaese Veneto-Friulano. *Mem. Soc. Geol. It. (Roma)* 57: 301–313.
- GRAD, K. & FERJANČIČ, L. 1974: Osnovna geološka karta Jugoslavije 1 : 100.000, list Kranj (Basic geological map of Yugoslavia, sheet Kranj). Savezni geološki zavod, Beograd.
- GRAD, K. & FERJANČIČ, L. 1976: Kranj; Osnovna geološka karta Jugoslavije 1 : 100.000, tolmač lista Kranj (Basic geological map of Yugoslavia, guidebook for sheet Kranj). Savezni geološki zavod, Beograd.
- GRANDIĆ, S., BOROMISA-BALAŠ, E. & ŠUŠTERŠIĆ, M. 1997a: Exploration concept and characteristic of the Dinarides stratigraphic and structural model in the Croatian offshore area (Part I). *Nafta (Zagreb)* 48/4: 117–128.
- GRANDIĆ, S., BOROMISA-BALAŠ, E. & ŠUŠTERŠIĆ, M. 1997b: Exploration concept and characteristics of the stratigraphic and structural models of the Dinarides in Croatian offshore area (Part II: Hydrocarbon Consideration). *Nafta (Zagreb)* 48/8–9: 249–266.
- GRANDIĆ, S., KRATKOVIĆ, I., KOLBAH, S. & SAMARŽLIJA, J. 2004: Hydrocarbon potential of stratigraphic and structural traps of the Ravni Kotari area - Croatia. *Nafta (Zagreb)* 55/7–8: 311–327.
- HERAK, M. 1986: A new concept of geotectonics of the Dinarides. *Acta geologica* 16/1, Prirodoslovna istraživanja (Zagreb) 51: 1–42.
- HERAK, M. 1999: Tectonic Interrelation of the Dinarides and the Southern Alps. *Geol. Croat. (Zagreb)* 52/1: 83–98.
- JURKOVŠEK, B., TOMAN, M., OGORELEC, B., ŠRIBAR, L., DROBNE, K., POLJAK, M. & ŠRIBAR, L.J. 1996: Formacijska geološka karta južnega dela Tržaško-Komenske planote: Kredne in paleogenske karbonatne kamnine (Geological map of the southern part of the Trieste-Komen plateau: Cretaceous and Paleogene carbonate rocks). *Geološki zavod Ljubljana (Ljubljana)*: 1–143.
- KORBAR, T. 2009: Orogenic evolution of the External Dinarides in the NE Adriatic region: a model constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates. *Earth-Science Reviews*, 96/4: 296–312.
- MAGAŠ, N. 1968: Osnovna geološka karta Jugoslavije 1 : 100.000, list Cres (Basic geological map of Yugoslavia, sheet Cres). Savezni geološki zavod, Beograd.
- MAMUŽIĆ, P., MILAN, A., KOROLIJA, B., BOROVIĆ, I. & MAJCEN, Ž. 1969: Osnovna geološka karta Jugoslavije 1 : 100.000, list Rab (Basic geological map of Yugoslavia, sheet Rab). Savezni geološki zavod, Beograd.
- MARINČIĆ, S. & MATIČEC, D. 1991: Tektonika i kinematika deformacija na primjeru Istre (Tectonics and kinematics of deformations – an Istrian Model). *Geol. vjesnik (Zagreb)* 44: 257–268.
- MATIČEC, D. 1994: Neotectonic Deformations in Western Istria, Croatia. *Geol. Croat. (Zagreb)* 47/2: 199–204.
- MARTON, E. 1987: Palaeomagnetism and tectonics in the Mediterranean region. *Journal of Geodynamics* 7: 33–57.
- MERLINI, S., DOGLIONI, C., FANTONI, R. & PONTON, M. 2002: Analisi strutturale lungo un profilo geologico tra la linea Fella-Sava e l'avampaese adriatico (Friuli Venezia Giulia-Italia). *Mem. Soc. Geol. It. (Roma)* 57: 293–300.
- MIHEVC, A. 1994: Morfološke značilnosti Matarskega podolja. *Ann. Ser. hist. nat.* 4/4: 163–168.
