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Transverse Dinaric zone of increased compression between the Kraški rob and Hrušica Regions, NE Microadria

Prečnodinarska cona povečane kompresije med Kraškim robom in Hrušico, NE Mikroadrija

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Ključne besede: NE Mikroadrija (Jadranska mikroplošča), Istra, istrsko potisno območje, črnokalska anomalija, traverza Kraški rob – Hrušica, zložbena zgradba, ovojni (envelopni) prelom

Abstract

The Kvarner fault divides the Microadria (Adria microplate, the Adria stable core) into the Po and Adria segments. The Istra block, which is sandwiched between the right-lateral Kvarner Fault and the left-lateral Sistiana Fault lies at the extreme eastern edge of the Po segment. Both faults run transversely to the Dinarides and reach their thrust boundary in the east. The Microadria has been moving towards the Dinarides since the Middle Miocene. The movement of the Istra block is exposed in relation to the neighbouring blocks, so an extensive pushed area (the Istra Pushed Area) was formed in the External Dinarides, which is bent towards the northeast. It is defined by two flexural zones, one lying in the extension of the Sistiana Fault and the other in the extension of the Kvarner Fault. The structure of the Dinaric thrust border on the north-eastern side of the Istra block is complex. Its prominent structural element is the Črni Kal Anomaly, due to which a zone of increased compression developed within the Istra Pushed Area and transversely to the Dinarides (Kraški rob – Hrušica Traverse), which lies between the Sistiana and Kvarner Flexural Zones. In terms of kinematics, it differs greatly from these two, and various geomorphologically responsive deformations have occurred within it. Mt. Vremščica (1027 m), which represents a transpressive anticline within the wider zone of the Raša Fault is the most prominent. In order to understand the genesis of the Classical Karst relief, it is important to know that the Mt. Vremščica ridge rose from the levelled karst surface.

Izvleček

Kvarnerski prelom deli Mikroadrijo (Jadranska mikroplošča, stabilno jedro Adrije) na padski in jadranski segment. Na skrajnem vzhodnem robu padskega segmenta leži istrski blok, ki je umeščen med desnozmični Kvarnerski in levozmični Sesljanskim prelom. Oba preloma potekata prečno na Dinaride in segata do njihove narivne meje. Mikroadrija se že od srednjega miocena naprej pomika proti Dinaridom, premikanje istrskega bloka je nasproti sosednjim blokom eksponirano, zato se je v Zunanjih Dinaridih izoblikovalo obsežno potisno območje (istrsko potisno območje), ki je usločeno proti severovzhodu. Določata ga dve upogibni coni, ena leži v podaljšku Sesljanskega, druga v podaljšku Kvarnerskega preloma. Zgradba narivne meje Dinaridov na severovzhodni strani istrskega bloka je zapletena, njen izstopajoči strukturni element je črnokalska anomalija, zaradi katere se je v istrskem potisnem območju in prečno na Dinaride razvila cona povečane kompresije (traverza Kraški rob - Hrušica), ki leži med sesljansko in kvarnersko upogibno cono. V kinematskem smislu od obeh močno odstopa, v njej so nastale različne geomorfološko odzivne deformacije, najbolj vidna med njimi je Vremščica (1027 m), ki predstavlja transpresivno antiklinalo znotraj širše cone Raškega preloma. Za razumevanje geneze reliefa Klasičnega krasa je pomembno vedeti, da se je greben Vremščice dvignil iz uravnanega kraškega površja.

Introduction

Blašković & Aljinović (1981), and Blašković (1991; 1999) already showed that the Dinaric foothills in the Istra and Kvarner are moving towards the Dinarides, and a more specific structural justification for the movement of Istra was given in the discussion on the basics of understanding the tectonics of the north-western Dinarides and Peninsula Istra (Placer et al., 2010) and in discussion of the Sistiana Fault and Sistiana Bending Zone (Placer et al., 2021b). In these discussions, it was established that Istra, which is part of the Microadria (Adriatic microplate), lies in a block (the Istra block) between two strike-slip faults: the left-lateral Sistiana Fault in the northwest and the complex right strike-slip Kvarner Fault in the southeast (Fig. 1). Both faults lie transversely to the Dinarides and extend only as far as the Dinaric Thrust Belt boundary. In the Dinarides, their influence is reflected in the clockwise Sistiana and anticlockwise Kvarner Flexural Zones, which run in the direction of both faults. In this article, the term Sistiana Bending Zone is replaced by the term Sistiana Flexural Zone because it better corresponds to the tectonic terminology. The part of the Microadria northwest of the Sistiana Fault was designated as the Friuli block, which is less exposed to the Dinarides than the Istra block. The movement of the Istra block is compensated by the lateral bending of the External Dinarides towards the northeast and by underthrusting in the area of their thrust boundary. This is how the Istra-Friuli Thrust-Underthrust Zone and the Istra Pushed Area, defined by both flexural zones, were formed. The process of pushing is more important

Uvod

Da se Dinarsko predgorje na območju Istre in Kvarnerja premika proti Dinaridom sta opozorila že Blašković in Aljinović (1981) ter Blašković (1991; 1999), določnejša strukturna utemeljitev premikanja Istre pa je bila podana v razpravi o osnovah razumevanja tektonike severozahodnih Dinaridov in Istre (Placer et al., 2010) ter v razpravi o Sesljanskem prelomu in sesljanski upogibni coni (Placer et al., 2021b). V teh razpravah je bilo ugotovljeno, da leži Istra, ki je del Mikroadrije (Jadranske mikroplošče), v bloku (istrski blok) med dvema zmičnima prelomoma, levozmičnim Sesljanskim prelomom na severozahodu in desnozmičnim Kvarnerskim prelomom na jugovzhodu. Oba preloma ležita prečno na smer Dinaridov in segata le do njihove narivne meje. V Dinaridih se njun vpliv odraža v levosučni sesljanski in desnosučni kvarnerski upogibni coni, ki potekata v smeri obeh prelomov. Del Mikroadrije severozahodno od Sesljanskega preloma je bil označen kot furlanski blok, ki pa je proti Dinaridom manj izpostavljen od istrskega bloka. Premikanje istrskega bloka je kompenzirano z bočnim upogibom Zunanjih Dinaridov proti severovzhodu in s podrivanjem v območju njihove narivne meje. Tako sta nastala istrsko-furlanska podrivna cona in istrsko potisno območje, ki ga določata obe upogibni coni. Proces potiskanja je pomembnejši od podrivanja. V podrivni coni naj bi se paleogenski narivi, ki označujejo konec dinarske narivne faze, transformirali v neogenske do recentne podrive. Recentno dviganje krovnih grud v območju

Fig. 1. Tectonic subdivision of Istra penninsula and its Dinaric hinterland. Updated after Placer et al. (2010, Fig. 3; 2021b, Fig. 1).
Sl. 1. Tektonska rajonizacija polotoka Istre in dinarskega zaledja. Dopolnjeno po Placer et al. (2010, sl. 3; 2021b, sl. 1).

1 Dinarides. External Dinaric Thrust Belt: T – Trnovo Nappe, H – Hrušica Nappe, S – Snežnik Nappe / Dinaridi. Zunanjedinarski narivni pas: T – Trnovski pokrov, H – Hrušiški pokrov, S – Snežniški pokrov

2 Dinarides. External Dinaric Imbricated Belt / Dinaridi. Zunanjedinarski naluskani pas

3 Microadria: stable core, imbricated borderland (autochton *sensu lato*) / Mikroadrija: stabilno jedro, naluskano obrobje (avtohton *sensu lato*)

4 Microadria: stable core (autochton *sensu stricto*) / Mikroadrija: stabilno jedro (avtohton *sensu stricto*)

5 Southern Alps / Južne Alpe

6 Southern Alps thrust boundary / narivna meja Južnih Alp

7 External Dinaric Thrust Belt boundary, nappe bondary / meja Zunanjedinarskega narivnega pasu, meja pokrova

8 Thrust plane within Dinaric thrust boundary / nariv v coni narivne meje Dinaridov

9 Istra-Friuli Thrust-Underthrust Zone (Placer et al., 2010, Istra-Friuli Underthrust Zone) / istrsko-furlanska narivno-podrivna cona (Placer et al., 2010, istrsko-furlanska podrivna cona)

10 BuF – Buje reverse Fault / BuF – Bujski reverzni prelom

11 Anticlinoria: a – Čičarija Anticlinorium, b – Trieste-Komen Synclinorium, c – Ravnik Anticlinorium / antiklinoriji: a – Čičarijski antiklinorij, b – Tržaško-Komenski antiklinorij, c – Ravenski antiklinorij

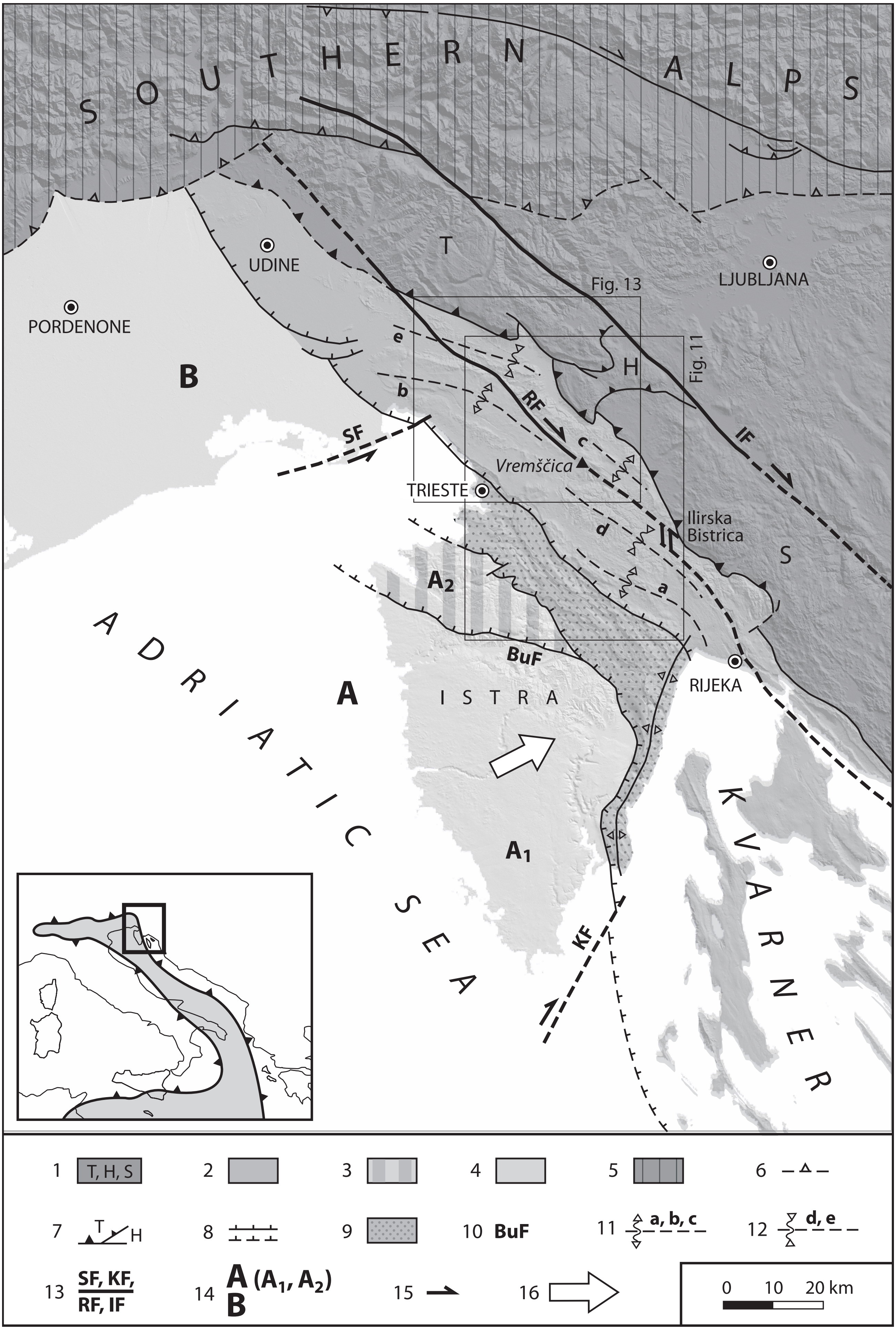
12 Synclinoria: d – Brkini Synklinorium, e – Vipava Synclinorium / sinklinoriji: d – Brkinski sinklinorij, e – Vipavski sinklinorij

13 Important sub-vertical fault: SF – Sistiana Fault, KF – Kvarner Fault, RF – Raša fault, IF – Idrija Fault / pomembnejši subvertikalni prelom: SF – Sesljanski prelom, KF – Kvarnerski prelom, RF – Raški prelom, IF – Idrijski prelom

14 Microadria structural block: A – Istra block (A1 – South Istra Structural Wedge, A2 – North Istra Structural Wedge), B – Friuli block / strukturni blok Mikroadrije: A – istrski blok (A1 – južnoistrski strukturni klin, A2 – severnoistrski strukturni klin), B – furlanski blok

15 Relative movement direction of the fault block / relativna smer premika prelomnega krila

16 General direction of South Istra Structural Wedge movement / generalna smer premikanja južnoistrskega strukturnega klina


S O U T H E R N A L P S
T
UDINE
LJUBLJANA
PORDENONE
Fig. 13
Fig. 11
e
H
B
b
RF
SF
c
IF
Vremščica
TRIESTE
Ilirska Bistrica
d
S
A2
a
A D R I A T I C S E A
BuF
RIJEKA
A
I S T R A
K V A R N E R
A1
KF
1 T, H, S
2
3
4
5
6
7 T H
8
9
10 BuF
11 a, b, c
12 d, e
13 SF, KF, RF, IF
14 A (A1, A2) B
15
16
0 10 20 km

than underthrusting. In the underthrust zone, the Paleogene thrusts, which mark the end of the Dinaric thrust phase, are supposed to transform into Neogene to recent thrusts. The recent uplift of the Paleogene nappes in the Istra-Friuli Thrust-Underthrust Zone was determined in Istra by the reambulation of levelling lines (Rižnar et al., 2007).

Istra is a visible part of the Istra block, divided into the South Istra and North Istra Structural Wedges (Fig. 1). According to the established directions of movement and parallel deformations, the South Istra Structural Wedge should move towards the Dinarides faster than the northern one.

The above-mentioned fundamental findings stimulated a series of focused researches: the recent movement of Istra towards the Dinarides was proven by GPS measurements (Weber et al., 2010), the more intense movement of the tip of the South Istra Structural Wedge towards the Dinarides was confirmed by measurements of the local rotation of magnetic poles in cave sediments in the thrust units of the Dinarides (Vrabec et al., 2018); large sub-recent gravity phenomena in the area of the Istra Pushed Area were investigated (Placer et al., 2021a), and more precisely the Sistiana Flexural Zone was investigated (Placer et al., 2021b). Publications regarding the seismicity of the area in question are not covered here.

Geophysical surveys of the seabed of the Gulf of Trieste have shown that the mapped structures from Istra continue to the northwest. In this sense, the articles published after the discovery of the Buzet Thrust (Placer et al., 2004), which forms the south-western border of the Istra-Friuli Thrust-Underthrust Zone, are important. The subsea structure is shown in the articles by Carulli (2006; 2011), Busetti et al. (2010a; 2010b; 2012; 2013), Trobec et al. (2017), and Novak et al. (2020).

The findings of the aforementioned research are shown in Figure 1 within the structure of this part of the Dinarides.

When studying the geomorphology of the Istra Pushed Area, it was shown that the movement of the Istra block caused not only lateral faulting, but also contraction of the Dinarides. Thus, the folds folded more intensively, and the blocks adapted to the contraction by moving along the existing discontinuities. Therefore, it is necessary to solve the structure of geological objects within the Pushed Area in two stages: firstly, the structural geometry in the Paleogene at the end of thrusting must be determined, and then the successive deformations that occurred during the phase of Neogene-recent thrusting according to the Paleogene structural pre-set. Among the studied features, e.g. Kras (Trieste-Komen

istrsko-furlanske podrivne cone, je bilo v Istri ugotovljeno z reambulacijo nivelmanov (Rižnar et al., 2007).

Istra je vidni del istrskega bloka, razdeljena na južnoistrski in severnoistrski strukturni klin (sl. 1). Po ugotovljenih smereh gibanja in vzporednih deformacijah, naj bi se južnoistrski strukturni klin premikal proti Dinaridom hitreje od severnega.

Zgoraj omenjene temeljne ugotovitve so vzpodbudile vrsto usmerjenih raziskav: z meritvami GPS je bilo dokazano recentno premikanje Istre proti Dinaridom (Weber et al., 2010), intenzivnejše premikanje konice južnoistrskega strukturnega klina proti Dinaridom je bilo potrjeno z meritvami lokalne rotacije magnetnih polov v jamskih sedimentih, ki ležijo v narivnih enotah Dinaridov (Vrabec et al., 2018), raziskani so bili veliki subrecentni gravitacijski pojavi v območju istrskega potisnega območja (Placer et al., 2021a), natančneje je bila raziskana sesljanska upogibna cona (Placer et al., 2021b). Objave o seizmiki obravnavanega prostora tu niso zajete.

Geofizikalne raziskave podmorja Tržaškega zaliva so pokazale, da se kartirane strukture iz Istre nadaljujejo proti severozahodu. V tem smislu so pomembni članki, ki so bili objavljeni po odkritju Buzetskega nariva (Placer et al., 2004), ki tvori jugozahodno mejo istrsko-furlanske podrivne cone. Zgradbo podmorja prikazujejo članki Carulli-ja (2006; 2011), Busetti-jeve in sodelavcev (2010a; 2010b; 2012; 2013), Trobčeve in sodelavcev (2017) in Novakove in sodelavcev. (2020).

Ugotovitve omenjenih raziskav so v okviru zgradbe tega dela Dinaridov prikazane na sliki 1.

Pri proučevanju geomorfologije istrskega potisnega območja se je pokazalo, da premikanje istrskega bloka ni povzročilo le bočne usločitve, temveč tudi krčenje Dinaridov. Tako so se gube intenzivneje nagubale, bloki pa so se krčenju prilagodili s premiki po obstoječih diskontinuitetah. Zato je potrebno zgradbo geoloških objektov znotraj potisnega območja reševati dvostopenjsko, najprej je treba določiti strukturno geometrijo v paleogenu ob koncu narivanja, potem pa nasledstvene deformacije, ki so nastale v fazi neogensko-recentnega potiskanja po paleogenskem strukturnem predrisu. Izmed proučenih objektov, npr. Krasa (Tržaško-Komenskega antiklinorija), Škocjanskih jam, Brkinov (Brkinskega sinklinorija) ali Čičarije (Čičarijskega antiklinorija), po kompleksnosti dogajanja izstopa osameli hrbet Vremščice (1027 m). V tej razpravi je opisano zaporedje deformacij, ki je privedlo do nastanka omenjenega hrbta.

Anticlinorium), Škocjan caves, Brkini (Brkini Synclinorium) or Čičarija (Čičarija Anticlinorium), the isolated ridge of Mt. Vremščica (1027 m) stands out in terms of complexity. This discussion describes the sequence of deformations that led to the formation of the aforementioned ridge.

Instead of the term Istra-Friuli Underthrust Zone, the term Istra-Friuli Thrust-Underthrust Zone is used in this discussion, which better illustrates the role of this zone in the process of Paleogene thrusting and Neogene-recent underthrusting.

The structural geometry, kinematics, and geomorphology of Istra

The visible part of Istra consists of the South Istra (A_1) and North Istra Structural Wedges (A_2), which rest on the Istra-Friuli Thrust-Underthrust Zone (Fig. 1). Due to the movement of this part of Microadria, and thus also Istra, both units behave differently towards the Dinarides, so it makes more sense to name them according to their dynamic characteristics. Thus, we introduce the terms South Istra Pushed Wedge and North Istra Extrusion Wedge (Fig. 2): the first moves with its tip towards the Dinarides, while the other is being extruded to the northwest towards the Gulf of Trieste. Both of them created corresponding structural and resulting geomorphological forms. The boundaries of the two dynamic units are not entirely identical to their formal structural boundaries on the surface, so the designation Ad_1 is introduced for the South Istra Pushed Wedge, and Ad_2 for the North Istra Extrusion Wedge.

South Istra Pushed Wedge Ad_1

The South Istra Structural Wedge is bounded by the Buje reverse Fault in the north, and in the east by the Kvarner Fault and the segment of the outer boundary of the Istra-Furlania Thrust-Underthrust Zone between the Kvarner and Buje Faults. It is built of Jurassic, Cretaceous, Paleocene, and Eocene carbonate rocks and Eocene clastics. The bedding forms a gently buckled anticline, the axis of which plunges very gently to the east-northeast, but its direction is impossible to determine precisely because the dip of the bedding is so low. Given the location of the anticline between the Buje and Kvarner Faults, where the main geomorphological object is the Limska draga (Lim channel/dry valley), it is called the Lim Anticline. It should not be confused with the north–south trending West Istra Anticline, which lies offshore, west of Istra. The Lim Anticline is discussed in more detail later.

A closer examination of the structural wedge boundaries showed that the reverse Buje Fault

Namesto izraza istrsko-furlanska podrivna cona, je v tej razpravi uporabljen izraz istrsko-furlanska narivno-podrivna cona, ki bolje ponazarja vlogo te cone v procesu paleogenskega narivanja in neogensko-recentnega podrivanja.

Strukturna geometrija, kinematika in geomorfologija Istre

Vidni del Istre sestavljata južnoistrski (A_1) in severnoistrski strukturni klin (A_2), ki se naslanjata na istrsko-furlansko narivno-podrivno cono (sl. 1). Obe enoti se zaradi premikanja tega dela Mikroadrije, in s tem tudi Istre, proti Dinaridom, obnašata različno, zato ju je smiselneje imenovati tudi po njunih dinamskih značilnostih, tako uvajamo termina južnoistrski potisni klin in severnoistrski iztisni klin (sl. 2), prvi se s konico premika proti Dinaridom, drugi pa se iztiska (izriva) na severozahod proti Tržaškemu zalivu. Oba sta pri tem ustvarila ustrezne strukturne in iz njih izhajajoče geomorfološke oblike. Meje obeh dinamičnih enot niso povsem identične z njunimi formalnimi strukturnimi mejami na površini, zato je za južnoistrski potisni klin uvedena oznaka Ad_1 , za severnoistrski iztisni klina pa Ad_2.

Južnoistrski potisni klin Ad_1

Južnoistrski strukturni klin je na severu omejen z Bujskim reverznim prelomom, na vzhodu pa s Kvarnerskim prelomom in segmentom zunanje meje istrsko-furlanske narivno-podrivne cone med Kvarnerskim in Bujskim prelomom. Zgrajen je iz karbonatnih kamnin jurske, kredne, paleocenske in eocenske starosti ter iz eocenskih klastitov. Plasti tvorijo rahlo usločeno antiklinalo, katere os zelo blago tone proti vzhodu do severovzhodu, vendar je njeno smer natančneje nemogoče določiti, ker je vpad plasti majhen. Glede na lego antiklinale med Bujskim in Kvarnerskim prelomom, kjer je glavni geomorfološki objekt Limska draga, jo imenujemo Limska antiklinala. Menimo, da je ne smemo zamenjevati z Zahodnoistrsko antiklinalo, ki leži v podmorju zahodno od Istre v smeri sever-jug. Limska antiklinala bo natančneje obravnavana pozneje.

Natančnejši pregled mej strukturnega klina je pokazal, da Bujski reverzni prelom ne kaže znakov sekundarnega premikanja, vendar ga na zahodu seka Zambratijski prelom in več njemu vzporednih za katere domnevamo, da naprej proti vzhodu-jugovzhodu potekajo južno od Bujskega preloma. Zambratijski prelom ima vidne horizontalne drse (sl. 2, točka 1; sl. 5/1) iz

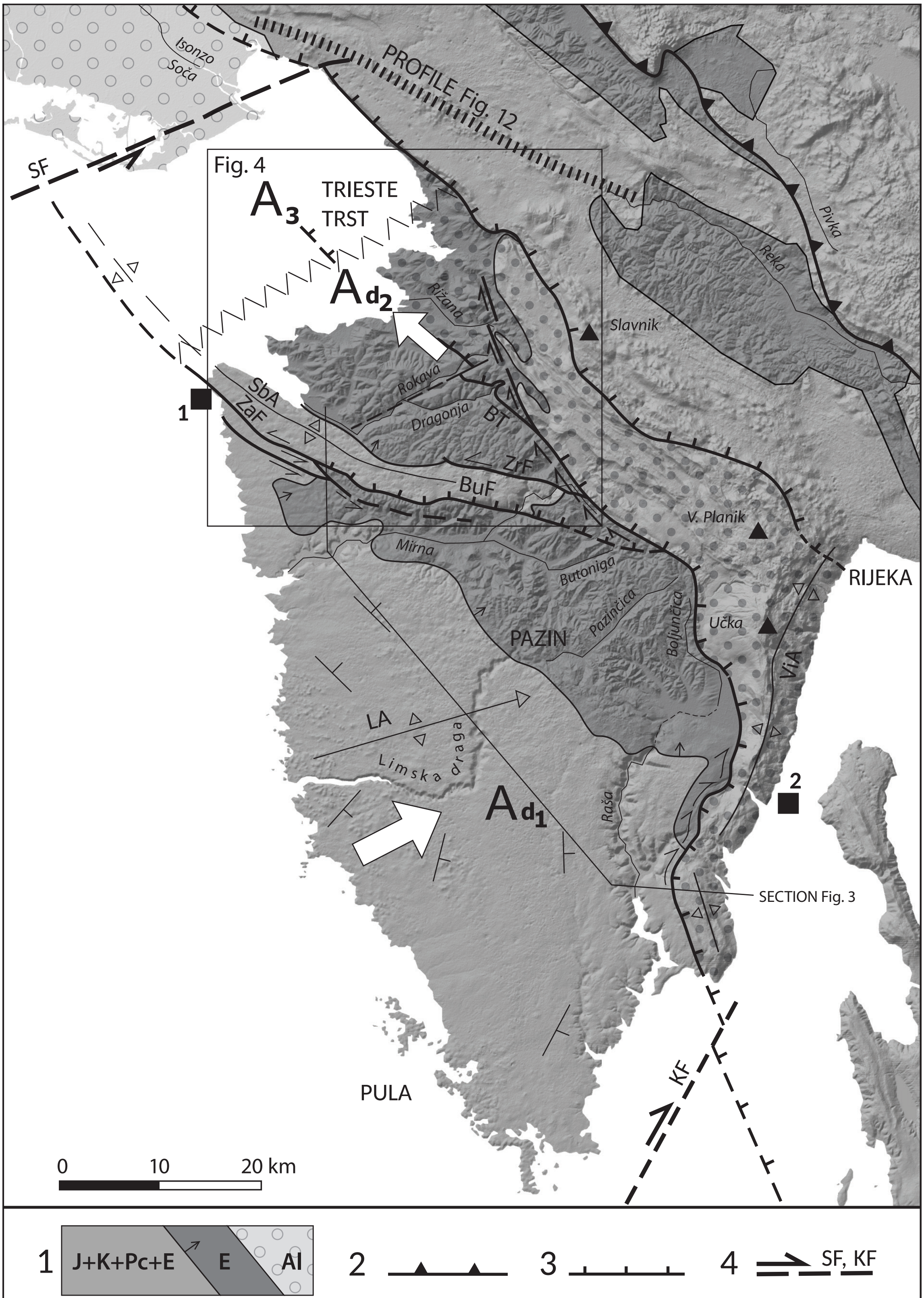


Fig. 2. Istra structural sketch and hydrographic network.

Sl. 2. Strukturna skica Istre in hidrografska mreža.

shows no signs of secondary movement, but it is cut in the west by the Zambratija Fault and several parallel ones, for which we assume continue south of the Buje Fault to the east-southeast. The Zambratija Fault has visible horizontal slickensides (Fig. 2, point 1; Fig. 5/1), from which it was not possible to determine the direction of the movement. It was determined on the basis of the rotation of the paleomagnetic poles in the vicinity of the fault, from which it indirectly follows that it is a left lateral strike-slip fault (Placer et al., 2010, fig. 4). The reverse Buje Fault did not become a left-lateral strike-slip, probably due to its uneven horizontal cross-section, which is manifested in a large bulge-like protrusion north of the lower Mirna River, which inhibited its movement. The Istra-Friuli Thrust-Underthrust Zone is morphologically strongly expressed in eastern Istra and runs almost parallel to the eastern Istrian coast, and thus also parallel to the Kvarner Fault. From the viewpoint above the Flanona Hotel in Plomin (Fig. 2, point 2), a south-easterly dipping fault plane (110/30) with prominent subhorizontal slickenides (Fig. 5/2), indicating dextral strike-slip (Placer et al., 2010, fig. 4) were found. It is obviously a Paleogene thrust plane rotated clockwise along the right strike-slip Kvarner Fault in the Neogene and then transformed into a strike slip fault plane. From these facts follows that the left-lateral strike-slip Zambratija Fault and several parallel ones formed next to the reverse Buje Fault, from which the left-lateral strike-slip Zambratija Zone was formed. Along the right-lateral strike-slip Kvarner Fault, the Istra-Friuli Thrust-Underthrust Zone bent to the south-southwest and became parallel to

katerih pa ni bilo mogoče ugotoviti smisla premika, ta je bil določen na podlagi rotacije paleomagnetnih polov v bližini preloma iz česar posredno izhaja, da gre za levo zmikanje (Placer et al., 2010, sl. 4). Bujski reverzni prelom ni postal levozmični verjetno zato, ker mu je to preprečeval njegov neravni horizontalni presek, ki se kaže v veliki trebušasti izboklini severno od spodnje Mirne. Istrsko-furlanska narivno-podrivna cona je v vzhodni Istri morfološko močno izražena in poteka skoraj vzporedno z vzhodno obalo Istre, s tem pa tudi s Kvarnerskim prelomom. Na razgledišču nad hotelom Flanona v Plominu (sl. 2, točka 2) je bila odkrita ploskev v smeri 110/30 z izrazitimi subhorizontalnimi drsami (sl. 5/2), ki kažejo na desno zmikanje (Placer et al., 2010, sl. 4). Očitno gre za paleogensko narivno ploskev, ki je bila v neogenu ob desnozmičnem Kvarnerskem prelomu zasukana v smeri urinega kazalca in nato transformirana v zmično ploskev. Iz dejstev torej izhaja, da je ob Bujskem reverznem prelomu nastal Zambratijski levozmični prelom in nekaj njemu vzporednih, iz katerih se je oblikovala zambratijska levozmična cona. Ob Kvarnerskem desnozmičnem prelomu se je istrsko-furlanska narivno-podrivna cona upognila proti jugo-jugozahodu in se postavila vzporedno s prelomom. Nastala je kombinirana kvarnerska desnozmična cona.

Da obstaja južnoistrski potisni klin potrjujejo tudi podatki paleomagnetnih raziskav jamskih sedimentov v Čičariji, ki kažejo na levo in desno krajevno omejeno rotacijo enot istrsko-furlanske narivno-podrivne cone. Konica klina je delovala

1 J + K + Pc + E – Jurassic, Cretaceous, Paleocene, and Eocene carbonates, E – Eocene flysch, Al – aluvium. Bedding strike and dip / J + K + Pc + E – jurski, kredni, paleocenski in eocenski karbonati, E – eocenski fliš, Al – aluvij. Vpad plasti

2 External Dinaric Thrust Belt boundary / meja Zunanjedinarskega narivnega pasu

3 Thrust plane within Dinaric thrust boundary: BuF – reverse Buje Fault, BT – Buzet Thrust / nariv v coni narivne mejne Dinaridov: BuF – Bujski reverzni prelom, BT – Buzetski narivni prelom

4 Strike-slip fault in the Microadria area: SF – Sistiana Fault, KF – Kvarner Fault / zmični prelom v območju Mikroadrije: SF – Sesljanski prelom, KF – Kvarnerski prelom

5 Lateral strike-slip faults: ZaF – Zambratija Fault, ZrF – Zrenj Fault / zmični prelomi: ZaF – Zambratijski prelom, ZrF – Zrenjski prelom

6 Istra-Friuli Thrust-Underthrust Zone / istrsko-furlanska narivno-podrivna cona

7 Neogene-recent right lateral strike-slip movements in the Paleogene thrust zone / desnozmični neogensko-recentni premiki v paleogenski narivni coni

8 Right lateral strike-slip fault in the Črni Kal Anomaly / desnozmični prelom v črnokalski anomaliji

9 Anticlines: LA – Lim Anticline, SbA – Savudrija-Buzet Anticline, ViA – East Istra Anticline / antiklinale: LA – Limska antiklinala, SbA – Savudrijsko-Buzetska antiklinala, ViA – Vzhodnoistrska antiklinala

10 Profile in Fig. 12 / Profil na sl. 12

11 North Istra Extrusion Wedge extrusion boundary / meja iztiskanja severnoistrskega iztisnega klina

12 Istra block: Ad1 – South Istra Pushed Wedge, Ad2 – North Istra Extrusion Wedge, A3 – Trieste parallelepiped / istrski blok: Ad1 – južnoistrski potisni klin, Ad2 – severnoistrski iztisni klin, A3 – tržaški paralelepiped

13 Observed evidence of strike-slip movement: 1 – Zambratija, 2 – Flanona / mesta vidnih dokazov zmikanja: 1 – Zambratija, 2 – Flanona

14 Strike–slip in the section in Fig. 3: left lateral strike-slip, right lateral strike-slip / zmični premik v profilu na sl. 3: levozmični prelom, desnozmični prelom

15 General direction of pushing, extrusion / generalna smer potiskanja, iztiskanja

the fault. Thus, a combined right-lateral strike-slip Kvarner Zone was formed.

The existence of the South Istra Pushed Wedge is also confirmed by the data from paleomagnetic research of the cave sediments in Čičarija, which indicate left and right locally limited rotation of the units of the Istra-Friuli Thrust-Underthrust Zone. The tip of the wedge worked so that the thrust units in front of it bent, with some rotating to the left and some to the right (Vrabec et al., 2018).

The structure of the South Istra Pushed Wedge is given in the sketch of the Lim Anticline cross-section in Figure 3, where the simplified structures of the Zambratija and Kvarner shear zones, and the Lim Anticline with the dry Limska draga are presented in dark hatch, and the surface flows of Mirna River with Butoniga and Raša River with Boljunčica are present in the anticline limbs. The reverse Buje Fault abuts on the Zambratija Fault at depth, with its left-lateral movement related to the Zambratija Fault or to its zone. The Kvarner Fault abuts on the outer border of the Istra-Friuli Thrust-Underthrust Zone, with dextral displacement along the Kvarner Fault and along the transformed segment of the Istra-Friuli Thrust-Undrethrust Zone.

We cannot yet speak more precisely about the age of the individual structural elements and geomorphology of the South Istra Pushed Wedge, but we can determine the sequence of their formation. There was no deposition in Istra in the Oligocene (Basic Geological Map - OGK sheets: Trieste, Ilirska Bistrica, Rovinj, Labin, Pula, Cres), so we assume that the area rose to the surface at the beginning of the Oligocene and a period of erosion

tako, da so se narivne enote pred njo upognile, del se je zasukal v levo, del pa v desno (Vrabec et al., 2018).

Zgradba južnoistrskega potisnega klina je podana v skici prečnega prereza Limske antiklinale na sliki 3, tu se vidi poenostavljeni strukturi zambratijske in kvarnerske zmične cone, Limsko antiklinalo s suho Limsko drago v temenu in površinska tokova Mirne z Butonigo in Raše z Boljunčico v krilih gube. Na Zambratijski prelom se v globini naslanja Bujski reverzni prelom, levozmični premik je vezan na prvega, oziroma na njegovo cono. Kvarnerski prelom se naslanja na zunanjo mejo istrsko-furlanske narivno-podrivne cone, desnozmični premik se dogaja ob Kvarnerskem prelomu in ob transformiranem segmentu istrsko-furlanske narivno-podrivne cone.

O starosti posameznih elementov strukture in geomorfologije južnoistrskega potisnega klina še ne moremo natančneje govoriti, lahko pa določimo zaporedje njihovega nastajanja. V Istri niso bile odložene oligocenske plasti (OGK, listi: Trst, Ilirska Bistrica, Rovinj, Labin, Pula, Cres), zato domnevamo, da se je v začetku oligocena območje dvignilo na površje in pričelo se je obdobje erozije v katerem se je izoblikovala primarna rečna mreža. Pričetek premikanja Mikroadrije proti Dinaridom še ni natančneje določen, domnevamo, da se je začelo v srednjem miocenu, kljub temu pa lahko razpravljamo o zaporedju dogodkov. Zaradi napredovanja klina med konvergentnima prelomoma (Kvarnerski prelom, Zambratijski prelom) proti severo severovzhodu je pričela rasti Limska

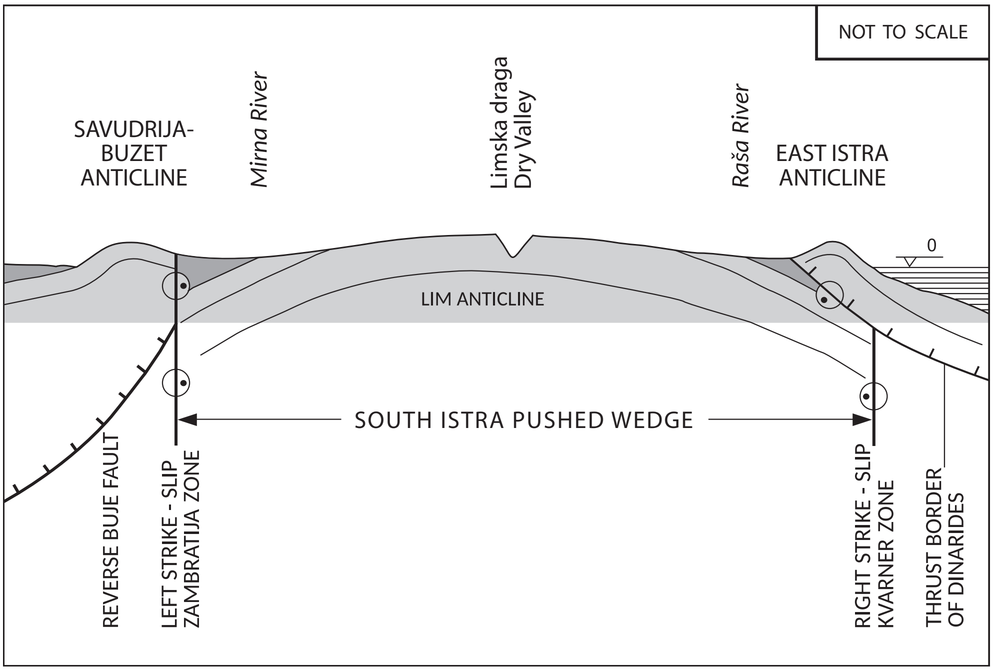


Fig. 3. Lim Anticline transversal cross section. Cross section trace in Figure 2. *Legend in Figure 2.*

Sl. 3. Skica prečnega profila Limske antiklinale. Potek profila na sl. 2. *Legenda na sliki 2.*

began, during which the primary river network (was) formed. The beginning of the Microadria movement towards the Dinarides is not yet precisely determined. It is assumed that it started in the middle Miocene; however, we can discuss the sequence of events. Due to the progress of the wedge between the convergent faults (Kvarner Fault, Zambratija Fault) towards the north-northeast, the Lim Anticline began to grow, and the Paleo-Mirna and Paleo-Raša flows, which were directed along the thrust wedge shear boundaries, submitted to its geometry. The Paleo-Pazinčica River flow, however, remained trapped in the crest of the anticline where it carved a deep valley. The karst surface peneplanation of southern Istra is today slightly buckled, as its uplift along the anticline axis was faster than the erosion of the Paleo-Pazinčica, which is why it retreated underground. The process of formation of the current geomorphological image of the South Istra Pushed Wedge was either continuous or multi-stage, but without detailed research it is impossible to determine this.

The South Istra Pushed Wedge geometry and dynamics are also strengthened by the springs of the most important rivers at its tip, Mirna and Butoniga rivers, Raša with its former tributary the Boljunčica river, and Pazinčica.

In the immediate hinterland of the pushed wedge tip is the highest peak of Čičarija, Mt. Veliki Planik (1272 m). Nearby is Mt. Vojak (1394 m), Mt. Učka's peak, which lies in the East Istra Anticline. It was formed from multiple structural units as a consequence of Paleogene thrusting and subsequent Neogene to recent movements along the Kvarner Fault.

North Istra Extrusion Wedge Ad_2

Formally, the North Istra Structural Wedge (Figs. 2 and 4A) is a unit between the reverse Buje Fault (BuF) and the Istra-Friuli Thrust-Underthrust Zone, more precisely the Buzet thrust Fault (BT), along its south-western border. The reverse Buje Fault lies under the Istra-Friuli Thrust-Underthrust Zone in the Buzet area. This point formally represents the tip of the wedge. The North Istra Structural Wedge is built of Cretaceous, Paleocene, and Eocene carbonates overlain by Eocene clastites; carbonates are exposed in the Savudrija-Buzet Anticline, which is an accompanying structure of the reverse Buje Fault, and in the tectonic window or half-window at Izola, which is an accompanying structure of the Križ Thrust (KT). The flysch beds plunge below the Istra-Friuli Thrust-Underthrust Zone.

antiklinala, njeni geometriji sta se podredila tokova paleo-Mirne in paleo-Raše, ki sta se usmerila vzdolž zmičnih meja potisnega klina, tok paleo-Pazinčice pa je ostal ujet v temenu antiklinale kjer je urezoval globoko dolino. Kraška uravnava južne Istre je danes rahlo usločena, njeno dviganje je bilo v osi antiklinale hitrejše od erozije paleo-Pazinčice, zato se je ta umaknila v podzemlje. Proces nastajanja sedanje geomorfološke podobe južnoistrskega potisnega klina je bil ali kontinuiran ali večstopenjski, brez detajlnih raziskav tega ni mogoče ugotoviti.

Geometrijo in dinamiko južnoistrskega potisnega klina utrjujejo tudi izviri pomembnejših rek v njegovi konici, Mirne in Butonige, Raše z nekdanjim pritokom Boljunčico in Pazinčice.

V neposrednem zaledju konice potisnega klina se nahaja najvišji vrh Čičarije, Veliki Planik (1272 m). V bližini je vrh Učke, Vojak (1394 m), ki pa leži v Vzhodnoistrski antiklinali. Ta je sestavljena iz več strukturnih enot in je nastala v prepletu učinkov paleogenskega narivanja in neogensko-recentnih premikov ob Kvarnerskem prelomu.

Severnoistrski iztisni klin Ad_2

Severnoistrski strukturni klin (sl. 2 in 4A) je v formalnem smislu enota med Bujskim reverznim prelomom (BuF) in istrsko-furlansko narivno-podrivno cono, natančneje Buzetskim narivnim prelomom (BT), ki leži na njeni jugozahodni meji. Na območju Buzeta leži Bujski reverzni prelom pod istrsko-furlansko narivno--podrivno cono. Ta točka formalno predstavlja konico klina. Severnoistrski strukturni klin je zgrajen iz krednih, paleocenskih in eocenskih karbonatov, ki jih prekrivajo eocenski klastiti; karbonati izdanjajo v Savudrijsko-Buzetski antiklinali, ki je spremljajoča struktura Bujskega reverznega preloma in v tektonskem oknu ali poloknu v Izoli, ki je spremljajoča struktura Križnega narivnega preloma (KT). Flišne plasti tonejo pod istrsko-furlansko narivno-podrivno cono.

V dinamičnem smislu je južna meja severnoistrskega iztisnega klina identična s severno mejo južnoistrskega potisnega klina, obstaja pa možnost, da je poleg zambratijske levozmične cone levozmično aktiven tudi Zrenjski prelom na severni strani Savudrijsko-Buzetske antiklinale. Severovzhodna meja severnoistrskega iztisnega klin pa ni identična z Buzetskim narivnim prelomom, temveč poteka poševno na do 12 km široko istrsko-furlanske narivno-podrivne cono, In a dynamic sense, the southern border of the North Istra Extrusion Wedge is identical to the northern boundary of the South Istra Pushed Wedge, but there is a possibility that, in addition to the strike-slip Zambratija Zone, the Zrenj Fault on the north side of the Savudrija-Buzet Anticline is active as well. The north-eastern border of the North Istra Extrusion Wedge is not identical to the Buzet Thrust, but runs obliquely to the 8 to 12 km-wide Istra-Friuli Thrust-Underthrust Zone, approximately from the upper Mirna to the lower Glinščica/Rosandra rivers in a SSE-NNW direction. This boundary is not represented by only one structural element, but rather by a complex fault zone in which subvertical faults in the SSE-NNW direction are the most important (Figs. 2 and 4A).

Before describing the zone between the upper Mirna and lower Glinščica/Rosandra rivers, let's look at the most important signs of lateral thrusting within the North Istra Extrusion Wedge (Figs. 2 and 4A). The most important is the normal Rokava Fault, which runs transversely to the wedge and indicates the direction of extrusion towards the Gulf of Trieste. The middle Dragonja and Rokava valleys were formed along the Rokava Fault (Placer et al. 2004; Placer, 2005). A large part of the upper Dragonja valley also runs transversely to the extrusion

približno od zgornje Mirne do spodnje Glinščice v smeri SSE-NNW. Te meje ne predstavlja le en element strukture, temveč kompleksna prelomna cona v kateri so najpomembnejši deznozmični subvertikalni prelomi v smeri SSE-NNW (sl. 2 in 4A).

Preden opišemo cono med zgornjo Mirno in spodnjo Glinščico, si oglejmo najpomembnejše znake bočnega izrivanja znotraj severnoistrskega iztisnega klina (sl. 2 in 4A); na prvem mestu je Rokavin normalni prelom, ki poteka prečno na klin in kaže na smer iztiskanja proti Tržaškemu zalivu. Po njem sta se izoblikovali dolini srednje Dragonje in Rokave (Placer et al., 2004; Placer, 2005). Prečno na iztisni klin poteka tudi večji del doline zgornje Dragonje in pa številne doline potokov, ki med srednjo Dragonjo in Bračano ponikajo v apnencu Savudrijsko-Buzetske antiklinale. Prečno na klin teče tudi srednja Mirna preko Savudrijsko-Buzetske antiklinale. Severozahodno od Rokavinega preloma ne prevladujejo več prečne doline, tu so spodnja Dragonja, Drnica, Badaševica, Rižana in Osapska reka poglobile svoje struge po drugih elementih strukture. Glede na to izgleda, da se je severozahodni del klina iztisnil kot sorazmerno homogen blok.

Fig. 4. North Istra Extrusion Wedge: A. North Istra structural sketch (updated and symplified after Placer, 2005, Fig. 1; 2007, Fig. 2; Placer et al., 2010, Fig. 5). B. Neogene to recent extrusion evidence in the northern Istra relief.

Sl. 4. Severnoistrski iztisni klin: A. Strukturna skica severne Istre (dopolnjeno in poenostavljeno po Placer, 2005, sl. 1; 2007, sl. 2; Placer et al., 2010, sl. 5). B. Znaki neogensko-recentnega iztiskanja v reliefu severne Istre.

1 K + Pc + E – Cretaceous, Paleogene and Eocene carbonates, E – Eocene flysch. Bedding strike and dip / 1 K + Pc + E – kredni, paleocenski in eocenski karbonati, E – eocenski fliš. Vpad plasti

2 Paleogene reverse and thrust faults: BuF – reverse Buje Fault, BT – Buzet Thrust KT – Križ Thrust IT – Izola Thrust / paleogenski reverzni in narivni prelomi: BuF – Bujski reverzni prelom, BT – Buzetski narivni prelom, KT – Križni narivni prelom, IT – Izolski narivni prelom

3 Paleogene backthrust fault (Strunjan structure) / paleogenski povratni reverzni prelom (Strunjanska struktura)

4 Neogene-recent reverse fault / neogensko-recentni podrivni reverzni prelom

5 Istra-Friuli Thrust-Underthrust Zone / istrsko-furlanska narivno-podrivna cona

6 Larger sub-vertical fault with prevailing strike-slip component, extrusion boundary: proved ZaF – Zambratija Fault, inferred ZrF – Zrenj Fault / večji subvertikalni prelom s prevladujočo zmično komponento, meja iztiskanja: dokazano ZaF – Zambratijski prelom, domnevno ZrF – Zrenjski prelom

7 Right lateral strike-slip faults in the Črni Kal Anomaly zone, extrusion boundary: 3 – Gračišče series, 4 – Kastelec series / desnozmični prelomi v območju črnokalske anomalije, extrusion boundary: 3 – gračiški niz, 4 – kastelski niz

8 Right lateral offset in the Neogene to recent underthrust reverse fault, extrusion boundary / desnozmični premik v ploskvi neogenskega do recentnega podrivnega reverznega preloma, meja iztiskanja

9 Normal fault. Proved, inferred: RoF – Rokava Fault / normalni prelom. Ugotovljen, domneven: RoF – Rokavin prelom

10 Extensional crack (Gračišče) / ekstenzijska razpoka (Gračišče)

11 Neogene antiformal deformation of the Paleogene thrust plane: a – Glinščica/Rosandra, b – Varda, c – Črni Kal, d – Movraž, e – Perci village near Buzet / v neogenu antiformno deformirane paleogenske narivne ploskve: a – Glinščica, b – Varda, c – Črni Kal, d – Movraž, e – Perci pri Buzetu

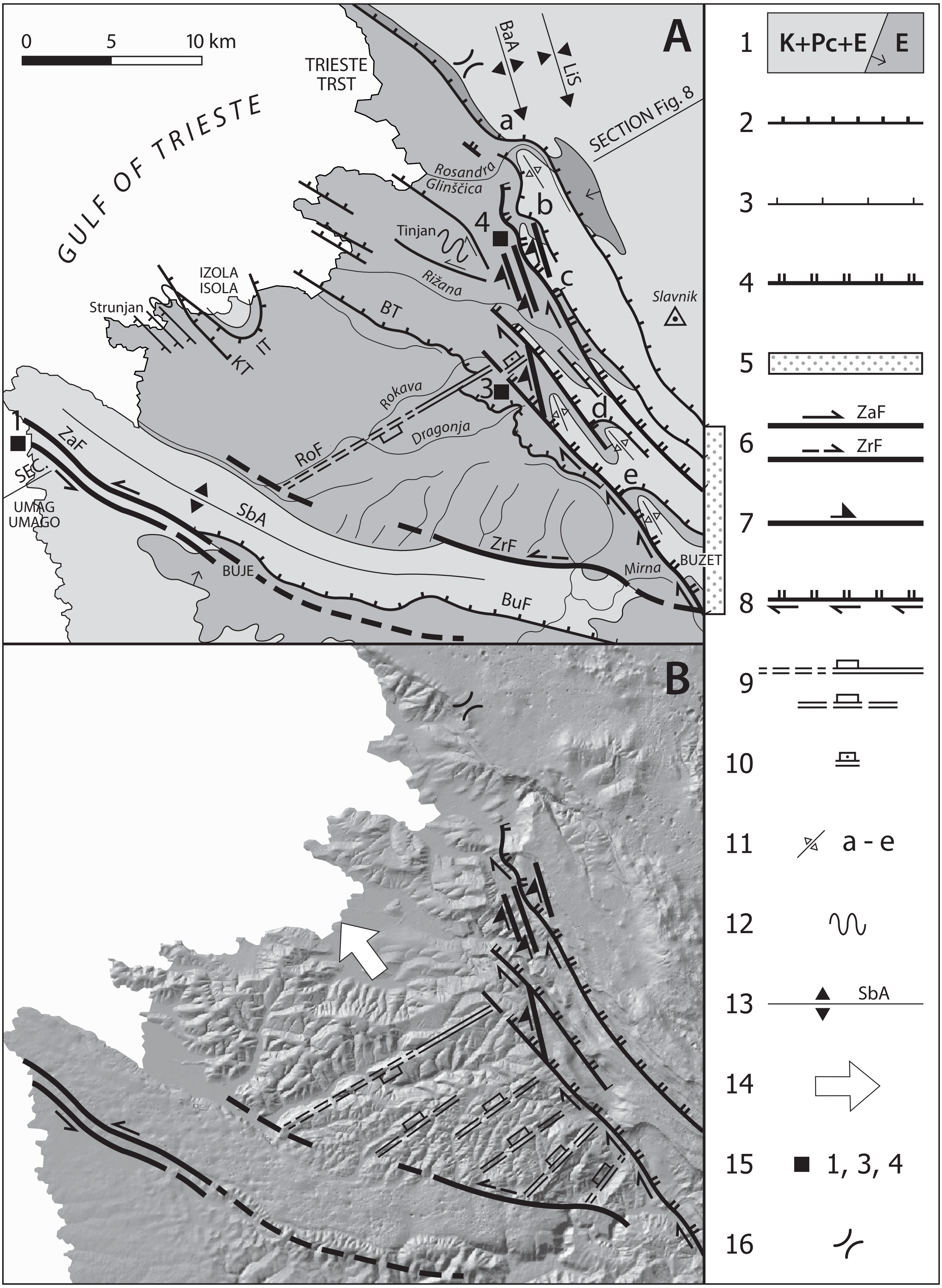
12 Spatialy restricted folds : Strunjan structure, Tinjan structure or Tinjan Extrusion Wedge / gube prostorsko omejenega obsega: strunjanska struktura, tinjanska struktura ali tinjanski iztisni klin

13 Larger folds: SbA – Savudrija-Buzet Anticline, BaA – Bazovica Anticline, LiS – Lipica Syncline / večje gube: SbA – Savudrijsko-Buzetska antiklinala, BaA – Bazovska antiklinala, LiS – Lipiška sinklinala

14 Extrusion direction / smer iztiskanja

15 Extrusion evidence locations: 1 – Zambratija, 3 – Gračišče, 4 – Kastelec / mesta z dokazi iztiskanja: 1 – Zambratija, 3 – Gračišče, 4 – Kastelec

16 A saddle above Trieste between Mt. Mai/Maj and Mt. Mote Calvo/Globojnar at elevation point 416 m / sedlo nad Trstom med Majem (Mai) in Globojnarjem (Monte Calvo) na koti 416 m


A
B
0 5 10 km
GULF OF TRIESTE
TRIESTE
TRST
IZOLA
ISOLA
Strunjan
KT
IT
BT
BaA
LiS
SECTION Fig. 8
Rosandra
Glinščica
Tinjan
Rižana
Slavnik
Rokava
Dragonja
RoF
ZaF
SEC.
UMAG
UMAGO
SbA
BUJE
ZrF
Mirna
BUZET
BuF
a
b
c
d
e
1
3
4
1 K+Pc+E E
2
3
4
5
6 ZaF ZrF
7
8
9
10
11 a - e
12
13 SbA
14
15 1, 3, 4
16

wedge, as well as numerous valleys of streams that sink between the middle Dragonja and Bračana rivers in the limestone of the Savudrija-Buzet Anticline. The middle Mirna also flows transversely across the wedge and the Savudrija-Buzet Anticline. Northwest of the Rokava Fault, transverse valleys no longer dominate: here the lower Dragonja, Drnica, Badaševica, Rižana and Osapska reka rivers have deepened their beds along other structural elements. Based on this, it appears that the north-western part of the wedge was extruded as a relatively homogeneous block.

Now let's take a look at the north-eastern border of the North Istra Extrusion Wedge between the upper Mirna and lower Glinščica/Rosandra rivers. In order to understand the causes of the shear zone formation that runs obliquely in the direction of thrusting, or underthrusting, we need to take a closer look at the Istra-Friuli Thrust-Underthrust Zone structure. In the Čičarija, it consists of several similar structural duplexes. The anticlines in the fronts of duplexes are composed of Paleogene limestone followed by the transitional marl or by flysch in some places. Each duplex is covered by the Pg limestone core of the next duplex of the same structure. The axes of the frontal limestone anticlines regionally plunge towards the northwest, so that in the north-western part of the Istra-Friuli Thrust-Underthrust Zone, the Paleogene limestones are no longer at the surface, but the transitional marl or flysch of the upper duplexes is thrust on the transitional marl and flysch of the lower ones. The described conditions can be seen on the OGK (sheet Trieste), simplified on the tectonic sketch of northern

Oglejmo si zdaj severovzhodno mejo severnoistrskega iztisnega klina med zgornjo Mirno in spodnjo Glinščico. Da bi razumeli vzroke nastanka zmične cone, ki poteka poševno na smer narivanja, oziroma podrivanja, si moramo podrobneje ogledati zgradbo istrsko-furlanske narivno-podrivne cone. Ta je na območju Čičarije sestavljena iz več podobnih narivnih lusk. V njenem jugovzhodnem delu ležijo v čelih lusk čelne antiklinale iz paleogenskega apnenca na katerem ležijo prehodni laporji in ponekod tudi fliš, ki ga prekriva paleogenski apnenec, ki gradi čelo naslednje luske enake zgradbe. Osi čelnih antiklinal iz apnenca regionalno tonejo proti severozahodu, tako da v severozahodnem delu istrsko-furlanske narivno-podrivne cone paleogenski apnenci niso več na površju, temveč je prehodni lapor ali fliš zgornjih lusk narinjen na prehodni lapor in fliš spodnjih lusk. Opisane razmere so vidne na OGK (list Trst), poenostavljeno na tektonski skici severne Istre, kjer je fliš označen s sivim odtenkom (sl. 2 in 4A). Severozahodni boki karbonatnih antiklinal v čelih lusk se na površju izklinjajo v pasu med zgornjo Mirno in spodnjo Glinščico v smeri SSE-NNW, narivne ploskve pa potekajo naprej po flišu proti NW. Potek narivnic v flišu na sliki 4A ni izrisan, temveč le nakazan v bližini morske obale, kjer narivnice praviloma ležijo v dnu zalivov, kar pomeni, da so ti nastali po tektonsko prizadetih conah. Narivnice v flišu med obalo in zmično cono v smeri SSE-NNW niso izrisane zato, ker jih je potrebno detajlno geološko skartirati. Karbonatne antiklinale v čelih lusk med zgornjo Mirno in spodnjo Glinščico

Fig. 5. Structural peculiarities of Istra and Istra-Friuli Thrust-Underthrust Zone.
Sl. 5. Strukturne posebnosti Istre in istrsko-furlanske narivno-podrivne cone.