- MIHEVC, A. 2007: The age of karst relief in West Slovenia. *Acta carsologica (Ljubljana)* 36/1: 35–44.
- MIKES, T., BÁLDI-BEKE, M., KÁZMÉR, M., DUNKL, I. & EYNATTEN, H. 2008: Calcareous nannofossil

- age constraints on Miocene flysch sedimentation in the Outer Dinarides (Slovenia, Croatia, Bosnia-Herzegovina and Montenegro). In eds. Siegesmund, S., Fügenschuh, B. & Froitzheim, N. *Tectonic Aspects of the Alpine-Dinaride-Carpathian System*. Geological Society, Special Publications (London) 298: 335–363.
- MLAKAR, I. 1964: Vloga postrudne tektonike pri iskanju novih orudenih con na območju Idrije. *Rudarsko-metalurški zbornik* (Ljubljana) 1: 18–25.
- MLAKAR, I. 1969: Krovna zgradba idrijsko žirovskega ozemlja (Nappe structure of the Idrija-Žiri Region). *Geologija* (Ljubljana) 12: 5–72.
- MLAKAR, I. & PLACER, L. 2000: Geološka zgradba Žirovskega ozemlja. V *Rudnik urana Žirovski vrh*, FLORJANČIČ, A. P. (eds), 34–45, Didakta, Radovljica.
- NICOLICH, R., DELLA VEDOVA, B., GIUSTINIANI, M. & FANTONI, R. 2004: Carta del sottosuolo della Pianura Friulana (Map of subsurface structures of the Friuli Plain), Università di Trieste: 1–32.
- NUSSBAUM, CH. 2000: Neogene Tectonics and Thermal Maturity of Sediments of the Easternmost Southern Alps (Friuli Area, Italy). Thesis, Inst. de Geologie, Université de Neuchatel.
- PAMIĆ, J., GLUŠIĆ, I. & JELASKA, V. 1998: Geodynamic evolution of the Central Dinarides. *Tectonophysics*, 297: 251–268.
- PAMIĆ, J. & HRVATOVIC, H. 2003: Main large thrust structures in the Dinarides – a proposal for their classification. *Nafta* (Zagreb) 54/12: 443–456.
- PERUZZA, L., POLI, M. E., REBEZ, A., RENNER, G., ROGLEDI, S., SLEJKO, D. & ZANFERRARI, A. 2002: The 1976–1977 seismic sequence in Friuli: new seismotectonic aspects. *Mem. Soc. Geol. It.* (Roma) 57: 391–400.
- PLACER, L. 1973: Rekonstrukcija krovne zgradbe idrijsko-žirovskega ozemlja (Reconstruction of the Nappe Structure of the Idrija-Žiri Region). *Geologija* (Ljubljana) 16: 317–334.
- PLACER, L. 1981: Geološka zgradba jugozahodne Slovenije (Geologic structure of southwestern Slovenia). *Geologija* (Ljubljana) 24/1: 27–60.
- PLACER, L. 1982: Tektonski razvoj idrijskega rudišča (Structural history of the Idrija mercury deposit). *Geologija* (Ljubljana) 25/1: 7–94.
- PLACER, L. 1996: O zgradbi Soviča nad Postojno (On the structure of Sovič above Postojna). *Geologija* (Ljubljana) 37/38 (1994/95): 551–560.
- PLACER, L. & ČAR, J. 1997: Structure of Mt. Blegoš between the Inner and Outer Dinarides. *Geologija* (Ljubljana) 40: 305–323.
- PLACER, L. 1999: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. *Geologija* (Ljubljana) 41(1998): 223–255.
- PLACER, L. 2002: Predhodna objava rezultatov strukturnega profiliranja Kraškega roba in Istre, AC Kozina – Srmin, Sečovelje (Preliminary results of structural profiling of the Kras edge and Istria, Kozina – Srmin Motorway, Sečovelje). *Geologija* (Ljubljana) 45/1: 277–280.
- PLACER, L., KOŠIR, A., POPIT, T., ŠMUC, A. & JUVAN, G. 2004: The Buzet Thrust Fault in Istria and overturned carbonate megabeds in the Eocene flysch of the Dragonja Valley (Slovenia). *Geologija* (Ljubljana) 47/2: 193–198.