1 Left-lateral strike-slip Zambratija Fault: sub-horizontal slickensides on the plane 30/90 (Fig. 2, location 1; Fig. 4A, location 1) / Zambratijski levozmični prelom: subhorizontalne drse v ploskvi 30/90 (sl. 2, točka 1; sl. 4A, točka 1)

2 Right-lateral strike-slip Kvarner Zone: right-lateral strike-slip along the plane 110/30, which was primarily parallel to the Dinarides. Above Flanona Hotel near Plomin (town) (Fig. 2, location 2) / kvarnerska desnozmična cona: desno zmikanje v ploskvi 110/30, ki je imela prvotno smer Dinaridov. Nad hotelom Flanona pri Plominu (sl. 2, točka 2)

3 Extensional crack in direction 340/50 at Gračišče (Fig. 4A, location 3) / ekstenzijska razpoka v smeri 340/50 pri Gračišču (sl 4A, točka 3)

4 Fault zone in flysch in direction 50/50 zone of Neogene-recent underthrust reverse faults above Gabrovica village (Fig. 4A, location »c«; Fig. 8, Istra-Friuli Thrust-Underthrust Zone) / prelomna cona v flišu v smeri 50/50 cona neogensko-recentnih podrivnih reverznih prelomov nad Gabrovico (sl. 4A, točka »c«; sl. 8, istrsko-furlanska narivno-podrivna cona)

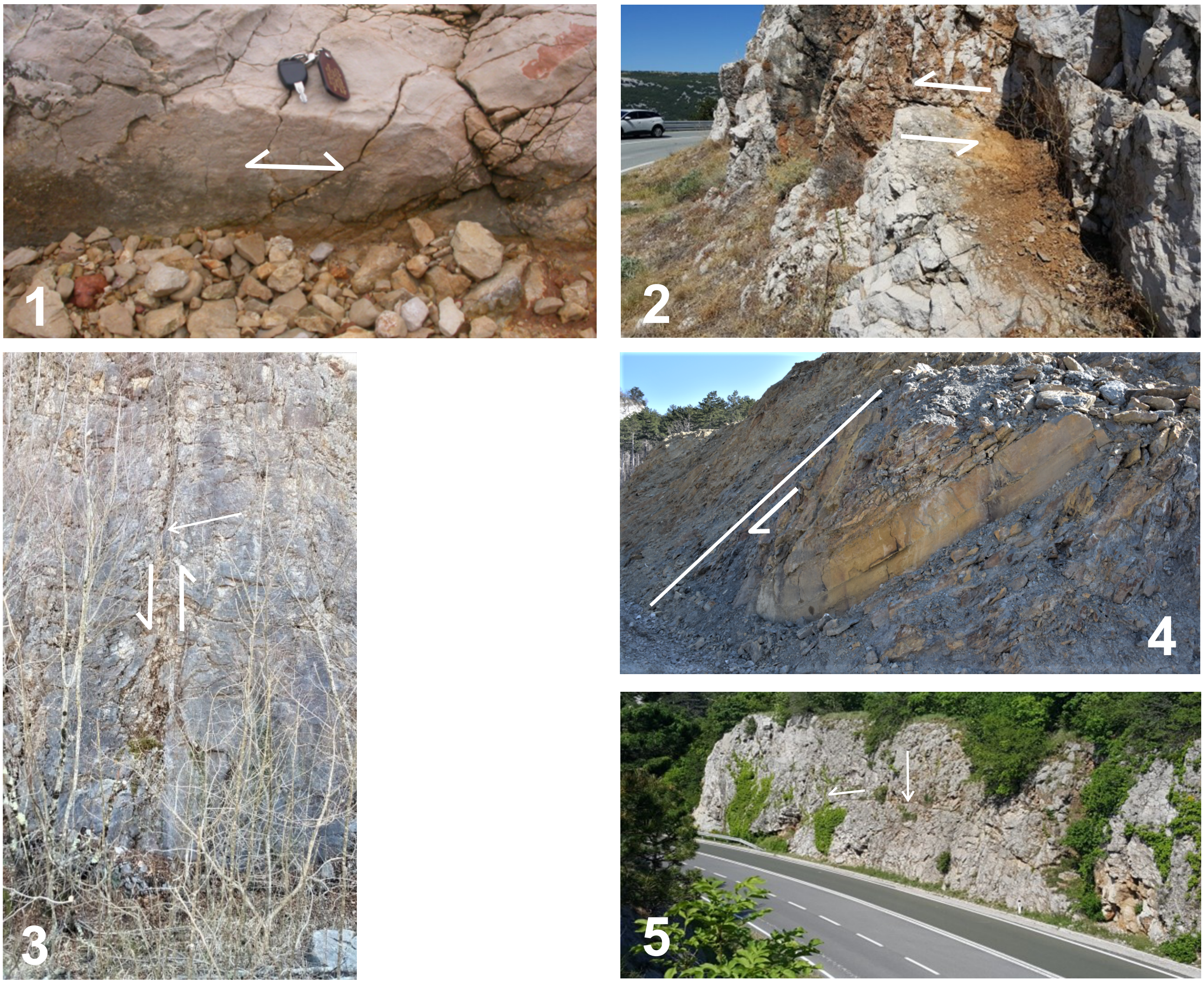
5 Antiformally bent paleogene thrust plane in the Varda road cut (Fig. 4A, location »b«) / antiformno usločena paleogenska narivna ploskev v cestnem useku Varda (sl. 4A, točk »b«

6 Antiformally bent paleogene thrust plane above Movraž village (Fig. 4A, location »d«) / antiformno usločena paleogenska narivna ploskev nad Movražem (sl. 4A, točka »d«)

7 Fault zone in flysch in direction 25/45 Paleogene thrust with stepped oblique cut, Valmarin (Škofije). Structural type of disordered jump (Fig. 7D) / prelomna cona v flišu v smeri 25/45 cona paleogenskega nariva, ki ima stopničasti poševni rez, Valmarin (Škofije). Strukturni tip neurejenega preskoka (sl. 7D)

8 Backthrust in the Strunjan structure in direction 230/60 (Figs. 4A and 8) / povratni reverzni prelom v strunjanski strukturi v smeri 230/60 (sl. 4A in 8)

9 Transverse folding in the Tinjan Extensional Wedge. Axial planes in direction 310/90 .Construction cave for the water reservoir at Slatine village (Fig. 4A, location 4) / prečno gubanje v tinjanskem iztisnem klinu. Osna ravnina gub v smeri 310/90 Izkop za vodohran v Slatinah (sl. 4A, točka 4)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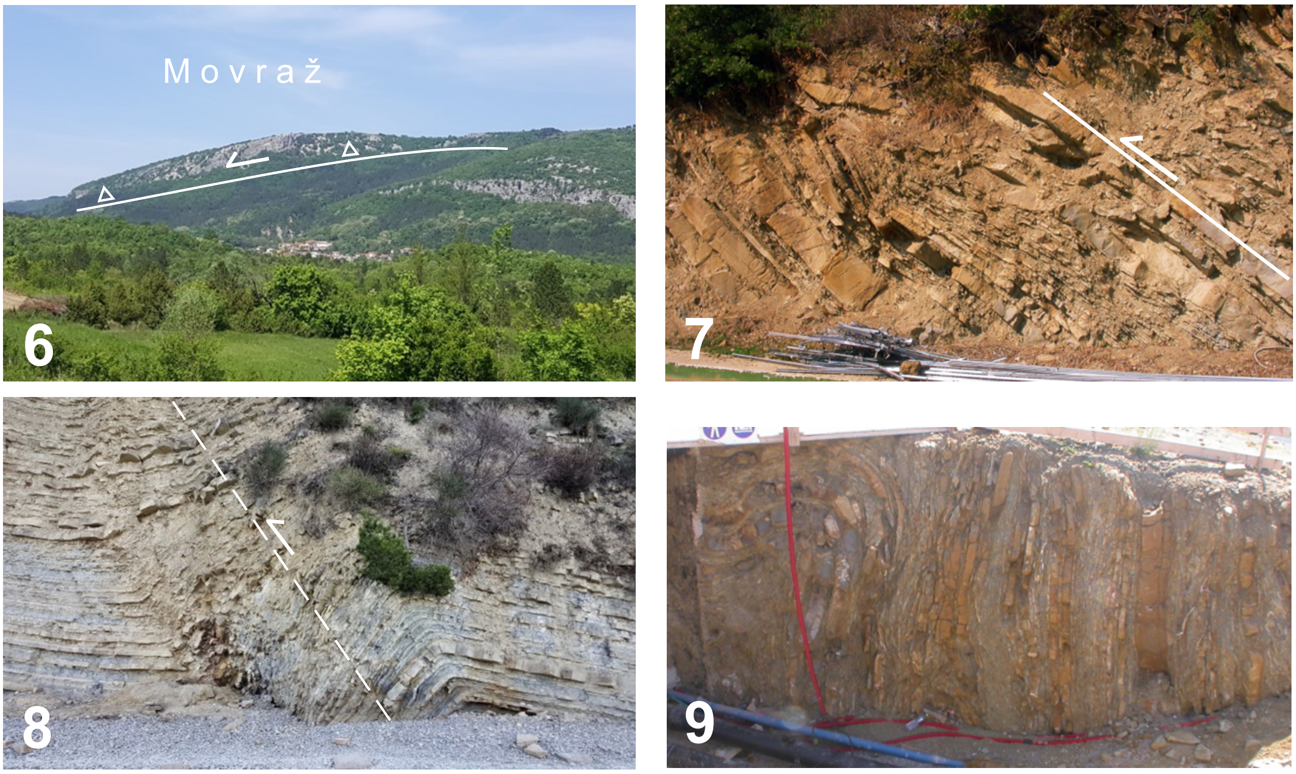
Movraž
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Istra, where the flysch is marked with a grey hatch (Figs. 2 and 4A). The north-western flanks (if a simple fold is determined e.g. by the northern and the southern limbs and an axial plane between them we are missing the term to describe the western and the eastern part of the fold. As there is no adequate term for these in the literature, a term flank is used here. Flank and limb should therefore not be interchangeable terms) of the carbonate anticlinesin the fronts of the duplexes pinch out on the surface in the SSE-NNW trending belt between the upper Mirna and the lower Glinščica/Rosandra, and the thrust planes continue in flysch towards the NW. The course of the thrusts in the flysch in Fig. 4A is not drawn, but only indicated near the sea coast, where thrust planes generally lie at the bottom of bays, which means that they were formed along tectonically affected zones. Thrusts in the flysch between the coast and the shear zone in the SSE-NNW direction are not fully drawn because they need to be geologically mapped in detail. The carbonate anticlines in the fronts of the duplexes between the upper Mirna and the lower Glinščica/Rosandra lie in an echelon series, which in reality represents a wider zone and not just a single set of duplexes.

The north-western edges of the echelon-arranged frontal carbonate anticlines are accompanied by the SSE-NNW trending subvertical right-lateral faults. These were mapped at the highway construction site in two areas (Placer, 2003; 2004): between the lower entrance to the Kastelec tunnel and the upper entrance to the Dekani tunnel (260/90, 250/90, 240/80) (Fig. 4A, point 4) and in the vicinity of Gračišče, where a fault (70/80) was measured, otherwise without visible slickensides, but in its western flank there are pronounced extensional fractures in the 350-0/70 direction, which indicate extrusion towards the north-northwest (Fig. 4A, point 3; Fig. 5/3). These two groups are referred to as the Kastelec and Gračišče sets of right-lateral strike-slip faults throughout the article. To understand their meaning, let's look at the structural analysis of the relationship between these faults and the thrust duplexes of the Istra-Friuli Thrust-Underthrust Zone, with frontal anticlines composed of Paleogene limestone and Eocene flysch in the Figure 6. In the analysis, we proceed from the idealized echelon arrangement of duplexes and frontal anticlines (Fig. 6A), where in the ground plane the edges of the Paleogene limestone anticlines are connected to form an envelope »e«, which runs in a 340° direction. This direction was chosen because it illustrates the location of the right-lateral strike-slip

ležijo torej v ešalonskem nizu, ki pa ni linearen, oziroma ne obsega le enega niza lusk, temveč zajema širšo cono.

Severozahodne robove ešalonsko razporejenih čelnih karbonatnih antiklinal spremljajo subvertikalni desnozmični prelomi v smeri SSE-NNW. Ti so bili na delovišču avtoceste kartirani na dveh območjih (Placer, 2003; 2004); med spodnjim vhodom v predor Kastelec in zgornjim vhodom v predor Dekani 260/90, 250/90, 240/80 (sl. 4A, točka 4) in v okolici Gračišča, kjer je bil izmerjen prelom 70/80, sicer brez vidnih drs, toda v njegovem zahodnem krilu nastopajo izrazite ekstenzijske razpoke v smeri 350-0/70, ki kažejo na iztiskanje proti severo-severozahodu (sl. 4A, točka 3; sl. 5/3). V nadaljevanju članka ti dve skupini imenujemo kastelski in gračiški niz desnozmičnih prelomov. Da bi razumeli njihov pomen, si na sliki 6 oglejmo strukturno analizo odnosa med temi prelomi in narivnimi luskami istrsko-furlanske narivno-podrivne cone v čelu katerih ležijo antiklinale iz paleogenskega apnenca in eocenskega fliša. V analizi izhajamo iz idealizirane ešalonske razporeditve lusk in čelnih antiklinal (sl. 6A), kjer so v tlorisni ravninin robovi antiklinal iz paleogenskega apnenca povezati z ovojnico ali envelopo »e«, ki poteka v smeri 340°. Ta smer je bila izbrana zato, ker ponazarja lego desnozmičnih prelomov kastelskega in gračiškega niza. Ovojnica ali envelopna »e« leži v ravnini, ki jo imenujemo ovojna ali envelopna ravnina »E«. Da bi ugotovili njen vpad je bila iz terenskih podatkov določena srednja lega paleogenskih narivnih ploskev »P«, ki znaša 50/30 in srednja lega plasti »D« v krilu čelne antiklinale, ki znaša 35/20. Konstruirana presečnica »s« na sliki 6B ima smer 341/11, zaokroženo 340/10, kar je enako smeri envelope »e« na sl. 6A. To pomeni, da ležita ovojnica »e« in presečnica »s« v ovojni ravnini »E«, ki ima smer 340 ° in vpad 90 °. V našem primeru je ovojna ravnina »E« konstruirana meja med območjem, kjer v luskah prevladuje paleogenski apnenc in območjem, ki je zgrajeno iz mehkejšega fliša, zato predstavlja labilno cono po kateri bi lahko nastal zmični prelom.

Konstrukcija na sliki 6 je idealizirana, vendar dobro ponazarja razmere v pasu med zgornjo Mirno in spodnjo Glinščico. Ovojna ravnina »E« ponazarja vzroke za nastanek kastelskega in gračiškega niza subvertikalnih desnozmičnih prelomov v smeri SSE-NNW, le da v naravi ne gre za eno ovojno ravnino ali zmični prelom, temveč za cono, ki je sestavljena iz več podobnih ešalonskih segmentov. Izločena sta kastelski faults of the Kastelec and Gračišče series. The envelope »e« lies in a plane called the envelope plane »E«. In order to determine its elements (azimuth and dip), the middle position of Paleogene thrust surfaces »P« was determined from the field data, which is 50/30, and the middle position of layer »D« in the limb of the frontal anticline, which is 35/20. Constructed intersection »s« in Figure 6B has a bearing of 341/11 rounded to 340/10, which is parallel to the direction of envelope »e« in Figure 6A. This means that envelope »e« and the intersection »s« lie in the envelope plane »E«, which has a 340° bearing and vertical dip. In our case, the enveloping plane »E« is a constructed boundary between an area dominated by duplexes of Paleogene limestone and an area built of softer (less rigid) flysch, so it represents a labile zone along which a strike-slip fault could occur.

The construction in Figure 6 is idealized, but it well illustrates the conditions in the belt between the upper Mirna and lower Glinščica/Rosandra rivers. The enveloping plane »E« illustrates the causes of the formation of the SSE–NNW trending Kastelec and Gračišče series of subvertical right-lateral strike-slip faults, except that *in-si*tu it is not a single enveloping plane or strike-slip fault, but a zone consisting of several similar echelon segments. Kastelec and Gračišče series are obliterated here because they are emphasized in the Figure 4A due to their importance.

Echelon-arranged carbonate anticlines, as presented in Figue 6A, represent a stack of competent blocks in a less competent medium, therefore we propose introducing the name stacked structure, and envelope fault for the fault that occurred along the envelope plane of the stacked structure.

The complex dextral strike-slip zone between the upper Mirna and the lower Glinščica/Rosandra, which is characterized by a stacked structure and enveloping faults, is called the Črni Kal Anomaly. The regional cause of its formation is explained in the chapter on the formation of the North Istra Extrusion Wedge and the South Istra Pushed Wedge.

In addition to the Paleogene thrust faults, reverse faults (Figs. 4A and 5/4) also occur in the Istra-Friuli Thrust-Underthrust Zone, representing the leading structures of the Kraški rob (geographic region along the SW margin of the Čičarija plateau between the villages of Socerb and Mlini Fig. 11) recent uplift. Next to them, the Paleogene thrusts planes are anticlinally bent (Fig. 5/5). In Fig. 4A, some examples of such deformation are marked with the letters »a« (Glinščica/Rosandra), »b« (Varda, Fig. 5/5), »c« (Črni Kal), »d« (Movraž,

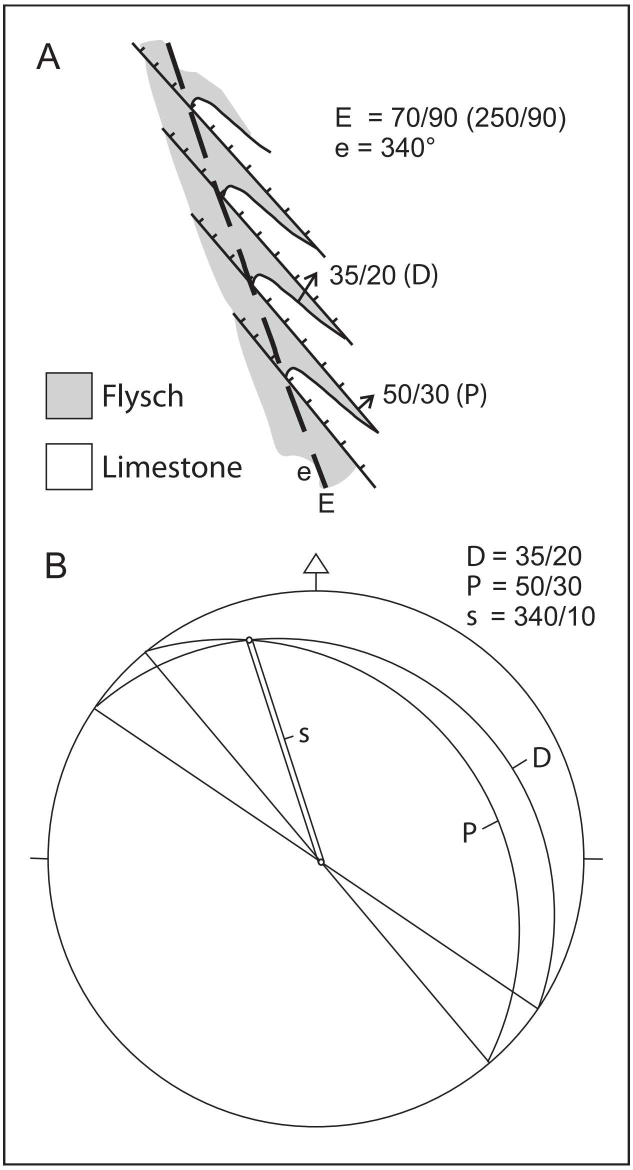


Fig. 6. Formation of Kastelec and Gračišče series of faults.
Sl. 6. Nastanek prelomov kastelskega in gračiškega niza.

A. Stacked structure: ideal echelon arrangement of Paleogene limestone and flysch duplexes.

The north-western edges of the thrusted frontal anticlines of Paleogene limestone form an echelon series whose »e« envelope is straight and runs due NNW (340°), which is oblique to the trust planes running NW (50°). / Zložbena zgradba: idealni ešalonski niz narivnih lusk iz paleogenskega apnenca in fliša. Severozahodni robovi čelnih antiklinal iz paleogenskega apnenca tvorijo ešalonski niz, katerega ovojnica »e« ali envelopa je ravna in poteka v smeri NNW (340°), kar je poševno na narivne ploskve lusk, ki potekajo v smeri NW (50°).

B. Construction of the intersection between the middle position of the thrust surfaces of the scales (»P« = 50/30) and the middle position of the bedding (»D« = 35/20). The intersection »s« lies in the direction 341/11, rounded 340/10, with its direction identical to the direction of the envelope »e«, which means that both lines lie in a single plane. It is vertical and called the enveloping plane »E«, which lies in the direction 70/90, (or 250/90). / Konstrukcija presečnice med srednjo lego narivnih ploskev lusk (»P« = 50/30) in srednjo lego plasti (»D« = 35/20). Presečnica »s« leži v smeri 341/11, zaokroženo 340/10, njena smer je identična s smerjo ovojnice ali envelope »e«, kar pomeni, da ležita obe premici v eni ravnini. Ta je vertikalna. Imenujemo jo ovojna ali envelopna ravnina »E«, ki leži v smeri 70/90, oziroma 250/90.

Fig. 5/6) and »e« (Perci near Buzet). Some of these Paleogene thrust surfaces show a certain degree of metamorphosis (verbally communicated by Dr. Bogomir Celarc, 2021), which, in addition to being folded, undoubtedly indicates their inactivity and that the reverse faults are younger, i.e. of Neogene-recent age. Unlike the others, they are called underthrust reverse faults. The antiformly bent thrust surface in Glinščica/Rosandra a, marked with »a«, is probably related to the Bazovica Anticline.

In the area of the Črni Kal Anomaly, there are SSE–NNW trending (Kastelec and Gračišče series) subvertical right-lateral strike-slip faults and SE-NW trending reverse underthrust faults. The relationship between them is multi-phased, in some places the first intersect the others, in others it is the other way around. In the zones characterised by reverse underthrust faults, signs of sub-horizontal extrusion towards the northwest to north-northwest are also found in the area of the Črni Kal Anomaly.

Based on the geometrical conditions on the tip of the North Istra Extrusion Wedge, we conclude that there exists an underthrusting reverse fault between Gračišče and Buzet, which is occasionally active also as a right-lateral strike-slip. The underthrusting kinematics next to it is indicated by the anticlinal folding »e«, while the extrusion is indicated by the transverse valleys parallel to the Rokava Fault (Fig. 4B). The Rokava Fault also terminates next to this underthrusting fault (Fig. 4A, point 3), due to which the Rokava valley suddenly turns to the southeast, and the Buzet Thrust also leans on it.

We assume that the oscillation between subhorizontal dextral strike-slip and underthrusting is a characteristic of the Istrian Pushed Area. With this mechanism and intermediate variants, we can explain large tectonic mirrors in the Raša fault zone mentioned in the chapter on the Raša fault in this article.

The discovery of the underthrust reverse faults requires a new geological mapping of the Istra-Friuli Thrust-Underthrust Zone, especially the part that takes place in flysch. The sketch of its already published (thrust) structure (Placer et al., 2004, Fig. 1; 2010, Fig. 5; Placer, 2005, Fig. 1; 2007, Fig. 2), is based on knowledge of the Buzet Thrust, examined from Buzet to the Gulf of Trieste coast and takes place exclusively in flysch layers (Placer et al., 2004). The Buzet Thrust Thrust plane on the surface obliquely intersects the strata everywhere at an angle of around 30°, and beds are folded into a flanking fold along the thrust plane, thus we

in gračiški niz, ki sta zaradi svojega pomena poudarjena na sliki 4A.

Ešalonsko razporejene karbonatne antiklinale, kot je to predstavljeno na sliki 6A, predstavljajo skladovnico ali zložbo kompetentnih blokov v manj kompetentnem mediju, zato predlagamo, da se uvede naziv zložbena zgradba ali zložbena struktura, za prelom ki je nastal po ovojni ravnini zložbene strukture pa ovojni ali envelopni prelom. Izraz zložbena zgradba izvajamo iz skladovnice drv, ki so zložena v zložbo, izraz skladovna zgradba bi bil neprimeren, ker se prekriva s skladi, oziroma plastmi.

Kompleksno desnozmično cono med zgornjo Mirno in spodnjo Glinščico, za katero je značilna zložbena zgradba in ovojni prelomi, imenujemo črnokalska anomalija. Regionalni vzrok za njen nastanek bo razložen v poglavju o nastanku severnoistrskega iztisnega in južnoistrskega potisnega klina. Poleg paleogenskih narivnih prelomov nastopajo v istrsko-furlanski narivno-podrivni coni tudi reverzni prelomi (sl. 4A in 5/4), ki predstavljajo vodilne strukture recentnega dviganja kraškega roba. Ob njih so ploskve paleogenskih narivov antiklinalno usločene (sl. 5/5). Na sliki 4A so nekateri primeri takih usločitev označeni z malimi črkami »a« (Glinščica), »b« (Varda, sl. 5/5), »c« (Črni Kal), »d« (Movraž, sl. 5/6) in »e« (Perci pri Buzetu). Nekatere paleogenske narivne ploskve od teh kažejo določeno stopnjo metamorfoze (ustno posredoval dr. Bogomir Celarc 2021), kar poleg tega, da so nagubane, nedvomno kaže na njihovo neaktivnost in da so reverzni prelomi mlajši, torej neogensko-recentne starosti. Za razliko od drugih jih imenujemo podrivni reverzni prelomi. Antiformna usločitev narivne ploskve v Glinščici, ki je označena z »a« je verjetno povezana z Bazovsko antiklinalo (Bazovica, bazovski: Merku, 2006, 42).

V območju črnokalske anomalije torej nastopajo subvertikalni desnozmični prelomi smeri SSE-NNW (kastelski in gračiški niz) in podrivni reverznimi prelomi smeri SE-NW. Odnos med njimi je večfazen, ponekod prvi sekajo druge, ponekod je obratno. V conah podrivnih reverznih prelomov najdemo v območju črnokalske anomalije tudi znake subhorizontalnega iztiskanja proti severozahodu do severo-severozahodu.

Po geometrijskih razmerah na območju konice severnoistrskega iztisnega klina sklepamo, da obstoja med Gračiščem in Buzetom podrivni reverzni prelom, ki je postal občasno tudi desnozmičen. Na podrivno kinematiko ob njem kaže antiklinalna usločitev »e«, na iztiskanje

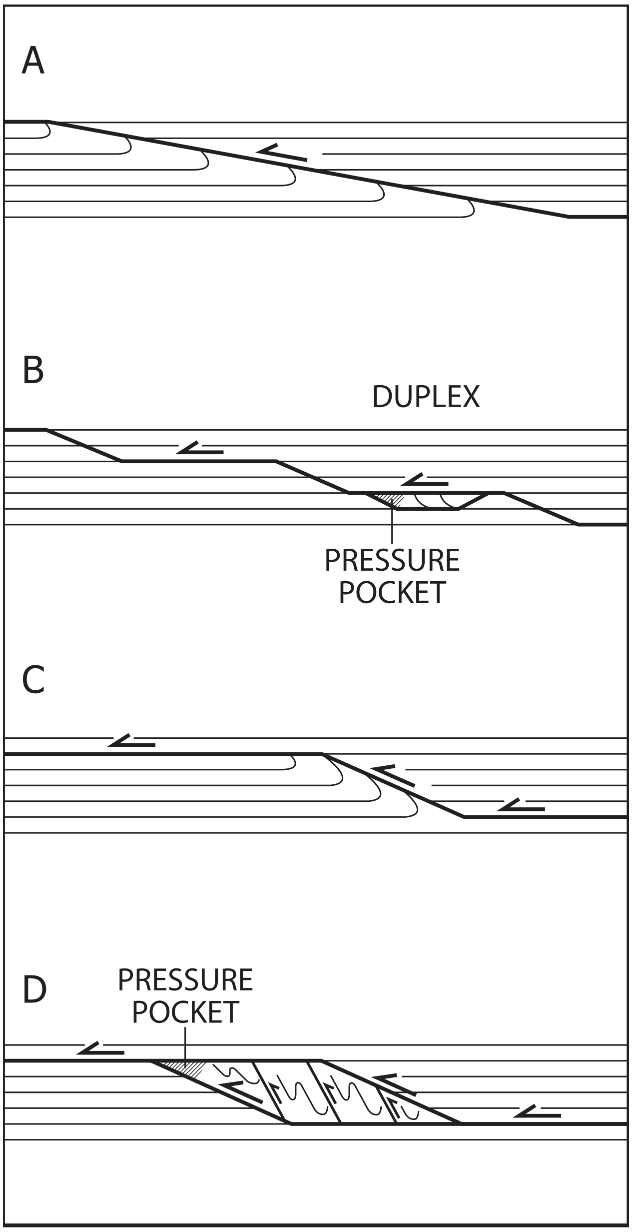


Fig. 7. The course of the thrust plane in flysch layers. Profile. A. Straight oblique cut. B. Stepped oblique cut. C. Jump with natural folds. D. Disordered jump (Fig. 5/7).

Sl. 7. Potek narivne ploskve v flišnih plasteh. Profil. A. Premi poševni rez. B. Stopničasti poševni rez. C. Preskok z obnarivnimi gubami. D. Neurejeni preskok (sl. 5/7).

conclude that it is the same in depth. An example of an oblique cut is presented in Figure 7A. Other thrust faults in the flysch within the Istra-Friuli Thrust-Underthrust Zone have so far been interpreted in accordance with the structure of the Buzet Thrust. During later detailed research of this area, it was shown that the oblique cut in the flysch is not always straight, but is often stepped (Fig. 7B), which means that the thrust plane sometimes runs between the layers, and sometimes obliquely to them. The thrust plane dip in such a case is somewhat steeper. When it passes between layers, identical parallel interlayer deformations appear next to it, and locally duplexes may evolve, and when they

kažejo prečne doline potokov, ki so vzporedne Rokavinemu prelomu (sl. 4B). Ob njem se izklinja tudi Rokavin prelom (sl. 4A, točka 3), zaradi česar dolina Rokave nenadoma zavije proti jugovzhodu. Nanj se naslanja tudi Buzetski narivni prelom. Domnevamo, da je nihanje med subhorizintalnim desnim zmikanjem in podrivanjem značilnost istrskega potisnega območja, s tem mehanizmom in vmesnimi variantami lahko razložimo velika tektonska zrcala v prelomni coni Raškega preloma, ki jih v tem članku omenjamo v poglavju o Raškem prelomu.

Odkritje podrivnih reverznih prelomov terja ponovno geološko kartiranje istrsko-furlanske narivno-podrivne cone. Zlasti tistega dela, ki poteka v flišu. Skica njene narivne zgradbe, ki je bila doslej večkrat objavljena (Placer et al., 2004, sl. 1; 2010, sl. 5; Placer, 2005, sl. 1; 2007, sl. 2) je izhajala iz poznavanja Buzetskega narivnega preloma, ki je bil pregledan od Buzeta do obale Tržaškega zaliva in poteka izključno v flišnih plasteh (Placer et al., 2004). Njegova narivna ploskev na površju povsod poševno seka plasti pod kotom okoli 30°, ob njej so plasti večinoma povite v obnarivno gubo, zato sklepamo, da je tako tudi v globini, na sliki 7 ga predstavljamo kot primer premega poševnega reza. Ostale narivne prelome v flišu znotraj istrsko-furlanske narivno-podrivne cone, smo doslej interpretirali v skladu z zgradbo Buzetskega narivnega preloma. Pri poznejših detajlnih raziskavah tega ozemlja pa se je pokazalo, da poševni rez v flišu ni vedno raven, zelo pogosto je stopničast (sl. 7B), kar pomeni, da poteka narivna ploskev nekaj časa med plastmi, nekaj časa poševno nanje. V takem primeru je vpad narivne ploskve nekoliko bolj strm. Ko poteka med plastmi, nastopajo ob njej identične vzporedne medplastne deformacije, ponekod pa se razvijejo dupleksi. Pri preskoku iz enega nivoja plasti v drugega se pojavljata dva tipa zgradbe prelomne cone. V prvem primeru so se plasti zasukale v obprelomno gubo (sl. 7C), v drugem se razvije neurejeno zaporedje skoraj izoklinalnih gub in reverznih prelomov (sl. 7D in 5/7). Struktura drugega ali neurejenega tipa preskoka je na moč podobna novonastalim conam podrivnih reverznih prelomov (sl. 5/4). Pomemben kriterij razlikovanja so strukturni žepi, ki se nahajajo v čelih narivnih struktur neurejenega tipa (sl. 7D) in dupleksov (sl. 7B). V njih običajno nastopajo močno stlačene pretrte kamnine ali zgoščine, ki imajo glede na okoliški pretrti medij povečano volumsko gostoto. Obravnavane žepe imenujemo tlačni strukturni žepi, skrajšano tlačni žepi, ki predstavljajo novost v jump from one level to another, two types of fracture zone structure appear. In the first case, the layers are twisted into a fold along the fault (Fig. 7C), in the second a disordered sequence of almost isoclinal folds and reverse faults develops (Figs. 7D and 5/7). The structure of the second or disordered type of jump is very similar to newly formed zones of underthrust reverse faults (Fig. 5/4).

An important distinguishing criterion is the structural pockets located in the faces of thrust structures of disordered type (Fig. 7D) and duplexes (Fig. 7B). They usually contain highly compressed crushed rocks or clusters, which are denser compared to the surrounding crushed (but not compressed as in the pressure pocket) medium. Said pockets are structural pressure pockets, abbreviated as pressure pockets representing a novelty in the case of the thrust duplexes of the described type. Pressure pockets of this type were observed in thrust zones, while other zones of underthrust reverse faults have not been explored in this sense. However, they do not form in duplexes, which accompany the phenomena of underwater synsedimentary gravitational sliding. An exceptional example of the latter can be seen in the flysch cliff of Simonov zaliv (Simon bay) near Izola, which does not feature a pressure pocket at the head of the landslide, but a relaxed intertwining of layers that were only partially lithified at the time of sliding along the inclined seabed. Due to the importance of this phenomena, the structure is named the Kane landslide after the nearby hamlet and cape. In the Summaries and Excursions for the 4th Slovenian Geological Congress in Ankaran in 2014, the mentioned landslide was shown as an example of a thrust duplex structure (Vrabec & Rožič, 2014, 84-91).

The task of re-mapping is to take into account all these peculiarities; above all it is necessary to distinguish the zones of disordered jump of step thrust surfaces (Figs. 7B and 5/7) from the Neogene-recent zones of reverse thrust faults (Fig. 5/4).

The structural relationships in the North Istra Extrusion Wedge are sketched in profile in Figure 8. The Paleogene thrusts (Buzet Thrust, Izola Thrust, Križ Thrust, antiformally folded thrusts of the Kraški rob) and the reverse Buje Fault with its backthrusts. The left-lateral strike-slip Zambratija Fault, enveloping or envelope right-lateral strike-slip faults of the Črni Kal Anomaly, and underthrust reverse faults are also of Neogene-recent age.

Underthrusting occurs only in the north-eastern part of the profile along the underthrust reverse faults, where their hanging blocks are being uplifted. This is geomorphologically manifested

primeru narivnih dupleksov opisanega tipa. Tlačne žepe tega tipa smo opazovali v narivnih conah, medtem ko so ostale cone podrivnih reverznih prelomov v tem smislu neraziskane. Ne nastajajo pa v dupleksih, ki spremljajo pojave podvodnega singenega gravitacijskega drsenja, izjemen primer slednjega je viden v flišnem klifu Simonovega zaliva v Izoli, kjer se v čelu plazu ne nahaja tlačni žep temveč sproščeni preplet plasti, ki so bile v času polzenja po nagnjenem morskem dnu le delno strjene. Predlagamo, da ta primer poimenujemo po bližnjem zaselku in rtiču plaz Kane. V Povzetkih in ekskurzijah za 4. slovenski geološki kongres v Ankaranu leta 2014, je bil omenjeni plaz prikazan kot primer strukture narivnega dupleksa (Vrabec & Rožič, 2014, 84–91).

Naloga ponovnega kartiranja je upoštevati vse te posebnosti, predvsem je potrebno ločiti cone neurejenega preskoka stopničastih narivnih ploskev (sl. 7E in 5/7) od con neogensko-recentnih podrivnih reverznih prelomov (sl. 5/4).

Strukturni odnosi v severnoistrskem iztisnem klinu so skicirani v profilu na sliki 8. Paleogenske starosti so narivi (Buzetski, Izolski, Križni nariv, antiformno usločeni narivi Kraškega roba) in Bujski reverzni prelom s povratnimi narivi. Neogensko-recentne starosti so Zambratijski levozmični prelom, desnozmični ovojni ali envelopni prelomi črnokalske anomalije in podrivni reverzni prelomi.

Podrivanje se dogaja le v severovzhodnem delu profila ob podrivnih reverznih prelomih, ob katerih se dvigujejo njihove krovninske grude. To se geomorfološko kaže kot dviganje Kraškega roba, kar je povzročilo antiformni upogib paleogenskih narivnih ploskev. Aktualno dviganje kraškega roba dokazuje kontrolni izračun nivelmanskega vlaka preko Kraškega roba (Rižnar et al., 2007).

V profilu na sliki 8 je shematsko prikazana tudi lega desnozmičnih ovojnih prelomov. Njihov odnos do podrivnih reverznih prelomov je ambivalenten, prva opažanja so pokazala, da prevladujejo podrivne strukture z drsami po vpadu, vendar najdemo znake desnega zmikanja tudi v conah podrivnih reverznih prelomov. Domnevamo, da je v začetni fazi razvoja severnoistrskega iztisnega klina prevladovalo iztiskanje, pozneje podrivanje, verjetno pa se občasno še vedno pojavlja tudi iztiskanje.

V jugozahodnem delu profila pri kartiranju površja nismo našli neogensko-recentnih podrivnih struktur. V tem primeru je zanimiva primerjava seizmičnega profila morskega dna

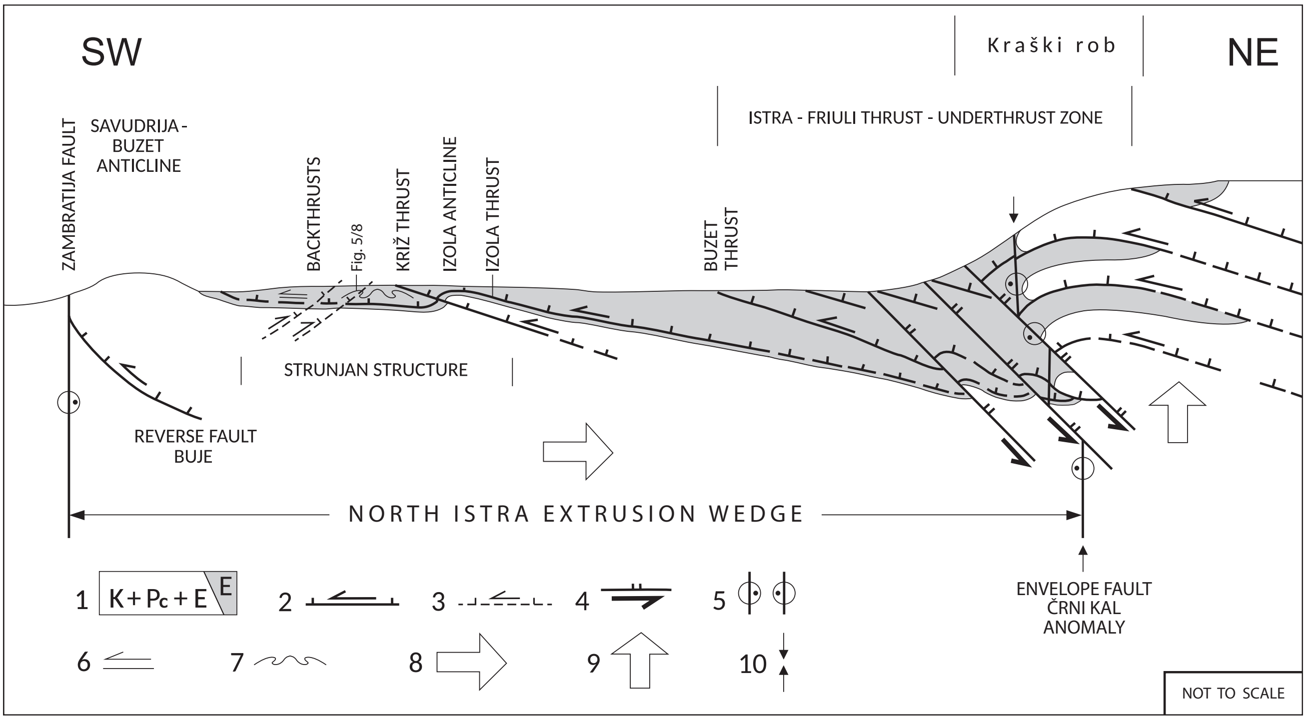


Fig. 8. Sketch of the cross-section of the North Istra Extrusion Wedge. The course of the profile in Fig. 4A. Adapted after Placer et al. (2010, Fig. 6).

Sl. 8. Skica prečnega profila severnoistrskega iztisnega klina. Potek profila na sl. 4A. Dopolnjeno po Placer et al. (2010, sl. 6).

1 K + Pc + E – Cretaceous, Paleocene and Eocene carbonates, E – Eocene flysch / K + Pc + E – kredni, paleocenski in eocenski karbonati, E – eocenski fliš

2 Paleogene reverse and thrust fault: reverse Buje Fault, Izola Thrust, Križ Thrust, Buzet Thrust / paleogenski reverzni in narivni prelom: Bujski reverzni prelom, Izolski narivni prelom, Križni narivni prelom, Buzetski narivni prelom

3 Paleogene backthrust fault / paleogenski povratni reverzni prelom

4 Neogene-recent underthrust reverse fault / neogensko-recentni podrivni reverzni prelom

5 Left strike-slip Zambratija Zone, a set of right strike-slip faults of the Črni Kal Anomaly (envelope faults) / zambratijska levozmična cona, niz desnozmičnih prelomov črnokalske anomalije (ovojni ali envelopni prelomi)

6 Area of interlayer movements in the Strunjan structure (Placer et al., 2010, Figs. 18 and 19) / območje medplastnih premikov v strunjanski strukturi (Placer et al., 2010, sl. 18 in 19)

7 Mirror folded area in the Strunjan structure / zrcalno nagubano območje v strunjanski strukturi

8 Direction of the Neogene-recent movement of the Istra block / smer neogensko-recentnega pomikanja istrskega bloka

9 Recent uplift of the Kraški rob / recentno dviganje kraškega roba

10 Sketch of the envelope faults position within the Črni Kal Anomaly / skica lege ovojnih (envelopnih) prelomov znotraj črnokalske anomalije

as the uplift of the Kraški rob, which caused the antiform bending of the Paleogene thrust surfaces. The current uplift of the Kraški rob is evidenced by the recalculation of the levelling lines across the Kraški rob (Rižnar et al., 2007).

The position of the right-lateral strike-slip envelope faults is schematically presented in profile in Figure 8. Their relationship to underthrust reverse faults is ambivalent: first observations showed that underthrust structures with slickensides along (parallel to) the bedding predominate, but evidence of dextral slip are also observed in underthrust reverse fault zones. It is assumed that extrusion was dominant in the initial phase of the North Istra Extrusion Wedge development, followed by underthrusting, but extrusion probably still occurs from time to time.

prečno na Izolsko antiklinalo (Busetti et al., 2013, sl. 3) z odsekom profila na sliki 8 med Savudrijsko-Buzetsko in Izolsko antiklinalo. Kartiranje je pokazalo, da sta poleg Izolske antiklinale vidna še medplastni nariv v prehodnem laporju antiklinale, ki smo ga poimenovali Izolski nariv in Križni nariv za katerega na kopnem ni bilo mogoče ugotoviti v kakšnem strukturnem odnosu je z Izolsko antiklinalo. Med Savudrijsko-Buzetsko antiklinalo in Križnim narivom ležijo povratni narivi, ki so spremljajoča struktura Bujskega reverznega preloma. V bloku med povratnimi narivi in Križnim narivom je fliš zrcalno simetrično naguban. V seizmičnem profilu se Izolska antiklinala nagiba proti jugozahodu, kar kaže na paleogensko čelno narivno gubo, ki je najbližja Križnemu narivu. Vendar ta

In the south-western part of the profile, no Neogene-recent underthrust structures were found during surface mapping. In this case a comparison of the seismic profile of the seabed transverse to the Izola Anticline (Busetti et al., 2013, Fig. 3) with the section of the profile in Figure 8 between the Savudrija-Buzet and Izola Anticlines is interesting. Geological mapping showed that there are also interlayer thrusts (the Izola, and the Cross Thrusts) visible in the transitional marl, in the Izola Anticline. It was not yet possible to determine their structural relationship with the Izola Anticline. Backthrusts and related structures between the Savudrija-Buzet Anticline and the Križ Thrust belong to the reverse Buje Fault. The flysch is mirror-symmetrically folded in the structural block between the backthrusts and the Križ Thrust. The Izola Anticline is tilted to the southwest in the seismic profile, indicating a Paleogene frontal thrust fold, which is closest to the Križ Thrust. The thrust fault is not visible in the seismic profile, so we assume that only a fold has developed there, which has not yet been broken by the thrust plane. Post-Paleogene reactivation is mentioned in the description of the seismic profile that only affected subvertical faults without significant impact on the structure. A fold in the flysch along the reverse underthrust indicates the symmetry of fold vergence in the Strunjan structure between the reverse thrusts and the Križ Thrust and is presented in Figure 5/8. This was formed successively: first, folds formed in the Križ Thrust footwall, then along backthrusts. Justification of the sequence of events is given in the chapter on the formation of the North Istra Extrusion Wedge and the South Istra Pushed Wedge. The Kane landslide in Simonov zaliv lies in the area of the Strunjan structure, but, as we have already mentioned, it is not a tectonic formation in origin, but rather a synsedimentary phenomenon in the flysch. The landslide slid in a direction of roughly 310°, while signs of Paleogene thrusting show a direction of some 220°.

The important question – the amount of displacement along the Paleogene thrusts, which represent the boundary of the Dinaric thrust structure – remains unanswered. While it could be relatively large, the debates regarding the structure of the Dinarides have failed to produce an acceptable solution.

Interpretation of the profile in Figure 8 represents some progress in understanding the mechanism of movement of the Microadria towards the External Dinarides, which includes thrusting and underthrusting. The progress is obvious after comparison with the Umag - Kozina profile (Placer et al., 2010, fig. 6), where the underthrusting was

v seizmičnem profilu ni viden, zato domnevamo, da se je na območju geofizikalnega profila razvila le guba, ki je narivna ploskev še ni pretrgala. V opisu seizmičnega profila je omenjena popaleogenska reaktivacija, ki pa je zajela le subvertikalne prelome brez pomembnega vpliva na zgradbo. Na sliki 5/8 je prikazana guba v flišu ob povratnem narivu, ki kaže na simetrijo vergence gub v strunjanski strukturi med povratnimi narivi in Križnim narivom. Ta je nastala zaporedoma, najprej so se razvile gube v talnini Križnega nariva, nato ob povratnih narivih. Utemeljitev zaporedja dogodkov je podana v poglavju o nastanku severnoistrskega iztisnega in južnoistrskega potisnega klina. Plaz Kane v Simonovem zalivu leži v območju strunjanske strukture, vendar, kot smo že omenili, po izvoru ni tektonska tvorba, temveč je sinsedimentarni pojav v flišu. Plaz je drsel v smeri okoli 310°, medtem ko kažejo znaki paleogenskega narivanja na smer okoli 220°.

Odprto ostaja vprašanje dolžine premika ob paleogenskih narivih, ki predstavljajo mejo dinarske narivne zgradbe. Ta bi bil lahko sorazmerno velik, vendar nam dosedanje razprave o zgradbi Dinaridov o tem še ne dajejo sprejemljivega odgovora.

Interpretacija profila na sliki 8 pomeni napredek pri razumevanju mehanizma premikanja Mikroadrije proti Zunanjim Dinaridom, ki zajema potiskanje in podrivanje. Napredek je viden po primerjavi s profilom Umag - Kozina iz leta 2010 (Placer et al., 2010, sl. 6), ko se je podrivanje obravnavalo kot reaktivacija paleogenskih narivnih ploskev v nasprotni smeri. Antiklinalno usločene paleogenske narivne ploskve ob podrivnih reverznih prelomih, ki so na sliki 4A označene z »a«, »b«, »c«, »d« in »e«, nastopajo tudi v jugovzhodnem delu istrsko-furlanske narivno-podrivne cone, npr. nad Brestom pod najvišjim vrhom Čičarije, Velikim Planikom (1272 m). V tem smislu predstavlja strukturni izziv tudi zgradba Učke, zato je potrebno ponovno strukturno obdelati celotno narivno-podrivno cono med Tržaškim in Reškim zalivom.

Narivi in prelomi znotraj severnoistrskega iztisnega klina se nadaljujejo proti severozahodu. Iz strukturne rekonstrukcije podmorja Tržaškega zaliva (Carulli, 2011, sl. 3) in geofizikalnega profila v smeri SW-NE (Busetti et al., 2012, sl. 2) je moč sklepati, da se zahodno od Savudrije os Savudrijsko-Buzetske antiklinale obrne proti severozahodu (sl. 2). O Zambratijskem prelomu ni podatkov, domnevamo pa, da spremlja Savudrijsko-Buzetsko antiklinalo v podmorju Bujski considered as a reactivation of Paleogene thrust planes in the opposite direction. Anticlinally deformed Paleogene thrust planes next to underthrust reverse faults, shown in Figure 4A, marked with »a«, »b«, »c«, »d« and »e«, also occur in the south-eastern part of the Istra-Friuli Thrust-Underthrust Zone, e.g. above Brest under Mt. Veliki Planik (1272 m), the highest peak of Čičarija. In this sense, Mt. Učka also represents a structural challenge, so it is necessary to structurally remap the entire thrust-underthrust zone between the Gulf of Trieste and the Gulf of Rijeka.

Thrusts and faults within the North Istra Extrusion Wedge continue to the northwest. From the structural reconstruction of the Gulf of Trieste seabed (Carulli, 2011, fig. 3) and the geophysical profile in the SW-NE direction (Busetti et al., 2012, fig. 2), it can be concluded that the axis of the Savudrija-Buzet Anticline west of Savudrija turns to the northwest (Fig. 2). There is no information about the Zambratija Fault, but we assume that the reverse Buje Fault follows the Savudrija-Buzet Anticline, and Carulli (ib.) also assumed the same. The change of direction occurs also on the opposite side of the extrusion wedge. Here the SSE-NNW trending Črni Kal Anomaly (the complex shear zone between the upper Mirna and lower Glinščica/Rosandra rivers), turns due SE-NW. The Bazovica Anticline and the Lipica Syncline north-northwest of the lower Glinščica/Rosandra (Fig. 4A) have the same direction, so we believe that they probably represent the extreme structural limit of the Črni Kal Anomaly. This is also indicated by the change in the Kraški rob trend on the saddle between Mt. Mai /Maj (~ 443 m) and Mt. Monte Calvo/Globojnar (~ 442 m) above Trieste, where the Kraški rob turns from the SSE-NNW to the SE-NW direction (Fig. 4). Despite the apparently well-defined boundary on the mentioned saddle (elevation 416 m), it is quite clear that it is correct to speak only of the belt between the upper Mirna and the lower Glinščica/Rosandra, since the Črni Kal Anomaly cannot be strictly bounded.

The North-Istra Extrusion Wedge thus transits into a parallelepiped roughly between Savudrija and Trieste, which is called the Trieste parallelepiped block or the Trieste parallelepiped. It is clear that due to the parallelopiped shape, the effect of extrusion is completely absent, therefore the space between Savudrija and Trieste is also the north-western limit of the extrusion wedge (Fig. 2). The Trieste parallelepiped (A3) formally lies in the extension of the North Istra Extrusion Wedge (Ad2) and represents its south-eastern margin extrusion boundary, so it makes sense to use the term only in the discussion of block dynamics.

reverzni prelom. Podobno je domneval tudi Carulli (ib.). Sprememba smeri se dogodi tudi na nasprotni strani iztisnega klina, tu se črnolakska anomalija, oziroma kompleksna strižna cona med zgornjo Mirno in spodnjo Glinščico v smeri SSE-NNW, obrne v smer SE-NW. Severo-severozahodno od spodnje Glinščice se nahajata Bazovska antiklinala in Lipiška sinklinala (sl. 4A), ki imata enako smer, zato menimo, da verjetno predstavljata skrajno strukturno mejo črnokalske anomalije. Na to kaže tudi sprememba smeri Kraškega roba na sedlu med Majem (Mai, okoli 443 m) in Globojnarjem (Monte Calvo, okoli 442 m) nad Trstom, kjer se kraški rob iz smeri SSE-NNW obrne v smer SE-NW. Kljub na videz dokaj natančno določeni meji na omenjenem sedlu (kota 416 m), pa je povsem jasno, da je korektno govoriti le o pasu med zgornjo Mirno in spodnjo Glinščico, saj črnokalske anomalije ni mogoče ostro omejiti.

Severnoistrski iztisni klin preide torej približno med Savudrijo in Trstom v paralelepiped, ki ga imenujemo tržaški paralelepipedni blok ali tržaški paralelepiped. Jasno je, da je zaradi paralelepipedne oblike povsem izostal učinek iztiskanja, zato je prostor med Savudrijo in Trstom hkrati tudi severozahodna meja iztisnega klina (sl. 2). Tržaški paralelepiped (A_3) leži formalno v podaljšku severnoistrskega iztisnega klina (Ad_2), vendar predstavlja njegovo jugovzhodno stranico meja iztiskanja, zato je termin smiselno uporabljati le v diskusiji o dinamiki blokov.

Glede na dinamiko severnoistrskega iztisnega klina bi bilo povsem mogoče, da bi zaradi ekstenzije v jugovzhodni polovici klina in blokade nasproti tržaškemu paralelepipedu, prišlo v severozahodni polovici iztisnega klina do gubanja prečno na iztiskanje, podobno kot v tinjanskem iztisnem klinu (Placer, 2005, sl. 3), kjer so te gube lepo razvite (sl. 4A in 5/9). Tinjanski iztisni klin je miniaturni pendant severnoistrskega iztisnega klina, zato bi tudi pri slednjem pričakovali med Rokavinim prelomom in jugovzhodno mejo tržaškega paralelepipeda več gub, ali pa vsaj eno veliko. Pri kartiranju površja teh nismo odkrili.

Geofizikalne raziskave Tržaškega zaliva so pokazale, da je predplio-kvartarna (večinoma flišna) kamninska podlaga prekrita z nekaj deset do nekaj sto metri plio-kvartarnega sedimenta (Busetti et al., 2010a, 2010b; Morelli & Mosetti, 1968; Trobec et al., 2018) Relief flišne podlage v skrajnem vzhodnem delu zaliva je bil v večji meri izoblikovan med mesinijsko

Considering the dynamics of the North Istra Extrusion Wedge, it would be quite possible that due to the extension in the south-eastern half of the wedge and the blockage opposite the Trieste parallelepiped, folding transverse to the extrusion would occur in the north-western half of the extrusion wedge, much like the Tinjan Extrusion Wedge (Placer, 2005, Fig. 3), where these folds are well developed (Figs. 4A and Fig. 5/9). The Tinjan Extrusion Wedge is a miniature pendant of the North Istra Extrusion Wedge, so we would expect several folds, or at least one large one between the Rokava fault and the south-eastern Trieste parallelepiped boundary, but these were not detected at surface mapping.

Geophysical surveys of the Gulf of Trieste have shown that the Pre-Plio-Quaternary bedrock (mostly flysch) is covered by tens to several hundred meters of Plio-Quaternary sediment (Busetti et al., 2010a, 2010b; Morelli and Mosetti, 1968; Trobec et al., 2018). The relief of the flysch substrate in the easternmost part of the bay was formed to a great extent during the Messinian erosion phase and to a lesser extent during a shorter Pliocene erosion episode (Busetti et al., 2010a, 2010b). The complex formation of the relief indicates that the surface currents during periods of erosion generally flowed westward (Morelli and Mosetti, 1968), which is comparable to the direction of the present-day river network in the extreme north-western part of Istra (i.e. Dragonja, Rižana, Glinščica/Rosandra, etc.). The youngest Late Pleistocene sedimentary sequences, deposited just before the last transgression in the eastern and central part of the area of the present-day Gulf of Trieste, show the general direction of the water currents towards the south, with one channel even running roughly parallel to the present-day coastline of the eastern part of the Gulf of Trieste (Novak et al., 2020; Ronchi et al., 2023; Trobec et al., 2017). It is very difficult to compare Late Quaternary river networks with river networks on flysch due to the far younger geomorphology, where sedimentation plays a greater role in shaping the surface compared to erosion. The shape of the river network in the Late Pleistocene was largely influenced by the topography of the time (Ronchi et al., 2023), since in the area of the present-day Gulf of Trieste, the terrain rose to the northwest (Trobec et al., 2018) due to the Soča megafan from the last glacial maximum (Fontana et al., 2014, 2010, 2008), which also covers the south-eastern part of the Gulf of Trieste. Possible transverse folding in the south-eastern part of the Gulf of Trieste could therefore only be determined from the structural map of the contact between carbonates and flysch.

erozijsko fazo ter deloma med krajšo pliocensko erozijsko epizodo (Busetti et al., 2010a, 2010b) Kompleksna izoblikovanost reliefa nakazuje, da so površinski tokovi v obdobjih erozije v splošnem tekli proti zahodu (Morelli & Mosetti, 1968), kar je primerljivo s smerjo današnje rečne mreže v skrajnem severozahodnem delu Istre (i.e. Dragonja, Rižana, Glinščica, itd.). Najmlajša poznopleistocenska sedimentna zaporedja, ki so se odložila tik pred zadnjo transgresijo na vzhodnem in osrednjem delu današnjega območja Tržaškega zaliva, pa kažejo generalno smer vodotokov proti jugu, pri čemer je en kanal tekel celo približno vzporedno z današnjo obalno črto vzhodnega dela Tržaškega zaliva (Novak et al., 2020; Ronchi et al. 2023; Trobec et al., 2017). Poznokvartarne rečne mreže zelo težko primerjamo z rečno mrežo na flišu, saj gre za precej mlajšo geomorfologijo, kjer ima sedimentacija večjo vlogo pri izoblikovanju površja v primerjavi z erozijo. Na obliko rečne mreže v poznem pleistocenu je v večji meri vplivala takratna paleotopografija (Ronchi et al., 2023), saj se je na območju današnjega Tržaškega zaliva teren dvigal proti severozahodu (Trobec et al., 2018) zaradi Sočine megapahljače iz zadnjega glacialnega viška (Fontana et al., 2014, 2010, 2008), ki prekriva tudi jugovzhodni del Tržaškega zaliva. Morebitno prečno gubanje v jugovzhodnem delu Tržaškega zaliva, bi bilo torej mogoče ugotoviti le iz strukturne karte stika med karbonati in flišem. To je sicer objavil Carulli (2011, sl. 3), vendar je njegov izdelek pregleden, zato ga ni mogoče uporabiti v ta namen.