- PLACER, L. 2005: Strukturne posebnosti severne Istre (Structural curiosity of the northern Istria). *Geologija* (Ljubljana) 48/2: 245–251.
- PLACER, L. 2007: Kraški rob. Geološki prerez vzdolž AC Kozina – Koper (Kraški rob (landscape term). Geologic section along the motorway Kozina – Koper (Capodistria). *Geologija* (Ljubljana) 50/1: 29–44.
- PLACER, L. 2008a: Vipavski prelom. *Geologija* (Ljubljana) 51/1: 101–105.
- PLACER, L. 2008b: Principles of the tectonic subdivision of Slovenia. *Geologija* (Ljubljana) 51/2: 205–217.
- PLACER, L. 2009: Tektonska razčlenitev Slovenije (Tectonic subdivision of Slovenia). V *Geologija Slovenije* (In *Geology of Slovenia*), Uredniki/Eds. PLENIČAR, M. et al., Ljubljana. In print.
- PLENIČAR, M. 1959: Tektonski okni pri Knežaku (Two tectonic windows at Knežak). *Geologija* (Ljubljana) 5: 5–10.
- PLENIČAR, M., POLŠAK, A. & ŠIKIĆ, D. 1969: Osnovna geološka karta Jugoslavije 1 : 100.000, list Trst (Trieste) (Basic geological map of Yugoslavia, sheet Trst (Trieste)). Savezni geološki zavod, Beograd.
- PLENIČAR, M., POLŠAK, A. & ŠIKIĆ, D. 1973: Osnovna geološka karta Jugoslavije 1 : 100.000, tolmač lista Trst (Trieste) (Basic geological map of Yugoslavia, guidebook for sheet Trst (Trieste)). Savezni geološki zavod, Beograd.
- POLJAK, M. 1986: Strukturna evolucija slovenskih Vanjskih Dinarida u terciaru i kvarteru (The structural evolution of the Slovene Outer Dinarides in Tertiary and Quaternary). XI. Kongr. Geol. Jugoslavije, Knj.3, 299–322, Tara.
- POLJAK, M. & RIŽNAR, I. 1996: Structure of the Adriatic - Dinaric Platform Along the Sečovelje - Postojna Profile. *Geol. Croat.* (Zagreb) 49/2: 345–346.
- POLŠAK, A. 1967: Osnovna geološka karta Jugoslavije 1 : 100.000, list Pula (Basic geological map of Yugoslavia, sheet Pula). Savezni geološki zavod, Beograd.
- POLŠAK, A. & ŠIKIĆ, D. 1973: Osnovna geološka karta Jugoslavije 1 : 100.000, list Rovinj (Basic geological map of Yugoslavia, sheet Rovinj). Savezni geološki zavod, Beograd.
- PONTON, M. 2002: La tettonica del gruppo del M. Canin e la linea Val Resia-Val Coritenza (Alpi Giulie occidentali). *Mem. Soc. Geol. It.* (Roma) 57: 283–292.
- PRELOGOVIĆ, E., PRIBIČEVIĆ, B., IVKOVIĆ, Ž., DRAGIČEVIĆ, I., BULJAN, R. & TOMLJENOVIC, B. 2004: Recent structural fabric of the Dinarides and tectonically active zones important for petroleum-geological exploration in Croatia. *Nafta* (Zagreb) 55/4 (2003): 155–161.
- PREMRU, U. 1980: Geološka zgradba osrednje Slovenije. *Geologija* (Ljubljana) 23/2: 227–278.
- PREMRU, U. 1983: Osnovna geološka karta Jugoslavije 1 : 100.000, list Ljubljana (Basic geological

- cal map of Yugoslavia, sheet Ljubljana). Savezni geološki zavod, Beograd.
- PREMRU, U. 2005: Tektonika in tektogeneza Slovenije (Tectonics and Tectogenesis of Slovenia). Geološki zavod Slovenije (Ljubljana): 1–515.