Prečnodinarska cona povečane kompresije v zaledju črnokalske anomalije

V tem poglavju so opisane deformacije, ki so v istrskem potisnem območju nastale zaradi dinamike severnoistrskega iztisnega klina. Tu je med črnokalsko anomalijo, ki je prostorsko blizu Kraškemu robu in Hrušico nastala cona povečane kompresije, ki v celoti prečka Zunanjedinarski naluskani pas in sega še v čelni del Zunanjedinarskega narivnega pasu. Zaradi njune specifične zgradbe in zaradi nasledstvenega značaja novih deformacij, so te v vsaki enoti opisane posebej. Samostojno poglavje je namenjeno Raškemu prelomu, ker je v njegovi prelomni coni povečana kompresija povzročila nastanek transpresivne antiklinale, ki se je iz kraške uravnave dvignila kot Vremščica (1027 m).

This was published by Carulli (2011, Fig. 3), but as his work represents a review article it cannot be used for this purpose.

Transverse Dinaric zone of increased compression in the hinterland of the Črni Kal Anomaly

This chapter describes the deformations that occurred in the Istra Pushed Area due to the North Istra Extrusion Wedge dynamics. Here, between the Črni Kal Anomaly, which is close to the Kraški rob, and Mt. Hrušica a zone of increased compression has formed, which crosses the entire External Dinaric Imbricated Belt and extends into the frontal part of the External Dinaric Thrust Belt. Due to their specific structure and due to the hereditary nature of the new deformations, they are described separately in each unit. A separate chapter is devoted to the Raša Fault, because the increased compression of its fault zone caused the formation of a transpressive anticline, which rose from the karstic levelled terrain as Mt. Vremščica (1027 m).

External Dinaric Imbricated Belt

The External Dinaric Imbricated Belt in the territory under consideration is bounded by the Istra-Friuli Thrust-Underthrust Zone and the External Dinaric Thrust Belt boundary. (Fig. 1). The term »imbricated belt« is inappropriate for this part of the Dinarides because it doesn't consist of imbricates (horses) but of folds. Nevertheless, the term is acceptable because horses characterize the rest of this belt in the External Dinarides. The Istra hinterland is made up of large, folded units, the Trieste-Komen and Čičarija Anticlinoria and the Vipava and Brkini Synclinorium. There is also slightly smaller Ravnik Anticlinorium.

All of the listed units represent an example of complete (ideal) folding and are spatially displaced across compartments (Placer, 2005, Fig. 2), which means that equivalent folded structures do not lie in consecutive compartments but skip across the width of the compartment. The Vipava Synclinorium continues in its direction into the Ravnik Anticlinorium, the Trieste-Komen Anticlinorium into the Brkini Synclinorium, and the Čičarija Anticlinorium is exposed and does not transit into the synclinorium. In theory, complete folding is expressed in sets of linear folds displaced for a compartment (a set width). It usually covers larger homogeneously constructed areas, but there are only two folded sets with a frontal anticlinorium and a rear synclinorium that are being displaced (offset). The term frontal refers to the thrust structure of the Dinarides: the Trieste-Komen frontal Anticlinorium

Zunanjedinarski naluskani pas

Zunanjedinarski naluskani pas je na obravnavanem ozemlju omejen z istrsko-furlansko narivno-podrivno cono in mejo Zunanjedinarskega narivnega pasu (sl. 1). Termin »naluskani pas« je za ta del Dinaridov neustrezen, ker ga ne sestavljajo luske temveč gube, vendar je kljub temu sprejemljiv, ker so luske značilne za preostali del tega pasu v Zunanjih Dinaridih. Zaledje Istre je zgrajeno iz velikih nagubanih enot, Tržaško-Komenskega in Čičarijskega antiklinorija ter Vipavskega in Brkinskega sinklinorija. Tu je še Ravniški antiklinorij, ki je nekoliko manjši.

Vse naštete enote predstavljajo primer popolnega gubanja in so prostorsko zamaknjene po predalih (Placer, 2005, sl. 2), kar pomeni, da ekvivalentne nagubane strukture ne ležijo v zaporednih predalih, temveč preskakujejo za širino predala. Vipavski sinklinorij se po smeri nadaljuje v Ravniški antiklinorij, Tržaško-Komenski antiklinorij v Brkinski sinklinorij, Čičarijski antiklinorij pa je izpostavljen in se ne izteka v sinklinorij. V teoriji se popolno gubanje izraža v linearnih in predalčno zamaknjenih gubah in običajno zajema obsežnejša homogeno zgrajena območja, tu pa gre za specifičen primer, kjer obstojata le dva nagubana niza s čelnim antiklinorijem in začelnim sinklinorijem, ki sta zamaknjena. Termin čelni se nanaša na narivno zgradbo Dinaridov, Tržaško-Komenski čelni antiklinorij se previje v začelni Vipavski sinklinorij, Čičarijski čelni antiklinorij se previje v začelni Brkinski sinklinorij, ta pa v Ravniški antiklinorij (sl. 9A).

Predalčna nagubana zgradba ima določene zakonitosti, ki so zastopane tudi v našem primeru, pomembne so tri: 1. prehod antiklinale (antiklinorija) v sinklinalo (sinklinorij) in obratno, po smeri, se dogodi s cepljenjem gub, 2. v pravilni predalčni nagubani zgradbi se gube cepijo v prečno ležeči coni, imenovani cona cepljenja gub (sl. 9A in 9B), 3. ekvivalentne strukture v predalčno nagubani zgradbi se povezujejo z navzkrižnimi povezovalnimi gubami (nov termin), ki imajo usločeno os (undacija). Predalčno zamaknjeni antiklinali povezuje prečna antiklinala s konkavno usločeno osjo, sinklinali povezuje sinklinala s konveksno usločeno osjo (sl. 9C). Cona cepljenja gub je nasproti predalčnim gubam manj deformabilna (sl. 9D).

Vzrok za nastanek predalčne nagubane zgradbe v Zunanjedinarskem naluskanem pasu tiči v zgradbi in dinamiki Zunanjedinarskega narivnega pasu. Prečnodinarska cona ceplenja gub se namreč nahaja v podaljšku stika Snežniškega in Hrušiškega pokrova proti folds into the rear Vipava Synclinorium, and the Čičarija frontal Anticlinorium folds into the rear Brkini Synclinorium, which in turn folds into the Ravnik Anticlinorium (Fig. 9A).

The compartment-like folded structure has certain regularities (rules), which are also presented in our case, of which three are important: 1. the transition of an anticline (anticlinorium) to a syncline (synclinorium) and vice versa, according to direction, occurs by the splitting of folds. 2. in the correct crosswise-connecting folds, the folds are split in a transverse zone called the folds splitting zone (Figs. 9A and 9B). 3. equivalent structures in the crosswise-connecting folds are connected by crosswise-connecting folds (new term), which have a folded (buckled) axis (undation). The anticlines displaced by a compartment connect transverse anticlines with a concave folded axis, while synclines connect a syncline with a convex folded axis (Fig. 9C). The splitting folds zone is less deformable compared to the longitudinal folds (Fig. 9D).

The cause of the formation of the compartment-like folded structure in the External Dinaric Imbricated Belt lies in the structure and dynamics of the External Dinaric Thrust Belt. The Transverse Dinaric folds splitting zone is located in the extension of the contact between the Snežnik and Hrušica Nappes towards the southwest in the direction of thrusting. There is no similar phenomenon in the extension of the contact between the Hrušica and Trnovo Nappes, which could mean two things: that the position of the Transverse Dinaric folds splitting zone is accidental, or that the Hrušica Nappe extends far to the northwest under the Trnovo Nappe, and both nappes act together as a single unit. In contrast, the Snežnk Nappe under the Hrušica Nappe is expected to pinch out over a relatively short distance. That such an explanation is possible is shown by the hydrological connection between the Vipava River spring in the Hrušica Nappe and the sinks east of the Postojna basin in the Snežnik Nappe (Petrič et al., 2020). The Trnovo and Hrušica Nappes are older than the Snežnik

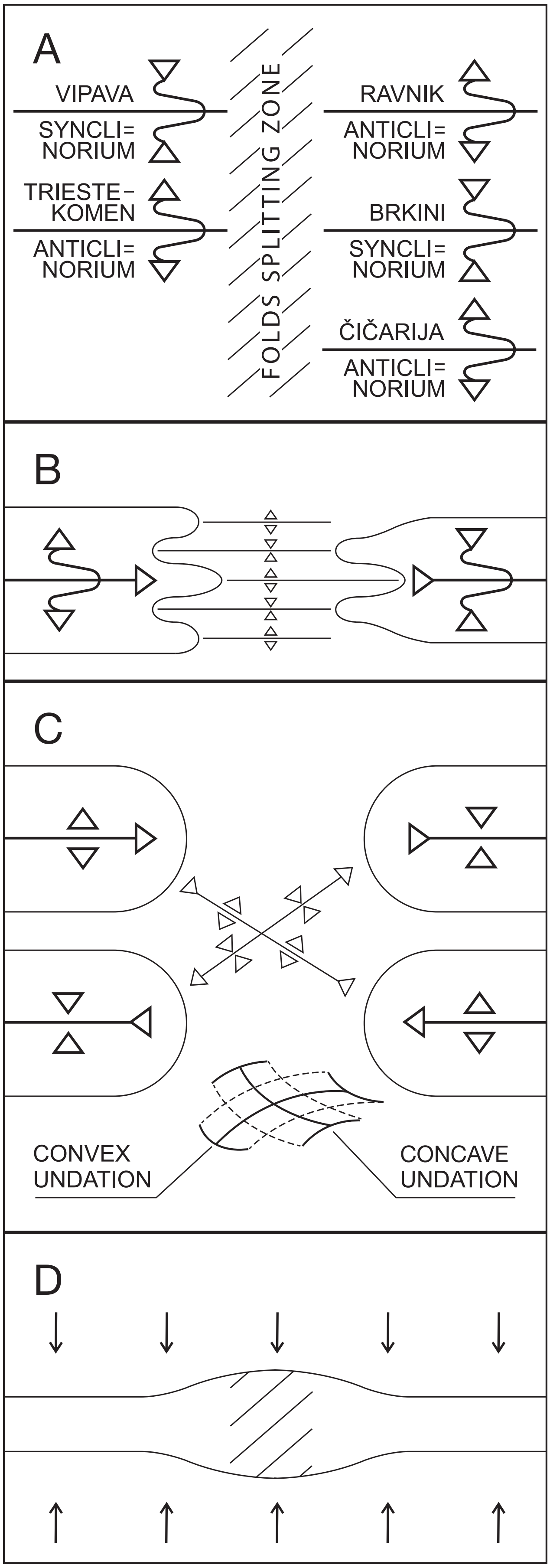
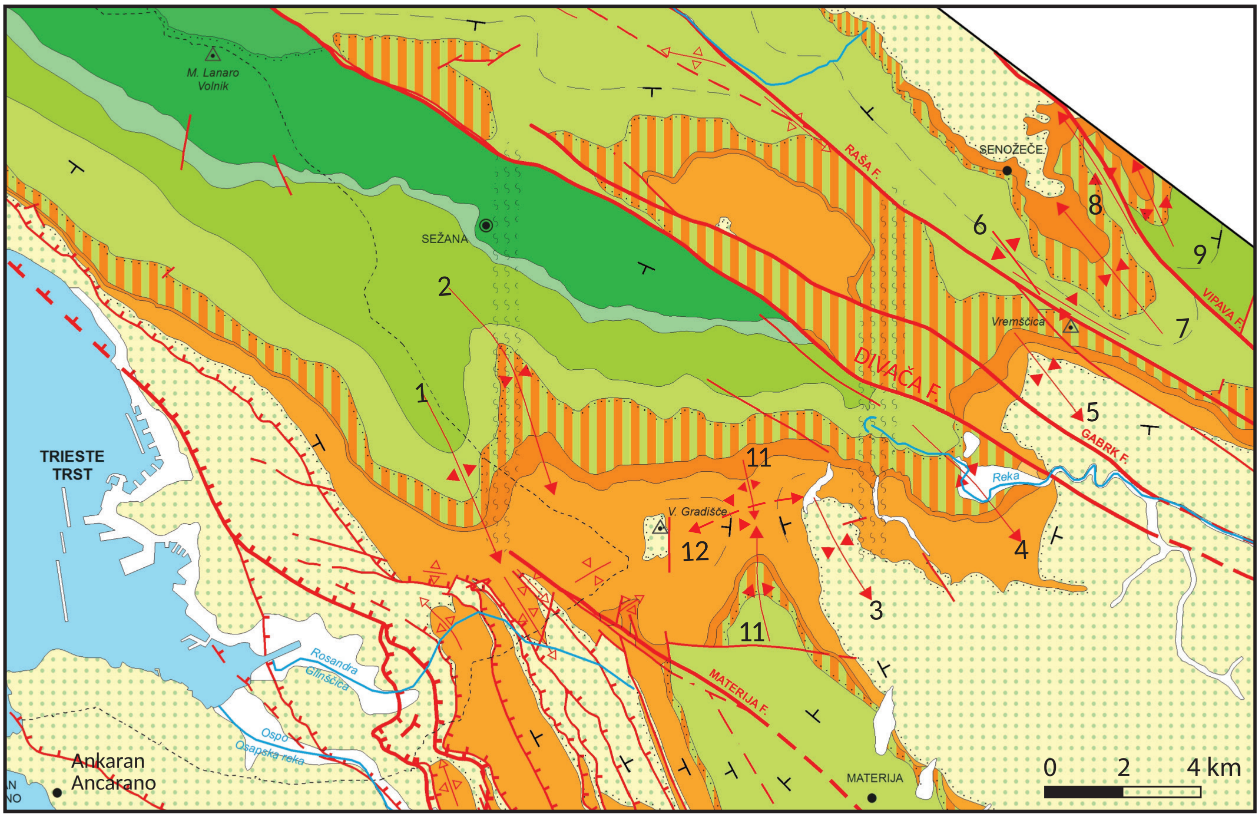


Fig. 9. Compartment-like folded structure, folds splitting and crosswise connecting folds: A. Structural sketch of the compartment-like folded territory of the External Dinaric Imbricated Belt. B. Folds splitting. C. Crosswise connecting folds: concavely bent anticline axis, convexly bent syncline axis; D. Reduced compressibility of the Senožeče Folds Splitting Zone.

Sl. 9. Predalčna nagubana zgradba, cepljenje gub in navzkrižno-povezovalne gube: A. Strukturna skica predalčno nagubanega ozemlja Zunanjedinarskega naluskanega pasu. B. Cepljenje gub. C. Navzkrižno-povezovalne gube: konkavno usločena os antiklinale, konveksno usločena os sinklinale; D. Zmanjšana stisljivost senožeške cone cepljenja gub.



STRATIGRAPHIC CHART after / STRATIGRAFSKA TABELA po: Jurkovšek, B. et al. 2013

AGE STAROST			FORMATION FORMACIJA			MAP KARTA
QUATERNARY KVARTAR			KV			
TERTIARY - TERCIAR	PALEOGENE PALEOGEN	EOCENE EOCEN	F	PP		
			ANA		KRAS GROUP KRAŠKA GRUPA	
		PALEOCENE PALEOCEN	TF	TF2		
				TF1		
			LIB			
CRETACEOUS - KREDA	UPPER CRETACEOUS ZGORNJA KREDA	MAASTRICHTIAN MAASTRICHTIJ				
		CAMPANIAN CAMPANIJ	LF			
		SANTONIAN SANTONIJ				
		CONIACIAN CONIACIJ	SF			
		TURONIAN TURONIJ	RF			
		CENOMANIAN CENOMANIJ	PF			
	LOWER CRETACEOUS SPODNJA KREDA	ALBIAN ALBIJ				
		APTIAN APTIJ	BF			
		VALANGINIAN VALANGINIJ				

DESCRIPTION OF FORMATIONS after / OPIS FORMACIJ po: Jurkovšek, B. 2008

KV: Quaternary deposit
Kvartarni nanos

F: FLYSCH. Alternation of marlstone, sandstone, breccia and conglomerate. Calcarenite intercalations and olistostromes. In the basis Transitional Beds (PP): breccia and basal marl
FLIŠ. Menjavanje laporovca, peščenjaka, breče in konglomerata. Vložki kalkarenita in olistostrome. V podlagi prehodne plasti (PP): breča in bazalni lapor

ANA: ALVEOLINID-NUMMULITID LIMESTONE. Bedded and massive limestone
ALVEOLINSKO-NUMULITNI APNENEC. Plastnati in masivni apnenec

TF: TRSTELJ FORMATION. Upper Trstelj Beds (TF2): Bedded calcarenite with foraminifers. Lower Trstelj Beds (TF1): Bedded, mainly miliolid limestone
TRSTELJSKA FORMACIJA. Zgornje trsteljske plasti (TF2): Plastnati kalkarenit s foraminiferami. Spodnje trsteljske plasti (TF1): Plastnati, pretežno miliolidni apnenec

LIB: LIBURNIA FORMATION. Bedded limestone, marly limestone and limestone breccia
LIBURNIJSKA FORMACIJA. Plastnati apnenec, laporasti apnenec in apnenčeva breča

LF: LIPICA FORMATION. Bedded and massive limestone with rudist biostromes and bioherms. Intercalations of platy and laminated Tomaj Limestone with chert
LIPIŠKA FORMACIJA. Plastnati in masivni apnenec z rudistnimi biostromami in biohermami. Vmes ploščasti in laminirani tomajski apnenec z rožencem

SF: SEŽANA FORMATION. Bedded limestone with rare rudist biostromes. Intercalations of bedded Pliskovica Limestone with chert and with pelagic microfossils and platy laminated Komen Limestone with chert. In the basis bedded limestone with oncoids and desiccation pores and thickly bedded to massive limestone with large amount of rudists
SEŽANSKA FORMACIJA. Plastnati apnenec z redkimi rudistnimi biostromami. Vmes plastnati pliskovški apnenec z rožencem in pelagičnimi mikrofosil ter ploščasti in laminirani komenski apnenec z rožencem. V podlagi plastnati apnenec z onkoidi in izsušitvenimi porami ter debeloplastnati do masivni apnenec z veliko količino rudistov

RF: REPEN FORMATION. Bedded limestone with chert and pelagic microfossils. Intercalations of platy and laminated Komen Limestone with chert and pelagic microfossils. In the basis massive, partly recrystallized Kopriva Limestone with displaced, locally broken and rounded rudist shells
REPENSKA FORMACIJA. Plastnati apnenec z rožencem in pelagičnimi mikrofosili. Vmes ploščasti in laminirani komenski apnenec z rožencem in pelagičnimi mikrofosili. V podlagi masivni in delno rekristalizirani koprivski apnenec s premeščenimi, mestoma zdrobljenimi in zaobljenimi lupinami rudistov

PF: POVIR FORMATION. Bedded, locally platy limestone with thicker dolomite intercalations and with rare intercalations of dolomitic breccia and limestone breccia. In upper part platy and laminated Komen Limestone with chert. In the basis emergence breccia
POVIRSKA FORMACIJA. Plastnati, lokalno ploščasti apnenec z debelejšimi vložki dolomita in redkimi vložki dolomitne breče ter apnenčeve breče. V zgornjem delu ploščasti in laminirani komenski apnenec z rožencem. V podlagi emerzijska breča

BF: BRJE FORMATION. Bedded limestone and dolomite with intercalations of dolomitic breccia and limestone breccia
BRSKA FORMACIJA. Plastnati apnenec in dolomit z vložki dolomitne in apnenčeve breče

Fig. 10. Structural-geological map of the Senožeče Folds Splitting Zone. Updated after Jurkovšek et al. (1996; 2008; 2013) and Placer (2015). The updates do not interfere with the thrust structure. *The key for the naming of the folds in Fig. 11.*

Sl. 10. Strukturno-geološka karta senožeške cone cepljenja gub. Dopolnjeno po Jurkovšek et al. (1996, 2008, 2013) in Placer (2015). Dopolnitve ne posegajo v narivno zgradbo. *Legenda poimenovanja gub na sl. 11.*

Nappe; this corresponds to the spatial lag between the Trieste-Komen and the Čičarija Anticlinoria, as well as a temporal lag, since in the nappe structure the younger units are formed below the older ones. In the Glinščica/Rosandra area, where the Trieste-Komen and Čičarija Anticlinoria meet, the thrust structures of the latter lie below the thrust structures of the former.

The area of the described splitting of folds is shown on a simplified structural map of the considered territory (Fig. 10), from where it is transferred to the digital model of the relief in Figure 11. Based on previous research, we conclude (OGK, sheets: Gorica, Postojna, Ilirska Bistrica; Jurkovšek et al., 1996; Placer, 2015) that there are three major folds on the south-eastern margin of the Trieste-Komen Anticlinorium, which are also part of the north-western margin of the Brkini Synclinorium. For the sake of easier discussion, we have now named them. In Figures 10 and 11 they are marked with numbers, the Artviže (3) and Gornje Ležeče Synclines (5), and the Famlje Anticline (4). Senožeče (7) and Laže Syncline (9), and Jelenje (8) and Razdrto Anticline (10) are clearly visible at the junction of the Vipava Synclinorium and the Ravnik Anticlinorium. The latter is presented only in Figure 11. Between the Gornje Ležeče and Senožeče Synclines, there is an anticline that also belonged to this group of split folds; however, it lies in the wider zone of the Raša Fault and is therefore strongly deformed. In Figures 10 and 11 it is only symbolically presented and named after the Vremščica Paleo-Vremščica Anticline (6).

jugozahodu v smeri narivanja. V podaljšku stika Hrušiškega in Trnovskega pokrova ni podobnega pojava, kar bi lahko pomenilo dvoje, da je lega prečnodinarske cone cepljenja gub slučajna, ali pa, da se Hrušiški pokrov razteza pod Trnovskim pokrovom še daleč proti severozahodu in delujeta obe krovni enoti skupaj kot enotna narivna gruda. V nasprotju s tem pa naj bi se Snežniški pokrov pod Hrušiškim kmalu izklinil. Da je taka razlaga mogoča, kaže hidrološka povezava med izvirom reke Vipave v Hrušiškem pokrovu in ponori vzhodno od Postojnske kotline v Snežniškem pokrovu (Petrič et al., 2020). Trnovski in Hrušiški pokrov sta starejša od Snežniškega; to ustreza prostorskemu zamiku med Tržaško-Komenskim in Čičarijskim antiklinorijem, pa tudi časovnemu zamiku, saj v krovni zgradbi mlajše enote nastajajo pod starejšimi. Na območju Glinščice, kjer se stikata Tržaško-Komenski in Čičarijski antiklinorij, narivne strukture slednjega ležijo pod narivnimi strukturami prvega.

Območje opisanega cepljenja gub je prikazano na poenostavljeni strukturni karti obravnavanega ozemlja (sl. 10), od koder je preneseno na digitalni model reliefa na sliki 11. Po dosedanjih raziskavah povzemamo (OGK, listi: Gorica, Postojna, Ilirska Bistrica; Jurkovšek et al., 1996; Placer, 2015), da nastopajo na jugovzhodnem obrobju Tržaško-Komenskega antiklinorija tri večje gube, ki so hkrati tudi del severozahodnega obrobja Brkinskega sinklinorija. Zaradi lažjega pogovora smo jih zdaj poimenovali, na

Fig. 11. Geomorphology of the Senožeče Folds Splitting Zone.

Sl. 11. Geomorfologija senožeške cone cepljenja gub.

1 External Dinaric Thrust Belt boundary, nappe boundary, nappe unit (T – Trnovo Nappe, H – Hrušica Nappe, S – Snežnik Nappe) / meja Zunanjedinarskega narivnega pasu, meja pokrova, pokrov (T – Trnovski pokrov, H – Hrušiški pokrov, S – Snežniški pokrov)

2 Istra-Friuli Thrust-Underthrust Zone / istrsko-furlanska narivno-podrivna cona

3 Črni Kal Anomaly / črnokalska anomalija

4 Two folds in the Črni Kal Anomaly influence zone: 1 – Bazovica Anticline, 2 – Lipica Syncline / gubi v vplivnem območju črnokalske anomalije: 1 – Bazovska antiklinala, 2 – Lipiška sinklinala

5 Subvertical NW striking faults (»Dinaric trend«) with a predominant shear offset component: IF – Idrija Fault, PF – Belsko Fault, RF – Raša Fault / subvertikalni prelomi dinarske smeri s pretežno zmično komponento premika: IF – Idrijski prelom, BF – Belski prelom, RF – Raški prelom

6 Compartment-like folded area: a – Čičarija Anticlinorium, b – Trieste-Komen Anticlinorium, c – Ravnik Anticlinorium, d – Brkini Synclinorium, e – Vipava Synclinorium / predalčno nagubano ozemlje: a – Čičarijski antiklinorij, b – Tržaško-Komenski antiklinorij, c – Ravniški antiklinorij, d – Brkinski sinklinorij, e – Vipavski sinklinorij

7 Splitting folds: 3 – Artviže Syncline, 4 – Famlje Anticline, 5 – Gornje Ležeče Syncline, 6 – Paleo-Vremščica Anticline, 7 – Senožeče Syncline, 8 – Jelenje Anticline, 9 – Laže Syncline, 10 – Razdrto Anticline / cepilne gube: 3 – Artviška sinklinala, 4 – Fameljska antiklinala, 5 – Gornjeležeška sinklinala, 6 – Paleovremška antiklinala, 7 – Senožeška sinklinala, 8 – Jelenja antiklinala, 9 – Laženska sinklinala, 10 – Razdrška antiklinala

8 Cross-connecting folds: 11 – Rodik-Preloka Anticline, 12 – Pared Syncline / navzkrižno-povezovalne gube: 11 – Rodiško-Preloška antiklinala, 12 – Paredska sinklinala

9 Undation of the nappe units: I – Nanos-Čaven antiform, II – Hrušica-Trnovo synform / undacija krovnih enot: I – nanoško-čavenska antiforma, II – hrušiško-trnovska sinforma

10 Sistiana Flexural Zone / sesljanska upogibna cona


0
5
10 km
TT
Trnovski gozd
Čaven
BF
HT
Hrušica
IF
Nanos
Postojna basin
KRAS
RF
ST
TRIESTE
TRST
Fig. 10
Kraški rob
Črni Kal
Ilirska Bistrica
a
b
c
d
e
1
2
3
4
5
6
7
8
9
10
11
12
I
II
TT
HT
IF

The considered folds splitting zone is several kilometres wide and lies transversely in the direction of the Dinaric fold axes. It is named after the village of Senožeče – the Senožeče Folds Splitting Zone.

The cross-connecting folds are partially preserved between the Trieste-Komen and Čičarija Anticlinoria, and the Brkini Synclinorium and the flysch depression in front of the Trieste-Komen Anticlinorium. They can be seen in the junction between the Rodik and Preloka Anticlines, named the Rodik-Preloka Anticline (11), which has a concave folded axis, and a convexly folded syncline lying transversely to it, which runs between the Brkini Synclinorium and the depression in front of the Trieste-Komen Anticlinorium. We named it the Pared Syncline (12). The degree of curvature of the axes of cross-connecting folds is weak, so in some places they are not mapped at all. Between the Trieste-Komen and Ravnik Anticlinoria and the Vipava and Brkini Synclinoria the cross-connecting folds are deformed along the Raša Fault.

As was already noted, the Lipica Syncline (2) and the Bazovica Anticline (1) on the margin of the Trieste-Komen Anticlinorium do not belong to the theoretical model of the Senožeče Folds Splitting Zone. This assumption is also confirmed by the general structural setting, since there are no folds connecting the lagged Trieste-Komen and Čičarija Anticlinoria southwest of the cross-connecting Rodik-Preloka Anticline (11) and Pared Syncline (12). The formation of the two mentioned folds (1 and 2) is related to the Črni Kal Anomaly, presumably with the antiformly bent Paleogene thrust surface in Glinščica/Rosandra area (Fig. 4A, area »a«).

Deformations that cannot be related to folds splitting but rather to an increased compression northeast of the Črni Kal Anomaly occur in the Senožeče Folds Splitting Zone. The connection to the increased compression is obvious, as the general structures of the south-western part of the Senožeče Folds Splitting Zone run parallel to the Črni Kal Anomaly (Fig. 11), which applies to the extreme north-western part of the Čičarija Anticlinorium and the Artviže Syncline (3) in the Brkini Synclinorium and also for the Lipica Syncline (2) and Bazovica Anticline (1). The cross-connecting folds of the Rodik-Preloka Anticline (11) and the Pared Syncline (12) also have a modified position. We will not discuss the kinematic mechanism of the adjustment of the mentioned structures in the direction of the Črni Kal Anomaly herein, but it would certainly be necessary to conduct some

slikah 10 in 11 so označene s številkami, tu ležijo Artviška (3) in Gornjeležeška sinklinala (5) ter Fameljska antiklinala (4). Na stiku Vipavskega sinklinorija in Ravniškega antiklinorija so lepo vidne Senožeška (7) in Laženska sinklinala (9) ter Jelenja (8) in Razdrška antiklinala (10). Slednja je vidna le na sliki 11. Med Gornjeležeško in Senožeško sinklinalo je obstajala antiklinala, ki je tudi pripadala tej skupini cepilnih gub, vendar leži v širši coni Raškega preloma in je zaradi tega močno deformirana. Na sliki 11 je le simbolno zabeležena in poimenovana po Vremščici Paleovremška antiklinala (6) (Paleovremščica anticline). Izognili smo se izrazu Paleovremščiška, ker je neroden, izraz paleoantiklinala Vremščice pa bi odstopal od pridevniške rabe za ostale gube, ki je prijaznejša do slovenščine.

Obravnavana cona cepljenja gub je široka nekaj kilometrov in leži prečno na osi gubanja Dinaridov. Imenujemo jo senožeška cona cepljenja gub.

Navzkrižno-povezovalne gube so delno ohranjene med Tržaško-Komenskim in Čičarijskim antiklinorijem ter Brkinskim sinklinorijem in flišno udorino pred Tržaško-Komenskim antiklinorijem. Vidimo jih v povezavi med Rodiško in Preloško antiklinalo, poimenovano Rodiško-Preloška antiklinala (11), ki ima konkavno usločeno os in prečno nanjo ležečo konveksno usločeno sinklinalo, ki poteka med Brkinskim sinklinorijem in udorino pred Tržaško-Komenskim antiklinorijem. Poimenovali smo jo Paredska sinklinala (12). Stopnja ukrivljenosti osi navzkrižno-povezovalnih gub je šibka, zato ponekod sploh niso kartirane. Med Tržaško-Komenskim in Ravniškim antiklinorijem ter Vipavskim in Brkinskim sinklinorijem sta navzkrižno-povezovalni gubi deformirani ob Raškem prelomu.

Kot je bilo že rečeno, Lipiška sinklinala (2) in Bazovska antiklinala (1) na robu Tržaško-Komenskega antiklinorija, ne sodita v teoretski model senožeške cone cepljenja gub. To predpostavko potrjujejo tudi splošne razmere, saj jugozahodno od navzkrižno-povezovalnih Rodiško-Preloške antiklinale (11) in Paredske sinklinale (12) ni gub, ki bi povezovale zamaknjena Tržaško-Komenski in Čičarijski antiklinorij. Nastanek obeh omenjenih gub (1 in 2) je povezan s črnokalsko anomalijo, domnevno z antiformno usločitvijo paleogenske narivne ploskve v Glinščici (sl. 4A, območje »a«).

V senožeški coni cepljenja gub nastopajo deformacije, ki jih ne moremo povezovati s cepljenjem temveč s povečano kompresijo severovzhodno od

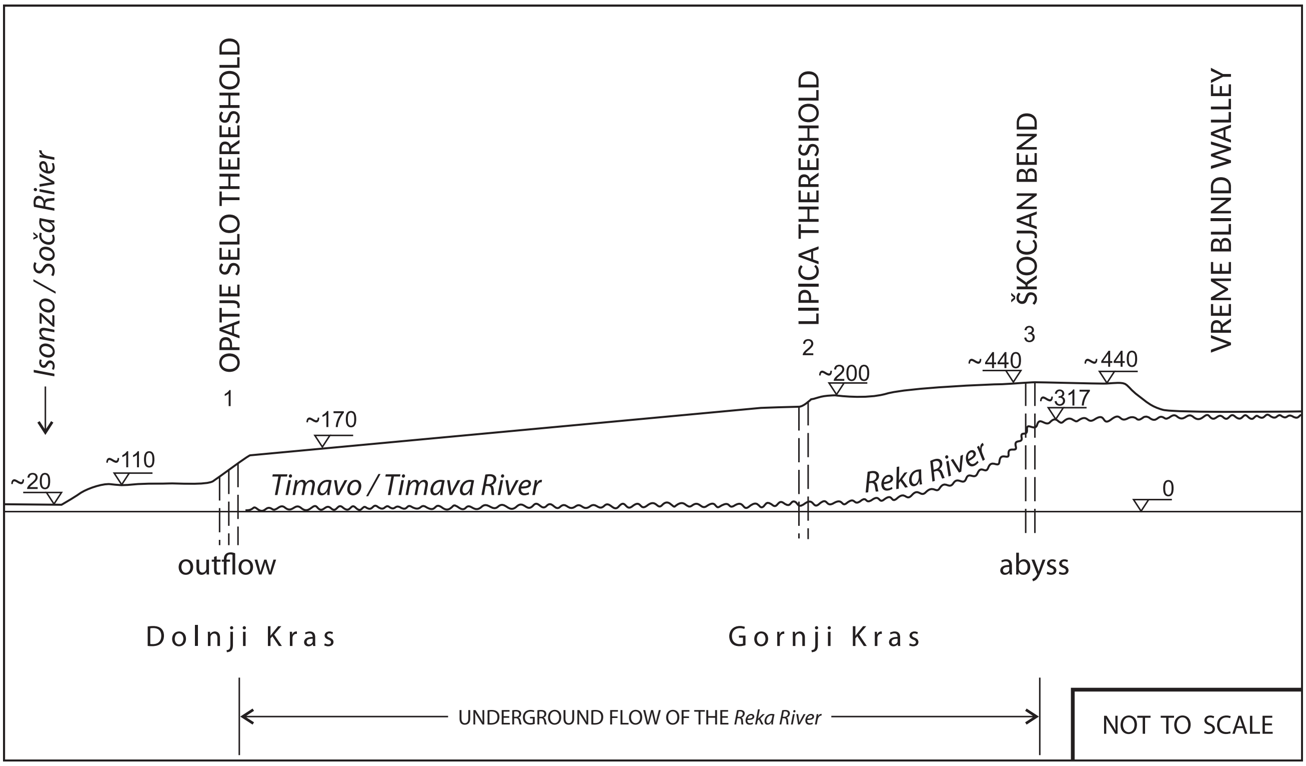


Fig. 12. Sketch of the longitudinal geomorphological cross section of Kras region. Position of the profile in Fig. 2.
Sl. 12. Skica vzdolžnega geomorfološkega profila Krasa. Lega profila na sl. 2.

detailed structural research before answering this question.

The effect of locally increased compression in the Dinaric hinterland of the Črni Kal Anomaly is also reflected in the longitudinal geomorphological profile of the Kras region (Fig. 12). Initially, the original peneplanation of the Trieste-Komen Plateau was sub-horizontal, whereas today it is inclined. From the Doberdob Plateau on the Spodnji Kras at an elevation of about 110 m, it gradually rises towards Gornji Kras to about 440 m on the Divača Kras, where the rise terminates at the Matavun Fault Zone, along which the Škocjan structural bend was formed (Placer, 2015). Behind the Škocjan structural bend lies the plateau of Goriče Kras (after the village of Goriče near Famlje), which is not inclined but remains horizontal at around 440 m. Somewhat below this settlement, at an elevation of about 400 m, lies the Naklo level, as a remnant of the blind Vreme valley highest terrace. The Škocjan structural bend played an active role in the formation of the present Notranjska Reka (river) sinking area and the longitudinal profile of the Škocjan Caves. In the simplified structural map of the Karst (Placer, 2015), the term Škocjanski prag (Škocjan treshold) was used for the structural bend, but it is not an elevation level, only an escarpment, which requires a new corresponding term.

črnokalske anomalije. Povezava je očitna zato, ker so generalne strukture jugozahodnega dela senožeške cone cepljenja gub vzporedne črnokalski anomaliji (sl. 11), to velja za skrajni severozahodni del Čičarijskega antiklinorija in za Artviško sinklinalo (3) v Brkinskem sinklinoriju in za Lipiško sinklinalo (2) in Bazovsko antiklinalo (1). Spremenjeno lego imata tudi navzkrižno-povezovalni gubi Rodiško-Preloška antiklinala (11) in Paredska sinklinala (12). Kakšen je bil kinematski mehanizem prilagoditve omenjenih struktur smeri črnokalske anomalije v tem članku ne bomo razpravljali, vsekakor pa bi bilo potrebno pred odgovorom na to vprašanje, izvesti detajlne usmerjene strukturne raziskave.

Učinek lokalno povečane kompresije v dinarskem zaledju črnokalske anomalije se odraža tudi v vzdolžnem zbirnem geomorfološkem profilu Krasa (sl. 12). Prvotna uravnava Tržaško-Komenske planote je bila ob svojem nastanku subhorizontalna, danes je nagnjena. Od Doberdobske planote na Spodnjem Krasu na višini okoli 110 m, se proti Gornjemu Krasu polagoma dviga do okoli 440 m na Divaškem Krasu, kjer se dviganje ustavi ob matavunski razpoklinsko-prelomni coni, po kateri je nastal škocjanski pregib (Placer, 2015). Za škocjanskim pregibom leži uravnava Goriškega Krasa (po vasi Goriče pri Famljah), ki ni nagnjena temveč ostaja na enaki višini okoli

External Dinaric Thrust Belt

Figure 11 also shows part of the External Dinaric Thrust Belt with the Snežnik, Hrušica and Trnovo Nappes. According to the regional research data (OGK, sheets: Tolmin, Videm, Kranj, Gorica, Postojna; Mlakar, 1969), we conclude that the overlying thrust plane of the Trnovo Nappe bends transversely to the Dinarides, so that from southwest to northeast the Trnovo synform, the Idrija antiform, Žiri synform and the Poljane-Vrhnika antiform (Placer et al., 2021a) stand out. In Figure 11, only a part of the Trnovo synform (II) is visible, the axis of which continues towards the southeast into the Hrušica Syncline. It is not possible from the data on the geologic map to determine whether the underlying Hrušica Nappe thrust plane is also synformly bent.

In the article on the relationship between tectonics and gravity phenomena at the boundary of the External Dinaric Thrust Belt (Placer et al., 2021a), it was established that the underlying thrust surfaces of the Hrušica Nappe below Nanos and the Trnovo Nappe below Mt. Čaven are convexly folded. The new terms Nanos and Čaven antiforms were introduced. Both therefore lie at the head of both thrust fronts, but they differ in amplitude – in the first it is around 250 m, in the second around 30 m.

The Nanos and Čaven antiforms at the head of the Hrušica and Trnovo Nappe belong to the same antiform unit (Placer et al., 2021a), so it makes sense to introduce the term Nanos-Čaven antiform (Fig. 11, I). The relationship between them is not clear because the intervening space is denuded, and the Sistiana Flexural Zone also passes through it (Placer et al., 2021b), due to which the axis of the antiform is bent laterally and its convex part rests on the Belsko Fault (formerly Predjama fault, Placer et al., 2021a). The lateral bending of the Nanos-Čaven antiform and the unusual change of the Belsko Fault trace are the result of the crossing of two Transverse Dinaric deformation zones in this area, the flexural zone of the Sistiana Fault and the now described zone of increased compression in the Dinaric hinterland of the Črni Kal Anomaly. A more detailed description of the effect of the aforementioned deformations in this area is beyond the scope of this article, and to prove the existence of a zone of increased compression it is important to note that the Nanos segment of the Nanos-Čaven antiform has a significantly larger amplitude than the Čaven segment.

440 m. Nekaj pod to uravnavo leži na koti okoli 400 m nakelski nivo, ki je ostanek najvišje terase Vremske slepe doline. Škocjanski pregib je imel dejavno vlogo pri nastajanju sedanjega ponornega območja notranjske Reke in vzdolžnega profila Škocjanskih jam. V poenostavljeni strukturni karti Krasa (Placer, 2015) je bil za škocjanski pregib uporabljen termin škocjanski prag, vendar ne gre za višinsko stopnjo temveč le za pregib, ki terja ustrezno spremembo naziva.

Zunanjedinarski narivni pas

Na sliki 11 je viden tudi del Zunanjedinarskega narivnega pasu s Snežniškim, Hrušiškim in Trnovskim pokrovom. Po podatkih dosedanjih regionalnih raziskav povzemamo (OGK, listi: Tolmin in Videm, Kranj, Gorica, Postojna; Mlakar, 1969), da krovna narivna ploskev Trnovskega pokrova undira prečno na Dinaride, tako da od jugozahoda proti severovzhodu izstopajo trnovska sinforma, idrijska antiforma, žirovska sinforma in poljansko-vrhniška antiforma, oziroma poljansko-vrhniški nizi (Placer et al., 2021a). Na sliki 11 je od naštetih viden le del trnovske sinforme (II), katere os se proti jugovzhodu nadaljuje v Hrušiško sinklinalo, medtem ko iz podatkov na karti ni mogoče ugotoviti ali je sinformno usločena tudi krovna narivna ploskev Hrušiškega pokrova.

V članku o odnosu med tektoniko in gravitacijskimi pojavi na meji Zunanjedinarskega narivnega pasu (Placer et al., 2021a) je bilo ugotovljeno, da sta krovni narivni ploskvi Hrušiškega pokrova pod Nanosom in Trnovskega pokrova pod Čavnom konveksno usločeni. Uvedena sta bila termina nanoška in čavenska antiforma. Obe torej ležita v čelu obeh pokrovov, vendar se razlikujeta po velikosti amplitude, pri prvi znaša okoli 250 m, pri drugi okoli 30 m.

Nanoška in čavenska antiforma v čelu Hrušiškega in Trnovskega pokrova pripadata isti antiformni enoti (Placer et al., 2021a), zato je smiselno uvesti termin nanoško-čavenska antiforma (sl. 11, I). Odnos med njima je nejasen zato, ker je vmesni prostor denudiran, preko njega pa poteka tudi sesljanska upogibna cona (Placer et al., 2021b), zaradi katere je os antiforme bočno upognjena, njen izbočeni del pa se naslanja na Belski prelom (prej Predjamski prelom, Placer et al., 2021a). Bočni upogib nanoško-čavenske antiforme in nenavadna sprememba smeri Belskega preloma sta posledica križanja dveh prečnodinarskih

Raša Fault

In order to understand the deformations along the Raša Fault in the area of the Transverse Dinaric zone of increased compression between the Kraški rob and Hrušica, it is necessary to look at its trace from a greater distance. The Raša Fault trace (Fig. 1) is drawn on the Italian side according to Carulli's (2006) data. On the Slovenian side, it is interpreted anew between Gorica and Dornberk, and from here to Vremščica by Poljak (2007), Jurkovšek et al. (1996), Jurkovšek (2010); Placer (2015), Placer et al. (2021b), and according to OGK data (sheets: Gorica, Trieste, Postojna and Ilirska Bistrica). Southeast of Vremščica, the Raša Fault trace is drawn on the basis of an exposed fault zone in the Stržen stream valley (Fig. 13) and on the basis of the interpretation of the formation of the pull-apart Ilirska Bistrica coal basin, which is said to have formed along the Raša Fault (Placer & Jamšek, 2011). In Figure 1, the visible part of the fault trace is marked with a solid line, and the invisible or presumed part with a dashed line.

For the purposes of this article, it is important to show in greater detail the conditions along the Raša Fault between Gorica and Vremščica (Fig. 13) and the Stržen valley. The damage zone is exposed in several places, in the village of Brdo near Dornberk (village) (Fig. 13, point 1), in the ravines and on the intermediate ridges between Tabor and Cvetrož village (Fig. 13, point 2), in the Zajčica road cut on the highway near Senožeče (Fig. 13, point 3), in three sand pits »V žlebu« (toponime) above Čepno beneath the Mt. Vremščica slope (Fig. 13, point 4) and along the Stržen (Fig. 13, point 5). There are also several small sand pits in the Raša valley next to the Raša Fault.

The structure of the Raša Fault is best visible in the Zajčica terraced road cut on the highway near Senožeče (Fig. 13, point 3; Fig. 14), and was also revealed in a large, abandoned sand pit near the road cut. The entire fault zone, about 80 m wide, is exposed in the east wall of the road cut (Fig. 14A). Its major part is enlarged in Figure 14B. Here, an anticlinal fold is still visible in the third terrace. The anticline can be detected upon closer inspection of the entire roadcut. The first terrace riser is already built up and covered with grass, which is why Figure 14C shows the mirror image of the western wall of the road cut at the height of the first terrace, which is no longer there today but the mentioned anticline was clearly visible here. In Figure 14D, the structure of the section is sketched with the stratigraphic data from Jurkovšek et al. (1996); on the left half, there is bedded Lipica Formation limestone (LF/K_2^{4-5}),

deformacijskih con na tem prostoru, upogibne cone Sesljanskega preloma in sedaj opisovane cone povečane kompresije v dinarskem zaledju črnokalske anomalije. Natančnejši opis učinka omenjenih deformacij na tem prostoru presega okvir tega članka, za dokazovanje obstoja cone povečane kompresije pa je pomembno, da ima nanoški segment nanoško-čavenske antiforme bistveno večjo amplitudo od čavenskega segmenta.

Raški prelom

Za razumevanje deformacij ob Raškem prelomu v območju prečnodinarske cone povečane kompresije med Kraškim robom in Hrušico, je potrebno pogledati na njegov potek z nekoliko večje razdalje. Trasa Raškega preloma (sl. 1) je na italijanski strani potegnjena po podatkih Carulli-ja (2006). Na slovenski strani je od Gorice do Dornberka interpretirana na novo, od tu do Vremščice pa po podatkih Poljaka (2007), Jurkovška et al. (1996), Jurkovška (2010), Placerja (2015) in Placerja et al. (2021b), ter po podatkih OGK (listi Gorica, Trst, Postojna, Ilirska Bistrica). Jugovzhodno od Vremščice je potegnjena na podlagi vidne prelomne cone v dolini potoka Stržena (sl. 13) in na podlagi interpretacije nastanka ilirskobistriškega premogovnega pull apart-skega ali razmičnega bazena, ki naj bi nastal ob Raškem prelomu (Placer & Jamšek, 2011). Na sliki 1 je vidni del trase označen s polno črto, nevidni ali domnevni del pa s prekinjeno črto.

Za ta članek je pomembno, da podrobneje prikažemo razmere ob Raškem prelomu med Gorico in Vremščico (sl. 13) ter dolino potoka Stržena. Zdrobljena cona je vidna na več mestih, v naselju Brdo pri Dornberku (sl. 13, točka 1), v grapah in na vmesnih grebenih med Taborom in Cvetrožem (sl. 13, točka 2), v useku Zajčica na avtocesti pri Senožečah (sl 13, točka 3), v treh peskokopih »V žlebu« nad Čepnim pod Vremščico (sl. 13, točka 4) in ob potoku Strženu (sl. 13, točka 5). Tudi v dolini Raše je ob Raškem prelomu več manjših peskokopov.

Najlepše je vidna zgradba Raškega preloma v terasastem useku avtoceste Zajčica pri Senožečah (sl. 13, točka 3; sl. 14), razkrita pa je bila tudi v veliki jami nekdanjega peskokopa blizu useka. Na sliki 14A je fotografija vzhodne stene useka, kjer je vidna celotna zdrobljena cona preloma, široka okoli 80 m. Njen večji del je povečan na sliki 14B, tu je v ježi tretje terase kljub porušenosti še opazna antiklinalna guba, ki jo je pri bolj natančnem pregledu mogoče zaznati na celotni višini useka. Ježa prve terase je že podzidana in zatravljena, zato je na sliki 14C prikazana

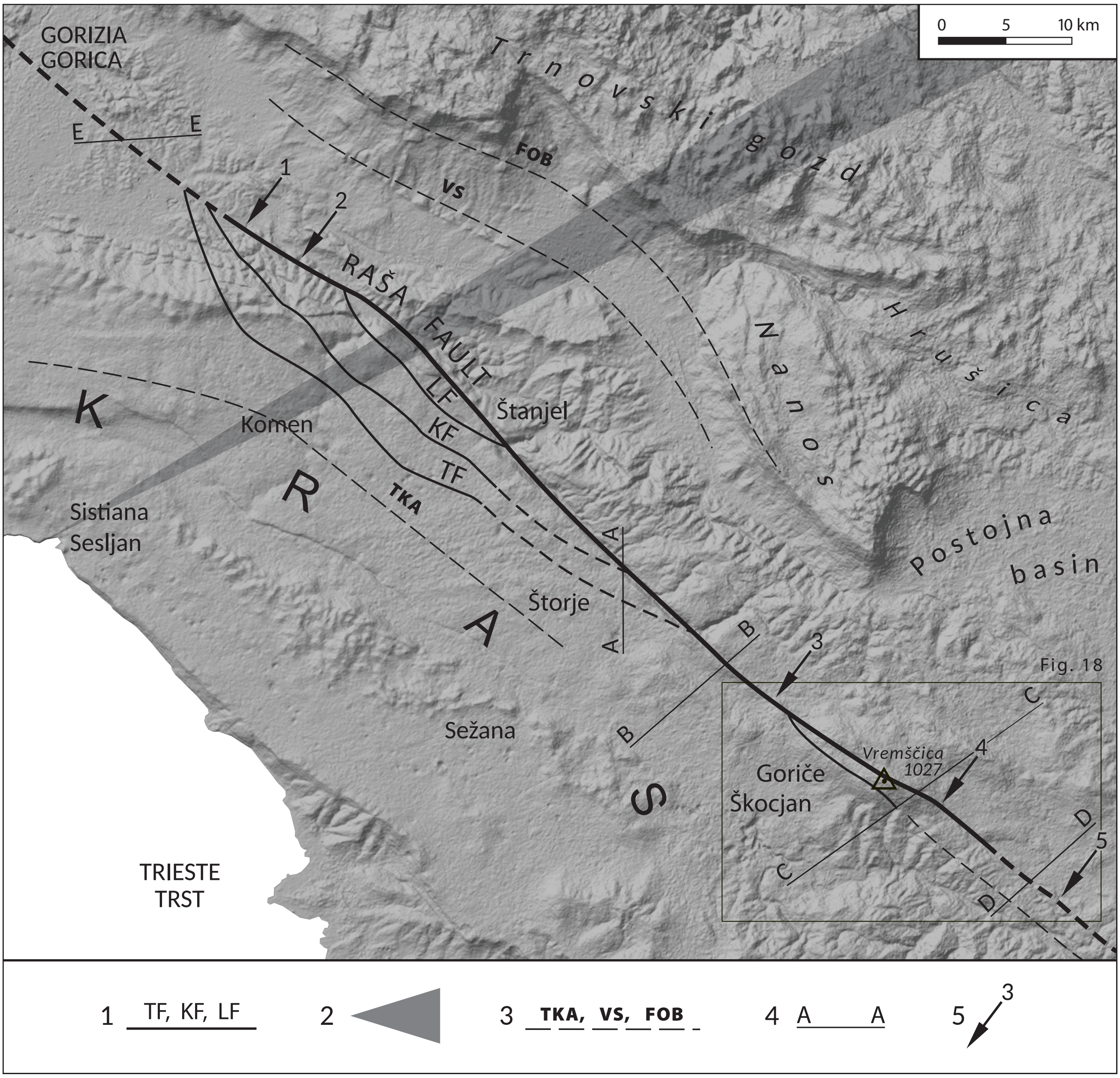


Fig. 13. Raša Fault between Gorica and the Stržen stream.
Sl. 13. Raški prelom od Gorice do potoka Stržen.

1 Adjusting faults: TF – Tomačevo Fault, KF – Kobjeglava Fault, LF – Lukovec Fault / izravnalni prelomi: TF – Tomačevski prelom, KF – Kobjeglavski prelom, LF – Lukovski prelom

2 Sistiana Flexural Zone / sesljanska upogibna cona

3 Bent structures in the Sisitiana Flexural Zone: TKA – Trieste-Komen Anticlinorium axis, VS –Vipava Synclinorium axis, FOB – External DinaricThrust Belt front / upognjene strukture v sesljanski upogibni coni: TKA – os Tržaško-Komenskega antiklinorija, VS – os Vipavskega sinklinorija, FOB – čelo Zunanjedinarskega narivnega pasu

4 Profiles across the Raša Fault: A – A Štorje - Stomaž, B – B Povir - Griško polje, C – C Vremska dolina - Mt. Vremščica - Ravnik, D – D Košanska dolina, E – E Brezavščak stream valley / profili preko Raškega preloma: A – A Štorje - Stomaž, B – B Povir - Griško polje, C – C Vremska dolina - Vremščica - Ravnik, D – D Košanska dolina, E – E Dolina potoka Brezavščka

5 Observation sites of the Raša Fault: 1 – Brdo near Dornberk, 2 – Saksidi, 3 – Zajčica, 4 – Čepno, 5 – Stržen / mesta opazovanja Raškega preloma: 1 – Brdo pri Dornberku, 2 – Saksidi, 3 – Zajčica, 4 – Čepno, 5 – Stržen

gently dipping to the northeast, followed by two stronger subvertical fault planes with an intermediate tectonized block, then the block folded into an asymmetric anticline slightly inclined to the southwest. Its wavelength is 20 m to 25 m with an amplitude of about 8 m. Towards the southwest,

zrcalna podoba zahodne stene useka v višini ježe prve terase, ki je danes ni več. Tu je bila omenjena antiklinala lepo vidna. Na sliki 14D je zgradba useka skicirana, stratigrafski podatki so navedeni po Jurkovšku et al. (1996); na levi polovici so plasti Lipiške formacije (LF/K_2^{4-5}), ki the anticline limb lies on a subvertical fault plane, behind which lies a block of tectonized beds of the Lipica Formation. It is completed by a set of several parallel fault surfaces, behind which lie Liburnia Formation beds (LIB/K-Pc), already a part of the south-western block of the Raša Fault. As the Liburnian Formation makes a part of the Karst Group of Formations, the KGF is used instead of the LIB/K-Pc designation in Figure 14D. In the sand pit, right-lateral strike slip fault surfaces with sub-horizontal slickensides and several completely flat subvertical tectonic mirrors, from a few metres to 25 m^2 in size, were observed in the Lipica Formation limestones. Tectonic mirrors were polished to a high gloss, and clearly indicate periodic polygonal movement of the fault blocks, confirmed also by barely visible striae in different directions. Signs of polygonal movement of the fault blocks were also observed in the fault zone of the Idrija Fault (Placer, 1980, fig. 12) and in the thrust plane of the Hrušica Nappe in the sand pit near Planina (Placer, 1994/95).

In the profile sketch (14D), it is necessary to draw attention to the compatibility of the geological structure and the surface: on the left, the gentle slope of the upland adapts to the gently inclined bedding; the top of the upland lies above the top of the extruded anticline; and the steep slope on the right lies in the inner fault zone. From the conditions in the profile, we conclude that the relief here is the result of tectonic formation.

Three successive sand pits opened in the limestones of the Lipica and Liburnia Formations (LF/K_2^{4-5}, LIB/K-Pc), separated by the main fault plane of the damage zone of the Raša Fault in the »V žlebu« valley above Čepno village (Fig. 13, point 4). The most telling are the fault surfaces in the middle sand pit, where horizontal tectonic slickensides occur, which indicate right-lateral strike slip motion and vertical slides with block movements in different directions. Other directions are also present.