- RIŽNAR, I., KOLER, B. & BAVEC, M. 2007: Recentna aktivnost regionalnih geoloških struktur v zahodni Sloveniji. *Geologija* (Ljubljana) 50/1:111–120.
- SAVIĆ, D. & DOZET, S. 1985: Osnovna geološka karta Jugoslavije 1 : 100.000, list Delnice (Basic geological map of Yugoslavia, sheet Delnice). Savezni geološki zavod, Beograd.
- SLEJKO, D., CARRARO, F., CARULLI, G. B., CASTALDINI, A., CAVALLIN, A., DOGLIONI, C., NICOLICH, R., REBEZ, A., SEMENZA, E. & ZANFERRARI, A. 1986: Seismotectonic Model of Northeastern Italy: an Approach. *Geologia Applicata e Idrogeologia* XXI/1, 153–165.
- ŠIKIĆ, D., POLŠAK, A. & MAGAŠ, N. 1969: Osnovna geološka karta Jugoslavije 1 : 100.000, list Labin (Basic geological map of Yugoslavia, sheet Labin). Savezni geološki zavod, Beograd.
- ŠIKIĆ, D., PLENIČAR, M. & ŠPARICA, M. 1972: Osnovna geološka karta Jugoslavije 1 : 100.000, list Ilirska Bistrica (Basic geological map of Yugoslavia, sheet Ilirska Bistrica). Savezni geološki zavod, Beograd.
- ŠRIBAR, L. 1995: Evolucija gornjekredne Jadransko-Dinarske karbonatne platforme u jugozapadnoj Sloveniji. MSC Thesis, pp. 89, University of Zagreb.
- ŠUŠNJAR, M., BUKOVAC, J., NIKLER, L., CRNOLATAC, I., MILAN, A., ŠIKIĆ, D., GRIMANI, I., VULIĆ, Ž. & BLAŠKOVIĆ, I. 1970: Osnovna geološka karta Jugoslavije 1 : 100.000, list Crikvenica (Basic geological map of Yugoslavia, sheet Crikvenica). Savezni geološki zavod, Beograd.
- TARI, V. 2002: Evolution of the northern and western Dinarides: a tectonostratigraphic approach. EGU Stephan Mueller Special Publication Series 1: 223–236.
- VELIĆ, I., VLAHOVIĆ, I. & MATIČEC, D. 2002: Depositional sequences and Paleogeography of the Adriatic Carbonate Platform. *Mem. Soc. Geol. It. (Roma)* 57: 141–151.
- VENTURINI, S. 2002: Il pozzo di Cargnacco 1: un punto di taratura stratigrafica nella pianura friulana. *Mem. Soc. Geol. It. (Roma)* 57: 11–18.
- VIDRIH, R. & RIBIČIČ, M. 2004: Potres 12. julija 2004 v zgornjem Posočju – preliminarne geološke in seizmološke značilnosti (The earthquake on July 12, 2004 in Upper Soča territory - NW Slovenia – preliminary geological and seismological characteristics). *Geologija* (Ljubljana) 47/2: 199–220.
- VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. 2005: Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. *Palaeogeography, Palaeoclimatology, Palaeoecology* (Amsterdam) 220/3–4: 333–360.
- VRABEC, M. 1994: Some thoughts on the pull-apart origin of karst poljes along the Idrija strike-slip fault zone in Slovenia. *Acta carsologica* (Ljubljana) 23: 158–168.
- WEBER, J., VRABEC, M., PAVLOVČIČ-PREŠEREN, P., DIXON, T., JIANG, Y. & STOPAR, B. 2010: GPS-derived motion of the Adriatic microplate from Istria Peninsula and Po Plain site, and geodynamic implications. *Tectonophysics*, (Amst.) 483/3–4: 214–222. doi: 10.1016/j.tecto.2009.09.001
- ZUPANČIČ, P., CECIĆ, I., GOSAR, A., PLACER, L., POLJAK, M. & ŽIVČIĆ, M. 2001: The earthquake of 12 April 1998 in the Krn Mountains (Upper Soča valley, Slovenia) and its seismotectonic characteristics. *Geologija* (Ljubljana) 44/1: 169–192.