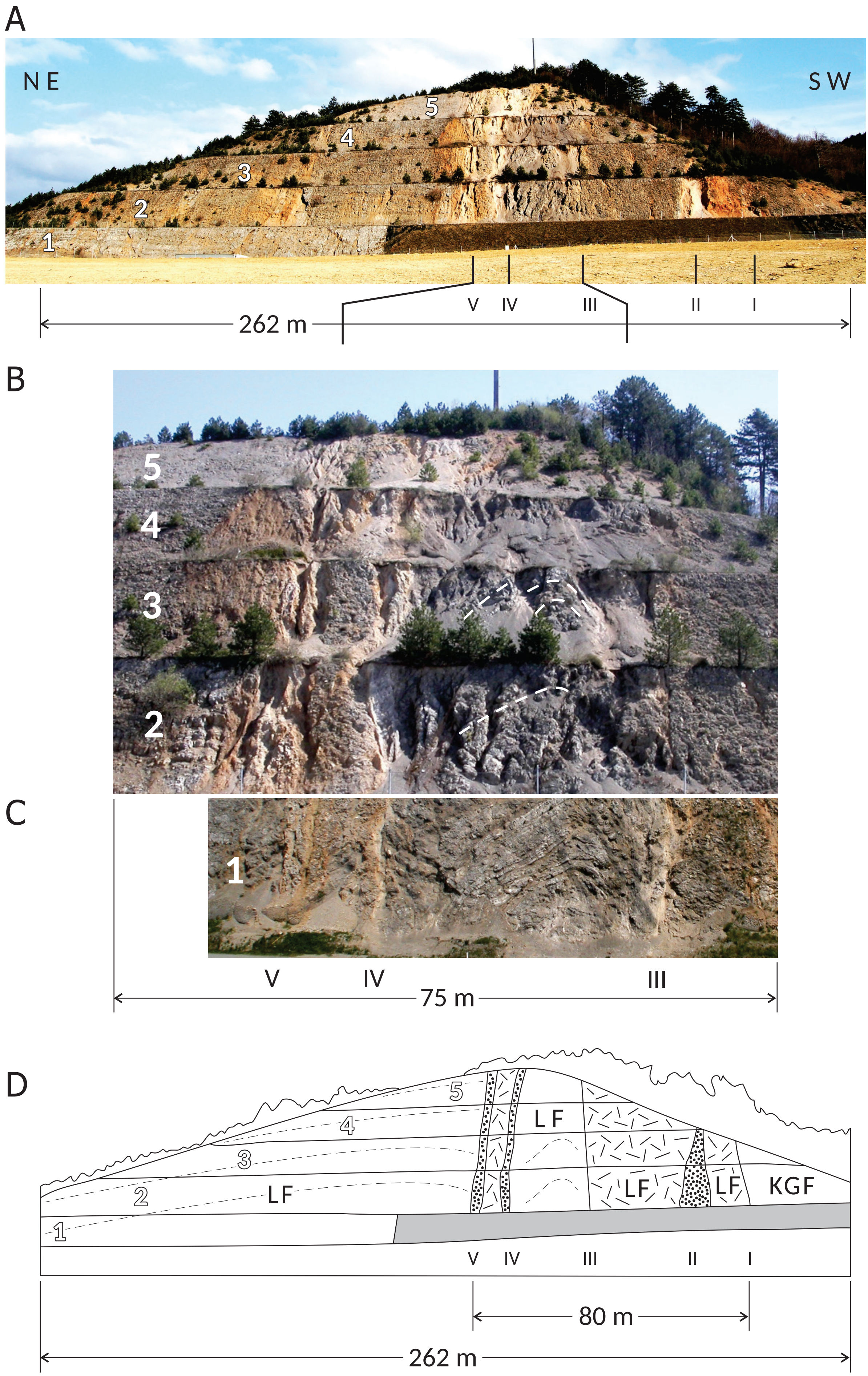
Flysch rocks occur in outcrops of the Raša Fault damage zone at Brdo near Dornberk (Fig. 13, point 1), between Tabor and Cvetrož (Fig. 13, point 2) and near Stržen (Fig. 13, point 5). In all cases, the main fault plane dips steeply towards the northeast; next to it lies a cut reverse flexure, which at first glance would indicate a simple reverse movement, but conditions at Zajčica and Čepno show that other movements also exist, so conclusions based on a limited set of data can be deceptive. Without detailed research of different parts of the fault zone, it is not possible to discuss the kinematics of the blocks along the Raša Fault. Only

položno vpadajo proti severovzhodu, sledita dve močnejši subvertikalni prelomni ploskvi z vmesnim zdrobljenim blokom, zatem blok naguban v asimetrično antiklinalo, ki je rahlo nagnjena proti jugozahodu. Njena valovna dolžina znaša okoli 20 m do 25 m, amplituda okoli 8 m. Proti jugozahodu se krilo antiklinale naslanja na subvertikalno prelomno ploskev, za katero je blok iz zdrobljenih plasti Lipiške formacije. Zaključi ga snop več prelomnih ploskev za katerimi ležijo plasti Liburnijske formacije (LIB/K-Pc), ki že pripadajo jugozahodnemu bloku Raškega preloma. Na sliki 14D je namesto Liburnijske formacije oznaka KGF (Kraška grupa formacij), katere del je tudi Liburnijska formacija. V peskokopu so bile v apnencih Lipiške formacije zabeležene desnozmične prelomne ploskve s subhorizontalnimi tektonskimi drsami in več povsem ravnih, od nekaj do 25 m^2 velikih subvertikalnih tektonskih zrcal, ki so bila polirana do visokega sijaja, kar jasno kaže na občasno poligonalno premikanje prelomnih kril, ki so ga potrjevale tudi komaj vidne strije v različnih smereh. Znaki poligonalnega premikanja prelomnih kril so bili opazovani tudi v prelomni coni Idrijskega preloma (Placer, 1980, sl. 12) in v narivni ploskvi Hrušiškega pokrova v peskokopu pri Planini (Placer, 1994/95).

V skici profila (14D) je potrebno opozoriti na skladnost geološke zgradbe in površja; na levi se položno pobočje vzpetine prilagaja položnim plastem, vrh vzpetine leži nad vrhom izrinjene antiklinale, strmo pobočje na desni leži v coni glavne prelomne ploskve. Iz razmer v profilu povzemamo, da je relief na tem mestu posledica tektonskega oblikovanja.

»V žlebu« nad Čepnim (sl. 13, točka 4) so odprti trije zaporedni peskokopi v apnencih Lipiške in Liburnijske formacije (LF/K_2^{4-5}, LIB/K-Pc), ki ju razdvaja glavna prelomna ploskev Raškega preloma. Najbolj povedne so prelomne ploskve v srednjem peskokopu, kjer nastopajo tektonske drse horizontalne smeri, ki kažejo na desno zmikanje in vertikalne drse z različno usmerjenimi premiki blokov. Prisotne pa so tudi druge smeri.

Izdanki zdrobljene cone Raškega preloma v Brdu pri Dornberku (sl. 13, točka 1), med Taborom in Cvetrožem (sl. 13, točka 2) ter ob Strženu (sl. 13, točka 5), so v flišnih kamninah. V vseh primerih glavna prelomna ploskev strmo vpada proti severovzhodu, ob njej leži pretrgana reverzna fleksura, kar bi na prvi pogled kazalo na enostavni reverzni premik, vendar Zajčica in Čepno kažeta, da obstojajo tudi drugačni premiki, zato je sklepanje na podlagi omejenega



A
NE
SW
1
2
3
4
5
V
IV
III
II
I
262 m
B
5
4
3
2
C
1
V
IV
III
75 m
D
5
4
3
2
1
LF
LF
LF
LF
KGF
V
IV
III
II
I
80 m
262 m

faulted rocks were observed in the outcrop next to Stržen (Fig. 13, point 5), but not the structure of the fault zone or the kinematics.

Displacements along the Raša Fault have not yet been investigated more precisely, but Jurkovšek et al. (1996, profile A – B) provides relatively reliable information about the vertical displacement between the two fault blocks in the profile between the villages of Štorje and Stomaž, which amounts 150 to 200 m (measured from the cross-section on the map). The direction of the horizontal component of the displacement is right-lateral, but its magnitude has not yet been determined.

In this article we are interested in the section of the Raša Fault, where the vertical uplift of its north-eastern block was measured (Jurkovšek et al., 1996, profile A – B). This profile is shown again (Fig. 15, profile A – A) for the sake of understanding the topic under discussion. The mentioned offset of 150 m to 200 m is significant because it was determined on the basis of systematic mapping and a good knowledge of the thickness of the strata. However, since we are studying the relationship between tectonics and geomorphology, it was necessary to check whether a similar vertical movement also exists in the karst formations between the two blocks of the Raša Fault.

A single karst ridge extends from Štanjel to Goriče pri Famljah, and plunges gently to the northwest in the south-western block of the Raša Fault in Figure 13. In the north-eastern block, there are fewer peneplained areas, which are found only in the vicinity of Senožeče, Volče and in Košanska dolina valley (Fig. 18). For a comparison with profile A – A it was necessary to choose a control profile as close as possible to that of Štorje for the sake of credibility. As such, the B – B profile from Povir village through the Divača-Sežana lowland (about 390 m), the Mt. Sopada ridge, the Senadolski dol (a dol is usually an elongated shallow valley in Dinaric Karst), the Mt. Selivec ridge, and the flat Griško polje field (about 540 m) below Mt. Veliki Ognjivec (636 m) seemed suitable (Fig. 15, profile B - B). The difference in the peneplane elevations between the Divača - Sežana lowland and the Griško polje field is around 150 m. The bottom of Senadolski dol is not

števila podatkov lahko varljivo; brez detajlnih raziskav različnih predelov prelomne cone ni mogoče govoriti o kinematiki blokov ob Raškem prelomu. V golici ob potoku Strženu (sl. 13, točka 5) je bila zabeležena le prelomna porušitev, ne pa tudi zgradba prelomne cone ali kinematika.

Premiki ob Raškem prelomu še niso bili natančneje raziskani, vendar podajajo Jurkovšek et al. (1996, profil A – B) sorazmerno zanesljiv podatek o vertikalnem premiku med obema prelomnima kriloma v profilu med Štorjami in Stomažem, ki znaša okoli 150 m do 200 m (izmerjeno iz profila na karti). Smer horizontalne komponente premika je desna, vendar njena velikost še ni določena.

V tem članku nas zanima odsek Raškega preloma, kjer je bil izmerjen vertikalni dvig njegovega severovzhodnega krila (Jurkovšek et al., 1996, profil A – B). Zaradi razumevanja obravnavane teme, ta profil ponovno prikazujemo (sl. 15, profil A – A). Omenjeni skok 150 m do 200 m je pomemben zato, ker je bil določen na podlagi sistematičnega kartiranja in dobrega poznavanja debeline plasti. Ker pa proučujemo razmerje med tektoniko in geomorfologijo, je bilo potrebno preveriti ali obstoja podoben vertikalni premik tudi pri kraških uravnavah med obema kriloma Raškega preloma.

Na sliki 13 se v jugozahodnem krilu Raškega preloma razteza enotna kraška uravnava od Štanjela do Gorič pri Famljah, ki neznatno visi proti severozahodu. V severovzhodnem krilu je uravnanih površin manj, najdemo jih le v okolici Senožeč, v Volčah in v Košanski dolini (sl. 18). Za primerjavo s profilom A – A je bilo potrebno zaradi verodostojnosti izbrati kontrolni profil čim bliže Štorjam. Kot tak se je zdel primeren profil B – B od Povirja preko Divaško-Sežanskega podolja (okoli 390 m), grebena Sopade, Senadolskega dola, grebena Selivca in uravnanega Griškega polja (okoli 540 m) pod Velikim Ognjivcem (636 m). Razlika v koti uravnav med Divaško-Sežanskim podoljem in Griškim poljem znaša tu okoli 150 m. Dno Senadolskega dola ni primerno za primerjavo, ker je preoblikovano ob

Fig. 14. Raša fault in the Zajčica roadcut (highway) (Figs. 13 and 18): A. Photo of the section. B. Part of the damage zone. C. Oblique anticline within the damage zone indicating reverse movement of the northeast limb. D. Sketch of the section: about 80 m wide Raša Fault damage zone. I – Southwestern boundary fault plane, which is also the main one; II, III, IV – internal fault planes; V – northeastern boundary fault plane. *Key for the stratigraphic markers in Fig. 15.*

Sl. 14. Raški prelom v useku avtoceste Zajčica (sl. 13 in 18): A. Fotografija useka. B. Del zdrobljene cone. C. Poševna antiklinala znotraj zdrobljene cone, ki kaže na reverzni premik severovzhodnega krila. D. Skica useka: okoli 80 m široka zdrobljena cona Raškega preloma. I – jugozahodna mejna prelomna ploskev, ki je hkrati glavna; II, III, IV – notranje prelomne ploskve; V – severovzhodna mejna prelomna ploskev. *Legenda stratigrafskih oznak na sl. 15.*

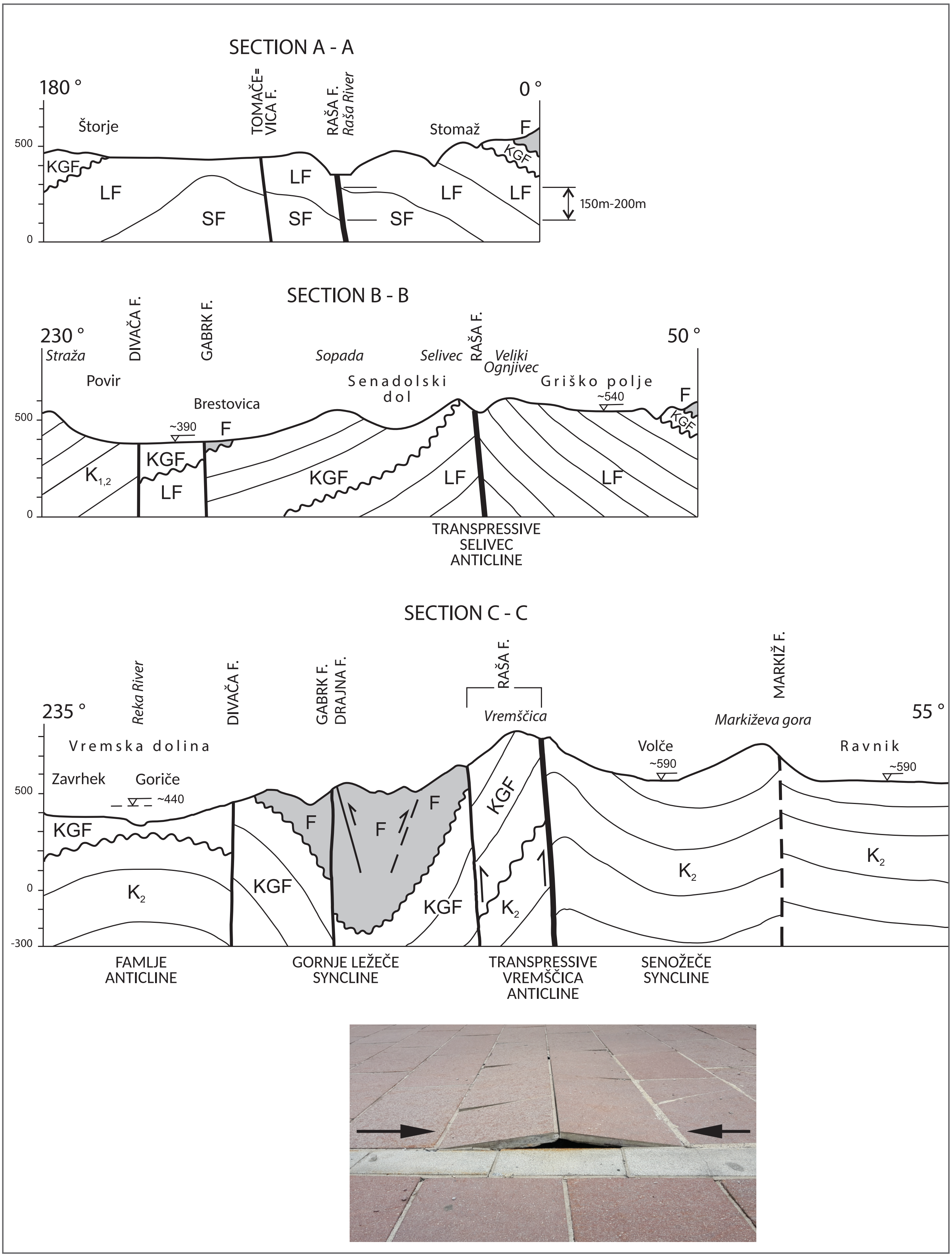
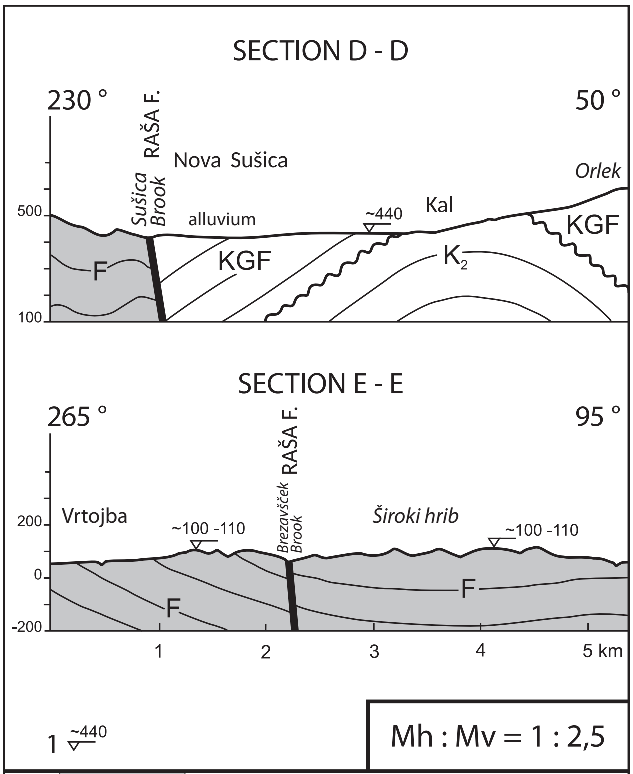


Fig. 15. Profiles across the Raša Fault: A – A Štorje - Stomaž (after Jurkovšek et al. 1996, profile A – B); B – B Povir - Griško polje; C – C Vremska dolina - Vremščica - Ravnik, in the photo a handy model of the transpressive Vremščica Anticline; D – D Košanska dolina; E – Brezavšček stream valley. 1 Approximate level of comparative peneplanation.

Sl. 15. Profili preko Raškega preloma: A – A Štorje - Stomaž (po Jurkovšek et al. 1996, profil A – B). B – B Povir - Griško polje; C – C Vremska dolina - Vremščica - Ravnik, na fotografiji priročni model Vremške transpresivne antiklinale; D – D Košanska dolina; E – E dolina potoka Brezavščka. 1 približni nivo primerjalne uravnave.



E	F	FLYSCH FORMATION
		UNCONFORMITY
Pc	KGF	KARST GROUP OF FORMATION
		UNCONFORMITY
K_2	LF	LIPICA FORMATION
		GEOLOGICAL BOUNDARY
	SF	SEŽANA FORMATION

Fig. 15. continuation
Sl. 15. nadaljevanje

suitable for comparison, because it was transformed by the Raša Fault, nor is the flood plain near Dolenja vas village, which was transformed and deepened by the Senožeški potok stream. The second control profile C – C runs from Zavrhek village through the Vreme valley, across the Vremščica ridge to the part of the plateau at Volče (around 590 m) and over Mt. Markiževa gora to Ravnik peneplain (around 590 m) northeast of here (Fig. 15, profile C – C). The starting peneplanation level in the south-western block lies in the vicinity of Goriče pri Famljah village (around 440 m), but the profile does not cover it, so its projection on the profile plane is indicated. Also in this profile, the difference in the height of the settlements between Goriče, Volče, and Ravnik peneplain is about 150 m. Both control profiles therefore indicate that the difference in the height of the peneplained territory between the north-eastern and south-western blocks of the Raša Fault is comparable to the geological offset in the A – A profile between Štorje and Stomaž.

Raškem prelomu, primerna pa ni tudi naplavna ravnica pri Dolenji vasi, ki jo je preoblikoval in poglobil Senožeški potok. Drugi kontrolni profil C – C poteka od Zavrhka preko Vremske doline, čez greben Vremščice na del uravnave pri Volčah (okoli 590 m) in preko Markiževe gore na Ravnik (okoli 590 m) severovzhodno od tod. Izhodiščna uravnava v jugozahodnem krilu je v okolici Gorič pri Famljah (okoli 440 m), vendar je profil ne zajema, zato je nakazana njena projekcija na profilno ravnino. Tudi v tem profilu znaša razlika v višini uravnav med Goričami ter Volčami in Ravnikom okoli 150 m. Oba kontrolna profila torej kažeta na to, da je razlika v višini uravnanega ozemlja med severovzhodnim in jugozahodnim krilom Raškega preloma primerljiva z geološkim skokom v profilu A – A med Štorjami in Stomažem.

Profila D – D in E – E kažeta drugačno podobo. Profil D – D poteka prečno na Raški prelom jugovzhodno od Vremščice mimo Nove Sušice, ki leži na uravnavi Košanske doline. Ta je v celoti v severovzhodnem krilu Raškega preloma, trasa samega preloma pa poteka od Gornje Košane na golico št. 5 (sl. 13 in 18) ob strugi Stržena. Med Gornjo Košano in Strženom Raški prelom ni zaznan v geomorfologiji terena, preseneča pa kota uravnave Košanske doline, ki znaša pri Novi Sušici okoli 440 m, kar je toliko kot v okolici Gorič pri Famljah severozahodno od Vremščice, to pa praktično pomeni, da se severovzhodno krilo Raškega preloma med Gornjo Košano in Strženom ni dvignilo nad jugozahodnim krilom. Koti uravnav Košanske doline (okoli 440 m) in v okolici Gorič (okoli 440 m) sta približno enaki.

Podoben ali enak, je podatek v profilu E – E preko doline Brezavščka med Gorico in Volčjo Drago, v katerem so povezani najvišji uravnani grebeni flišnega gričevja v jugozahodnem krilu Raškega preloma (Martinjak okoli 100 m, Bukovnik okoli 100 m in 110 m), s tistimi v severovzhodnem krilu (Široki hrib okoli 100 m, Lamovo okoli 100 m). Uravnana slemena in vrhovi na približno enako nadmorsko višino kažejo na večje uravnano flišno ozemlje, ki ga seka Raški prelom, vendar brez vidnega vertikalnega premika. Flišna uravnava na tem območju ni povezana z uravnanim Krasom, vendar je odnos med obema kriloma Raškega preloma mogoče primerjati med seboj. Obravnavana flišna uravnava je omejenega obsega in se proti severu kmalu konča ob geomorfološki meji v smeri zahod-vzhod. Ni raziskano ali gre za tektonsko ali erozijsko mejo.

Profiles D – D and E – E provide a different picture. Profile D – D runs across the Raša Fault southeast of Mt. Vremščica past Nova Sušica village, which lies on the Košana valley plateau entirely on the north-eastern block of the Raša Fault (Fig. 15, profile D – D). The Raša Fault trace runs from Gornja Košana village to outcrop No. 5 (Figs. 13 and 18) along the Stržen. The Raša Fault is not detected in the geomorphology of the terrain between Gornja Košana and Stržen, but the elevation of the Košana valley is surprising, which is roughly 440 m near Nova Sušica village, as much as in the vicinity of Goriče pri Famljah northwest of Mt. Vremščica, which in practical terms means that the northeast block of the Raša Fault between Gornja Košana and Stržen did not rise above the south-western block. The peneplanation elevations of the Košana valley (around 440 m) and in the vicinity of Goriče (around 440 m) are approximately the same.

The information in the profile E – E across the Brezavšček valley between Gorica and Volčja Draga village is similar or identical (Fig. 15, profile E – E), where the highest levelled ridges of the flysch hills in the south-western block of the Raša Fault (Mt. Martinjak about 100 m, Mt. Bukovnik about 100 m and 110 m) are connected, with those in the north-eastern block (Mt. Široki hrib about 100 m, Mt. Lamovo about 100 m). Level ridges and peaks at approximately the same altitude indicate a larger peneplained flysch area cut by the Raša Fault, but without visible vertical displacement. The peneplained flysch in this area is not related to the peneplained Karst, but the relationship between the two blocks of the Raša Fault can be compared with each other. The discussed peneplanation of flysch formation is of limited extent and soon ends to the north at the geomorphological boundary in the E–W direction. The question whether it is a tectonic or erosional boundary has not been investigated.

Let's return again to profiles B – B and C – C in Fig. 15. In profile B – B, in addition to the already mentioned peneplanation in both blocks of the Raša Fault, there are four more hills, Mt. Straža (542 m) above Povir village, Mt. Sopada ridge, Mt. Selivec ridge, and Mt. Veliki Ognjivec ridge (636 m). Mt. Straža among the Tabor hills was formed due to selective corrosion and is built from less soluble rocks of the upper part of the Povir Formation (dolomite). As a result of selective corrosion, Mt. Sopada was also formed, as until recently it was covered by flysch, which is still visible along the Gabrk Fault (Jurkovšek et al., 1996). The formation of Mt. Selivec and Mt. Veliki Ognjivec,

Vrnimo se ponovno k profiloma B – B in C – C na sliki 15. V profilu B – B so poleg že omenjenih uravnav v obeh krilih Raškega preloma še štiri vzpetine, Straža (542 m) nad Povirjem, greben Sopade, greben Selivca in greben Velikega Ognjivca (636 m). Straža v Taborskih gričih je nastala zaradi selektivne korozije, zgrajena je iz manj topnih kamnin zgornjega dela Povirske formacije (dolomit). Zaradi selektivne korozije je nastala tudi Sopada, saj jo je še do nedavnega pokrival fliš, ki je še viden ob Gabrškem prelomu (Jurkovšek et al., 1996). Drugačen je nastanek Selivca in Velikega Ognjivca, med katerima leži Raški prelom. V prelomnih krilih vpadajo plasti v nasprotnih smereh in so ob Raškem prelomu najbolj strme, ko se pa od preloma oddaljujemo, je vpad vse manjši, pri tem pa je pomembno, da je hkrati z bolj strmo lego plasti dvignjen tudi relief. Pred seboj imamo transpresivno antiklinalo, ki se je dvignila iz uravnanega sveta zaradi predisponirane lege plasti v coni Raškega preloma, imenujemo jo Selivška transpresivna antiklinala. Po zdrobljeni coni preloma je erozija ustvarila grapo, ki se izteka v dolino Raše. Grebena Selivca in Velikega Ognjivca sta ostanek vrha transpresivne antiklinale, ki jo je erozija po grapi med dviganjem razdelila na dva dela.

Po taki analizi se Senadolski dol pokaže kot netipična asimetrična kraška depresija, njegovo jugozahodno pobočje je del Sopade in je nastalo zaradi selektivne korozije, severovzhodno pobočje pa predstavlja krilo Selivške transpresivne antiklinale, zaradi katere se je že uravnano površje izbočilo. Senadolski dol je torej kombinirana tvorba, ki v strukturnem smislu predstavlja korozijsko modificirano krilo tranapresivne antiklinale. Podobnih in drugačnih dolov je na Krasu kar nekaj, brez dvoma pa bi jih našli tudi drugod, zato je smiselno, da tak genetsko mešani ali kombinirani kraški dol poimenujemo nevtralno, predlagamo termin kombinirani dol, kombidol ali komdol. Genetskih kombinacij, ki so prispevale k nastanku dolov je več, zato je nemogoče najti za vsako specifično kombinacijo posebno ime. Pred kratkim imenovani genetski tip dola razdol (Placer et al., 2021a), je nastal po snopu razpok ali po razpoklinski coni in je genetsko vezan samo na en fenomen. Ker gre za kraške pojave, je korozija dejavnik, ki ga ni treba vključevati v termin. Termin pradol, ki so ga predlagali Diercks et al. (2021) je rečnoerozijska tvorba, tu imata struktura in korozija drugoten pomen.

between which lies the Raša Fault, is different. Layers in both fault blocks plunge in opposite directions and are steepest at the Raša Fault and become continuously less steep as we move away from the fault. It is important that with increased dip of the bedding, the relief is also raised. The described structure is a transpressive anticline, which rose from the peneplained relief due to the predisposed position of the strata in the Raša Fault zone, hence the transpressive Selivec Anticline. Along the damage zone erosion carved a canyon that runs into the Raša valley. The Mt. Selivec and Mt. Veliki Ognjivec ridges are the remains of the top of the transpressive anticline, divided into two parts by erosion along the fault during uplift.

According to such analysis, Senadolski dol appears as an atypical asymmetric karst depression, its south-western slope is part of Mt. Sopada and was formed by selective corrosion, while its north-eastern slope represents the limb of the transpressive Selivec Anticline, due to which the already levelled surface bulged. Senadolski dol is therefore a combined formation, which structurally represents a corrosion-modified limb of a transpressional anticline. There are a number of similar and different dols in the Kras, and can no doubt be found elsewhere as well, so it makes sense to name such a genetically combined karst dol neutrally, thus we suggest the term combined dol called komdol (new term). There are several genetic combinations that contributed to the formation of dols, so it is impossible to find a special name for each specific combination. Razdol, one recently-named genetic type of dol (Placer et al., 2021a) was formed in a fracture system or in a fault zone and is genetically related to only one phenomenon. Since these are karst phenomena, corrosion is a factor that does not need to be included in the term. The term pradol proposed by Diercks et al. (2021) is used for a dol formed by river erosion. Structure and corrosion are of secondary importance here.

On this occasion, it makes sense to point out that there are also dols that are entirely the result of folding: for example, »Vrhpoljski dol« between the Krvavi potok stream and the village of Vrhpolje near Kozina, which is not a name given by the locals but represents a valley along the syncline, which is a secondary formation of the Materija Fault. Here we have a nice example of a folded primary peneplanation, but since it is a karst relief, this type of valley or dol could be called a synclinal valley or sindol (new term).

From the interpretation of the relief in profile B – B, it therefore follows that before the formation

Ob tej priliki je smiselno poudariti, da obstojajo tudi doli, ki so v celoti posledica gubanja. Tak je npr. »Vrhpoljski dol« med Krvavim potokom in Vrhpoljem pri Kozini, ki ga domačini sicer tako ne imenujejo, predstavlja pa dolino po sinklinali, ki je sekundarna tvorba Matarskega preloma. Tu imamo lep primer nagubane primarne uravnave, ker pa gre za kraški relief, bi ta tip doline ali dola lahko imenovali sinklinalni dol ali sindol.

Iz razlage reliefa v profilu B – B torej izhaja, da je pred nastankom Raškega preloma, na nivoju profila, obstajala enotna kraška uravnava iz katere sta se dvigala samo grebena Taborskih gričev in Sopade. Po nastanku Raškega preloma in v fazi transpresije se je severovzhodno krilo preloma dvignilo, hkrati pa je nastala tudi transpresivna antiklinala, ki jo je omogočila ugodna lega plasti v krilih preloma, ki so že pred nastankom Raškega preloma tvorile antiklinalo v sestavi senožeškega pasu cepljenja gub (sl. 11). Grapa po grebenu transpresivne antiklinale je lahko nastala samo v primeru, da je bila erozijsko dejavna že pred transpresivnim dvigom, saj je ob dviganju izgubila hidrografsko zaledje.

V profilu C – C je prikazana zgradba Vremščice, ki je podobna Selivcu, le da je izhodna struktura izrazitejša, ker se Vremščica, oziroma območje, ki ga prikazuje profil C – C, nahaja bliže osrednjega dela senožeškega pasu cepljenja gub. V njem sta zajeti Gornjeležeška in Senožeška sinklinala, med katerima je pred nastankom Raškega preloma ležala Paleovremška antiklinala. Po nastanku cepilnih gub je bilo celotno ozemlje, skupaj s Fameljsko in Paleovremško antiklinalo, uravnano. Za tem je poševno na Paleovremško antiklinalo (okoli 20°) nastal zmični Raški prelom, ob katerem se je, tako kot v primeru Selivca, v fazi transpresije dvignila transpresivna guba ob hkratnem dvigu severovzhodnega krila preloma. Gubo imenujemo Vremška transpresivna antiklinala. V primeru Vremščice je zaradi obstoja vzporednega kraka ob Raškem prelomu, verjetno prišlo tudi do izrivanja vmesnega bloka. Tako pri Selivcu kot pri Vremščici, je bilo dviganje severovzhodnega krila Raškega preloma in transpresivne antiklinale, lahko enofazen ali večfazen proces, v vsakem primeru pa je Vremška transpresivna antiklinala nasledstvena struktura Paleovremške antiklinale. V profilu C – C je tik ob Raškem prelomu še vidno njeno sleme. Fotografija pod profilom poenostavljeno ponazarja mehanizem nastanka Vremške antiklinale; položene talne plošče na tleh predstavljajo uravnano ozemlje, dve sta se of the Raša Fault, at the level of the profile, there was a single karstic peneplanation from which only the ridges of the Tabor hills and Mt. Sopada rose. After the formation of the Raša Fault and during the transpression phase, the north-eastern block of the fault rose, and at the same time a transpressive anticline was formed, which was made possible by the favourable position of the bedding in the fault blocks that already formed an anticline in the Senožeče Folds Splitting Zone before the formation of the Raša Fault (Fig. 11). The ravine along the crest of the transpressive anticline could only have formed if it was erosively active before the transpressive uplift, as it lost its hydrographic hinterland during the uplift.

Profile C – C shows the building of Mt. Vremščica, which is similar to Mt. Selivec, except that the outgoing structure is more pronounced because Mt. Vremščica, or the area shown by profile C – C, is located closer to the central part of the Senožeče Folds Splitting Zone. It includes the Gornje Ležeče and Senožeče Synclines, between which the Paleo-Vremščica Anticline took place before the formation of the Raša Fault. After the formation of split folds, the entire territory, together with the Famlje and Paleo-Vremščica Anticlines, was levelled (peneplained). Afterwards, the Raša Fault was formed obliquely (around 20°) to the Paleo-Vremščica Anticline, along which, as in the case of Mt. Selivec, a transpressive fold rose during the transpression phase at the same time as the north-eastern block of the Raša Fault rose. The fold is called the transpressive Vremščica Anticline. The intermediate block was probably pushed out in the case of Mt. Vremščica, due to the existence of a parallel fault branch along the Raša Fault. Both at Mt. Selivec and at Mt. Vremščica, the uplift of the north-eastern flank of the Raša Fault and the transpressive anticline may have been a single-phase or multiphase process, but in any case, the transpressive Vremščica Anticline is the successor structure of the Paleo-Vremščica Anticline. In profile C – C, its hinge is still visible right next to the Raša Fault. The photo below the profile illustrates the formation mechanism of the Mt. Vremščica Anticline; laid floor slabs on the ground represent a levelled area, with two of them later rising due to the shrinkage of that part of the bridge construction on which the slabs are laid. The contact between them illustrates the role of the Raša Fault.

The transpressive Vremščica Anticline is separated from the Selivec Anticline by a saddle, which is conditioned by a less pronounced anticlinal

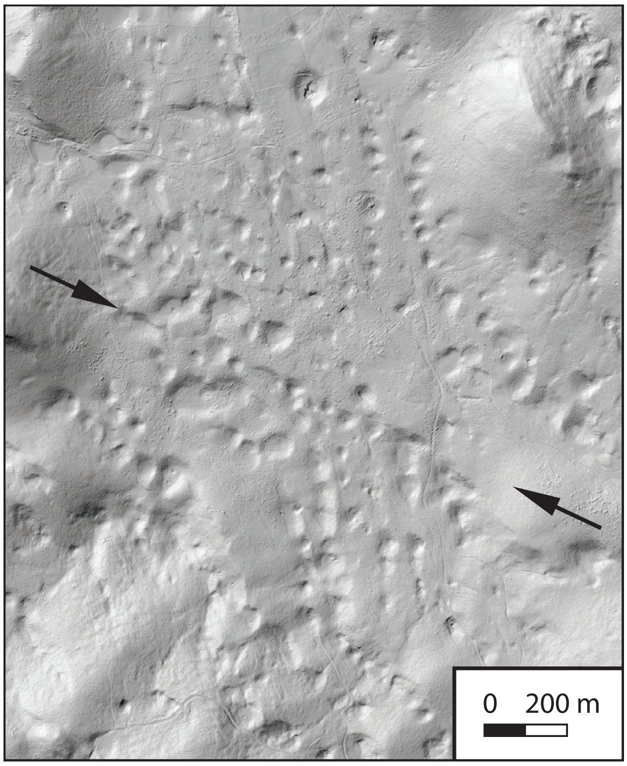


Fig. 16. Markiž Fault. Position in Fig. 18.
Sl. 16. Markižev prelom. Lega v prostoru na sl. 18.

pozneje dvignili zaradi krčenja dela konstrukcije mostu, na katerem so plošče položene. Stik med njima ponazarja vlogo Raškega preloma.

Vremška transpresivna antiklinala je od Selivške ločena s sedlom, ki je pogojeno z manj izrazito antiklinalno lego plasti. Sedlo leži v bližini useka Zajčica (sl. 14) in nima imena, vendar ga zaradi lažjega sporazumevanja imenujemo Senadolsko sedlo. Transpresivna guba tu ni odsotna temveč le manj izrazita, profil Zajčica lepo pojasnjuje njegovo zgradbo.

Domnevamo, da je zaradi transpresije dvignjena tudi Markiževa gora med uravnavama okoli Volč in na Ravniku (sl. 15, profil C – C) . Razteza se ob Markiževem prelomu vzporedno z Vremščico, le da je dvig tu skromnejši in asimetričen. Na obstoj Markiževega preloma posredno kažeta smer Markiževe gore in njeno dolgo, ravno, strmo severovzhodno pobočje, ki je verjetno zaradi hitrega dviga skoraj v celoti prekrito z deluvijem. Obstoj preloma podpira tudi izstopajoči linearni niz vrtač v smeri WNW -ESE, ki poteka preko manjše uravnave severozahodno od Markiževe gore proti Senožečam (sl. 16). Da gre za pomembnejšo mejo nakazujejo nizi vrtač v smeri NNW-SSE do N-S, ki se naslanjajo na omenjeni niz in so razviti v obeh krilih. Prostorska lega Markiževega preloma je vidna na sl. 18.

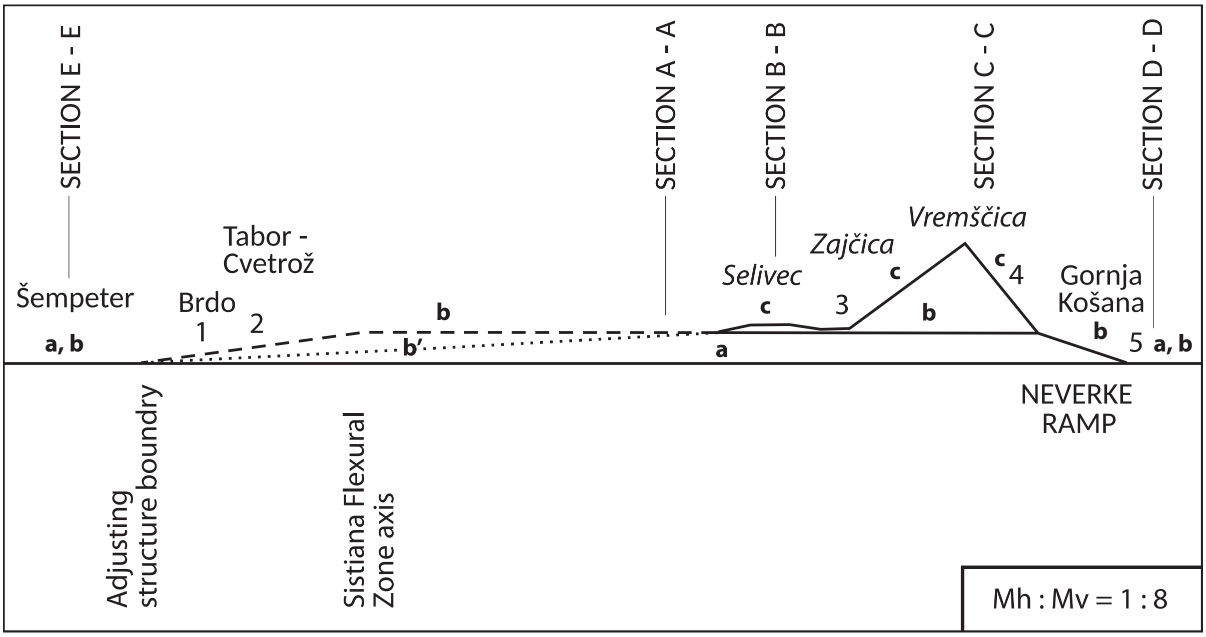


Fig. 17. Vertical displacement along the Raša Fault, based on the difference in elevation of the levelled areas: a – idealized starting level in the southwestern block of the Raša Fault; b – elevation level in the northeastern block of the Raša Fault (b´ – variant); c – Selivec and transpressive Vremščica Anticlines ridge level; 1 to 5 – observation sites along the Raša Fault.

Sl. 17. Vertikalni premik ob Raškem prelomu, ki temelji na razliki v višinskem nivoju uravnav: a – idealizirani izhodiščni uravnani nivo v jugozahodnem krilu Raškega preloma; b – nivo uravnav v severovzhodnem krilu Raškega preloma (b´ – varianta); c – nivo slemena Selivške in Vremške transpresivne antiklinale; 1 do 5 – opazovalna mesta ob Raškem prelomu.

position of the strata. The saddle is located near the Zajčica section (Fig. 14) and has no name, but for ease of communication we called it the Senadole saddle (after the village of Senadole). The transpressive fold is not absent here, but only less pronounced; the Zajčica profile nicely explains its structure.

We assume that Mt. Markiževa gora was also raised between the levelled relief around Volče and on Ravnik peneplain (Fig. 15, profile C – C) due to transpression. It stretches along the Markiž Fault parallel to Mt. Vremščica, except that the rise here is less pronounced and asymmetrical. The existence of the Markiž Fault is indirectly indicated by the direction of Mt. Markiževa gora and its long, flat, steep north-eastern slope, which is probably almost entirely covered by deluvium due to rapid uplift. The existence of the fault is also supported by a prominent linear series of dolines (usually round sinkholes) in the WNW-ESE direction, which runs over a small plane northwest of Mt. Markiževa gora towards Senožeče (Fig. 16). The importance of the boundary is indicated by the series of dolines in the NNW-SSE to N-S direction, which rest on the mentioned series and are developed in both fault blocks. The position of the Markiž Fault is presented in Figure 18.

Before the uplift of Mt. Vremščica, the area around Goriče, Volče and Ravnik was levelled, as in the case of Mt. Selivec. Since it is more or less obvious that Mt. Selivec, Mt. Vremščica, and Mt.

Tako kot pri Selivcu je tudi pri Vremščici prvotno uravnano površje pred nastankom Vremščice, združevalo območja Gorič, Volč in Ravnika. Ker je več ali manj očitno, da so Selivec, Vremščica in Markiževa gora nastali zaradi povečane transpresije, domnevamo, da so zaradi nasledstvenih deformacij ob povečani transpresiji nastale tudi nekatere druge pozitivne in negativne reliefne oblike okoli danes obstoječih uravnav. Kraški relief opisovanega ozemlja je torej seštevek primarno uravnanega ozemlja, selektivne korozije, erozije in nasledstvene tektonike, kar pomeni, da je treba h genezi reliefa posameznih območij pristopati kompleksno. V profilu C – C je zajeta tudi flišna Gornjeležeška sinklinala, ki pripada Brkinskemu sinklinoriju, zato jo je potrebno obravnavati drugače po litološki in strukturni plati. V sorazmerno stisnjeni sinklinali so bili ugotovljeni znaki vertikalnega izrivanja jedra, ki ga povezujemo z učinkom transpresije. Ob regionalni cesti Vremska dolina - Ribnica je nasproti vodarne Draga viden reverzni prelom 65/60, ki poteka v smeri osi Gornjeležeške sinklinale. Ob njem je videti tudi prevrnjene plasti. Območje ni detajlno kartirano, zato le sklepamo na obstoj konjugiranih dislokacij. Zaradi pomena omenjenega preloma za razumevanje zgradbe ozemlja, ga po bližnjem Drajnem potoku (sl. 18) imenujemo Drajni reverzni prelom.

Markiževa gora were formed due to increased transpression, we assume that some other positive and negative relief forms around the existing levelled areas were also formed due to successive deformations in the zone of increased transpression. The karst relief of the described area is therefore the sum of a primarily regulated territory, selective corrosion, erosion, and successive tectonics, which means that the genesis of the relief of individual areas must be approached with this complexity in mind. The Gornje Ležeče Syncline, covered in the C – C profile, belongs to the Brkini Synclinorium, so it needs to be treated differently in terms of lithology and structure. Signs of vertical core extrusion were found in the relatively tight syncline, associated with the transpression effect. A reverse fault 65/60 is exposed, running in the direction of the Gornje Ležeče Syncline axis along the Vremska dolina (Vreme valley) - Ribnica regional road, opposite the Draga water reservoir. Inverse bedding can also be seen next to it. The area is not mapped in detail, so we only infer the existence of conjugate dislocations. Due to the importance of the aforementioned fault for understanding the structure of the territory, it is called the reverse Drajna Fault after the nearby Drajna Stream (Fig. 18).

The Divača and Gabrk Faults, visible in profiles B – B and C – C, are older than the Raša Fault. No deformation was found in the area that could be definitively related to successional offsets.

The transverse profiles data is supplemented by a longitudinal schematically comparative geomorphological profile, which combines the two fault blocks of the Raša Fault (Fig. 17). Such comparison does not deal with real geomorphological data, but instead is meant to show the differences in the absolute elevation of the compared levelled areas between the two fault blocks: between those in the south-western block are shown with a horizontal line »a«, and with a dashed line »b« in the north-eastern block, which in the individual profiles is offset from the line »a« as much as the difference in the absolute elevation of the levelled areas. The two lines completely overlap in the area between Gorica and Volčja Draga, and there is no comparative data on the villages of Volčja Draga and Štorje, but in the vicinity of Štorje they are already well apart, at around 150 m to 200 m. From Štorje to Volče, the lines illustrating the elevations are separated, with the difference in elevation between them around 150 m everywhere. They are reunited in the Košana valley.

Line »a« is not only a construction aid but is very close its natural state, as the elevations of the

Divaški in Gabrški prelom, ki sta vidna v profilih B – B in C – C, sta starejša od Raškega preloma. Na obravnavanem prostoru ob njima nismo opazili deformacij, ki bi jih brez vsakega dvoma lahko pripisali nasledstvenim premikom.

Podatki prečnih profilov so dopolnjeni z vzdolžnim shematskim primerjalnim geomorfološkim profilom, ki združuje obe prelomni krili Raškega preloma (sl. 17). Tu ne gre za stvarne geomorfološke podatke temveč za prikaz razlik v absolutni višini primerjanih uravnav med obema prelomnima kriloma; tiste v jugozahodnem krilu so prikazane z vodoravno črto »a«, v severovzhodnem krilu s črto »b«, ki je v posameznih profilih toliko odmaknjena od črte »a«, kolikor znaša razlika v absolutni koti uravnav. Črti se povsem prekrivata na območju med Gorico in Volčjo Drago, od Volčje Drage do Štorij ni primerjalnih podatkov, vendar sta v bližini Štorij že krepko narazen, okoli 150 m do 200 m. Od Štorij do Volč sta črti, ki ponazarjata uravnave ločeni, višinska razlika med njima je povsod okoli 150 m. V Košanski dolini sta ponovno združeni.

Črta »a« ni le konstrukcijsko pomagalo, temveč je zelo blizu stanja v naravi, saj sta koti uravnav na območju Gorič in Košanske doline zelo blizu, okoli 440 m. Območje doline Brezavščka med Gorico in Volčjo Drago je izven take primerjave, vendar vseeno ustreza kriteriju vertikalnega premika.

Kakšen je potek črte »b« med Volčjo Drago in Štorjami ne vemo, lahko pa sklepamo, da se loči od črte »a« že daleč pred Štorjami, brez dvoma pa se ji ponovno priključi v Gornji Košani. Preden spregovorimo o tem si oglejmo strukturno skico Košanske doline na sliki 18. Raški prelom se od peskokopov »V žlebu« nad Čepnim (sl. 18, točka 4) spusti po geomorfološko močno odzivni grapi do Gornje Košane, od tu naprej proti strugi Sušice (sl. 18, točka 5) pa ga praktično na površju ni mogoče zaznati. Skrivnost nenadne spremembe v geomorfologiji tiči v reverznem prelomu, ki se v Gornji Košani odcepi od Raškega preloma in ga je potem mogoče slediti pod robom Košanskega hriba (589 m) najprej proti vzhodu in nato vzhodu-jugovzhodu do potokov Sušice in Stržena. Imenujemo ga Košanski reverzni prelom, v katerega čelu se je razvila Košanska antiklinala. Velikost premika ob Košanskem prelomu se od Raškega preloma proti vzhodu naglo zmanjšuje, kar pomeni, da gre za sekundarno tvorbo v širši coni Raškega preloma. Pomik ob Košanskem prelomu je pomemben zato, ker kaže, da se je prvotno enotno uravnano območje v severovzhodnem krilu preloma razdelilo na zgornji

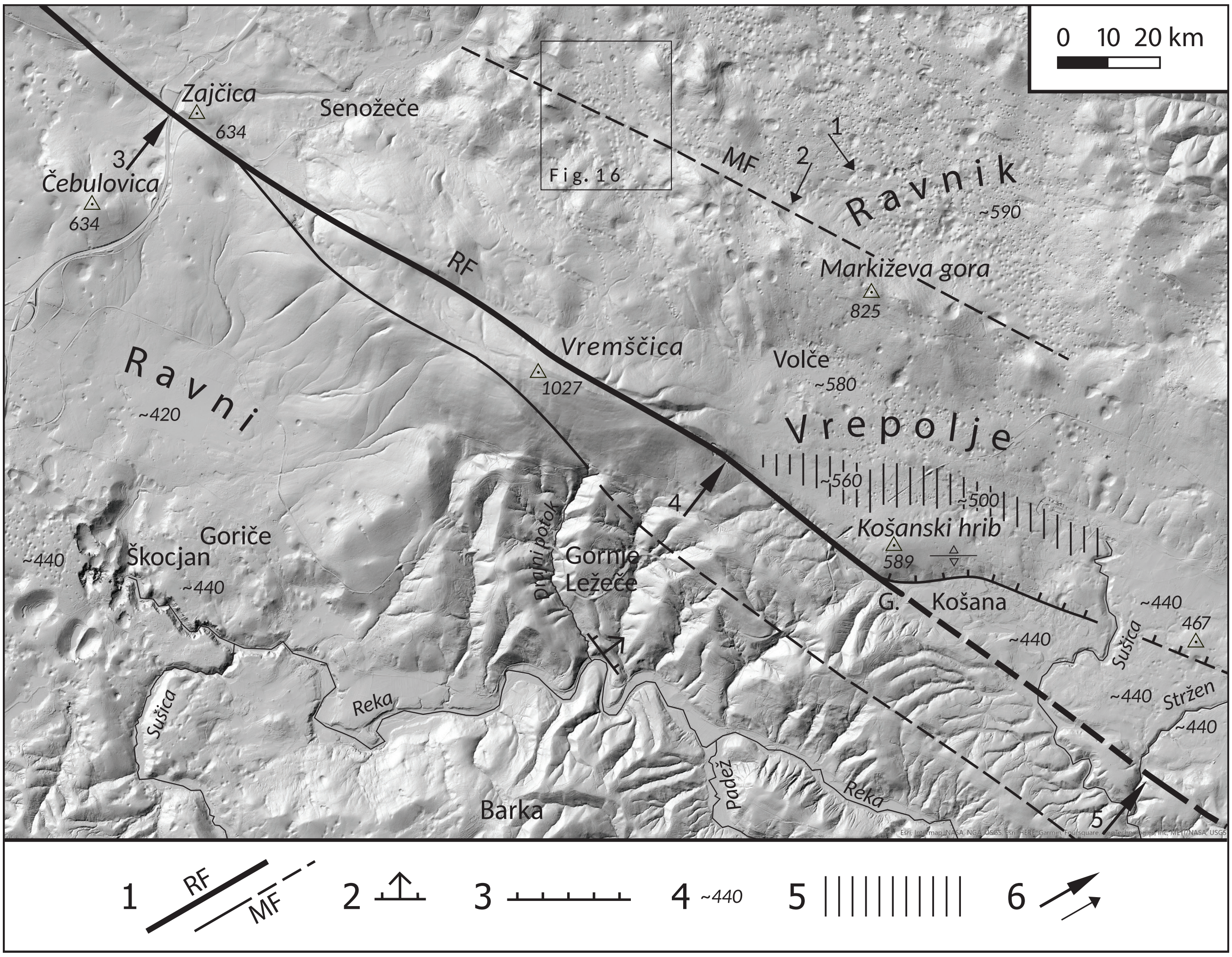


Fig. 18. Structural-geomorphological sketch of the Košana valley.
Sl. 18. Strukturno-geomorfološka skica Košanske doline.

1 Fault: RF – Raša Fault, MF – Markiž Fault / prelom: RF – Raški prelom, MF – Markižev prelom
2 Reverse Drajna Fault / Drajni reverzni prelom
3 Reverse Košana Fault / Košanski reverzni prelom
4 Approximate adjustment level (approx. 440 m) / približna kota uravnave (ok. 440)
5 Neverke ramp / neverška klančina (rampa)
6 Observation site: 3 – AC Zajčica section, 4 – sand pits »V žlebu« above Čepno, 5 – Stržen valley / opazovalno mesto: 3 – usek AC Zajčica, 4 – peskokopi »V žlebu« nad Čepnim, 5 – dolina Stržena

levelled areas of Goriče and the Košana valley are, at around 440 m, very close. The area of the Brezavšček valley between Gorica and the Volčja Draga valley is beyond such comparison, but still meets the criterion of vertical movement.

We do not know what the course of line »b« is between Volčja Draga and Štorje, but we can conclude that it separates from line »a« long before Štorje, and rejoins it at Gornja Košana village. Before we talk further about it, let's take a look at the structural sketch of the Košana valley in Figure 18. The Raša Fault descends from the »V žlebu« sand pits above Čepno village (Fig. 18, point 4) along a geomorphologically strongly responsive ravine to Gornja Košana; from here in the direction of the Sušica riverbed (Fig. 18, point 5) it is practically impossible to detect it on the surface. The secret

nivo okoli Volč (okoli 580 m) in spodnji nivo v Košanski dolini (okoli 440 m). Povezuje ju pas danes nagnjene uravnave severno od Košanskega hriba. Nagnjeni povezovalni pas nekdaj enotne uravnave imenujemo po bližnjem naselju Neverke neverška klančina ali neverška rampa. Vzhodno od stika neverške klančine z uravnavo Košanske doline se v krovni grudi Košanskega reverznega preloma dviga vzpetina, katere del je viden na sliki 18 (kota 467), ki ne potrjuje koncepta pojemanja reverznega premika ob tem prelomu proti vzhodu. Anomalija je slej ko prej povezana s prelomom v smeri SW-NE, ki poteka preko sedla med dolinama reke Pivke in notranjske Reke (OGK, list Ilirska Bistrica; Šebela, 2005, sl. 1). Nanj se naslanja Košanski reverzni prelom. Natančnejša razlaga presega okvir tega članka.

of the sudden change in geomorphology lies in the reverse fault, which splits off from the Raša Fault at Gornja Košana village and can then be followed under Mt. Košanski hrib (589 m) first to the east and then east-southeast to the Sušica and Stržen streams. We named it the reverse Košana Fault, at the head of which the Košana Anticline developed. The offset along the Košana Fault rapidly decreases from the Raša Fault to the east, which means that it is a secondary formation in the wider zone of the Raša Fault. The offset along the Košana Fault is important because it shows that the originally uniformly levelled area in the north-eastern block of the fault was divided into an upper level around Volče (around 580 m) and a lower level in the Košana valley (around 440 m). They are connected by a belt of what is today the inclined plane north of Mt. Košanski hrib. The inclined connecting belt is called Neverke ramp after the nearby village of Neverke. An elevation rises in the hanging wall of the reverse Košana Fault, part of which can be seen in Figure 18 (elevation point 467), to the east of the junction of the Neverke ramp with the levelled Košana valley, which does not confirm the concept of a decrease in the offset along this reverse fault to the east. The anomaly is in one way or another related to a fault in the SW-NE direction, which runs across the saddle between valleys of the Pivka and Reka rivers (OGK, sheet: Ilirska Bistrica; Šebela, 2005, fig. 1) and terminates at the reverse Košana Fault. A more detailed explanation is beyond the scope of this article.

Line »b« in the longitudinal profile in Figure 17 therefore joins line »a« along the Neverke ramp.

The discussion about where northwest of Štorje the effect of transpression along the Raša Fault should cease is theoretically interesting. A direct comparison with the Neverke ramp is not possible, but a hypothetical discussion is possible, for which we find a basis in the discussion of the Sistiana Flexural Zone (Placer et al., 2021b). The left-lateral strike-slip Sistiana Fault in the seabed of the Gulf of Trieste has a WSW-ENE trend in the area of Sistiana Bay. The fault is wedged out at the north-eastern boundary of the Istra-Friuli Thrust-Underthrust Zone. Further to the northeast, a flexural zone was formed in that direction, where the Trieste-Komen Anticlinorium, the Vipava Synclinorium, and the frontal part of the External Dinaric Thrust Belt are clearly bent (Fig. 13). The bending was the result of the movement of the Istran block towards the Dinarides, as its axis runs from Sistiana Bay towards the village of Spodnja Branica and Ajdovščina (Fig. 1). The Dinarides between the Sistiana and Kvarner Flexural Zones

Črta »b« v vzdolžnem profilu na sliki 17 se torej priključi črti »a« po neverški klančini.

Razprava o tem, kje severozahodno od Štorij naj bi izzvenel učinek transpresije ob Raškem prelomu, je teoretično zanimiva. Neposredna primerjava z neverško klančino ni mogoča, možna pa je hipotetična obravnava za katero najdemo osnovo v razpravi o sesljanski upogibni coni (Placer et al., 2021b). Sesljanski levozmični prelom v podmorju Tržaškega zaliva poteka v smeri WSW-ENE, na območju Sesljanskega zaliva se izklini ob severovzhodni meji istrsko-furlanske narivno-podrivne cone, naprej proti sevrovzhodu pa se je v njegovi smeri izoblikovala upogibna cona v kateri sta se lateralno vidno upognila Tržaško-Komenski antiklinorij, Vipavski sinklinorij in čelni del Zunanjedinarskega narivnega pasu (sl. 13). Os upogiba poteka od Sesljanskega zaliva proti Spodnji Branici in Ajdovščini, nastala pa je zaradi pomikanja istrskega bloka proti Dinaridom (sl. 1). Območje Dinaridov med sesljansko in kvarnersko upogibno cono je bilo torej izpostavljeno povečani transpresiji in učinku raznolike nasledstvene tektonike. Ker je v sesljanski upogibni coni bočno usločen tudi Raški prelom, bi se v apikalnem delu usločitve, torej na območju Spodnje Branice, vsaj teoretično črta »b« lahko odcepila od črte »a«. Vendar os upogibne cone ni ozka, niti natančno določena, v najširšem smislu bi njen vpliv proti severozahodu lahko segal do severovzhodne meje izravnalne zgradbe Raškega preloma, torej do stičišča Tomačevskega preloma z Raškim prelomom (sl. 13). V tem primeru bi se črta »b« lahko odcepila od črte »a« že na območju Volčje Drage. Za tako možnost govori deformacija flišnih plasti v Brdu pri Dornberku (sl. 13, točka 1). Za potrditev hipoteze bi bilo potrebno opraviti usmerjene terenske in modelne raziskave. Na sliki 17 sta za potek črte »b« od Selivca do meje izravnalne zgradbe Raškega preloma nakazani dve možnosti, »b« in »b´«.

Dvig Selivca in ekstremni dvig Vremščice je na sliki 17 prikazan s črto »c«, ki shematsko sledi njunemu slemenu in Senadolskemu sedlu med obema vzpetinama. Razmere na profilu na sliki 17 torej kažejo, da je transpresija dosegla največji učinek na območju Vremščice.

Poleg strukturnih kazalcev, da so Selivec, Vremščica in Markiževa gora antiklinalne, ali bolje antiformne deformacije prej uravnanega kraškega površja, obstajajo tudi krasoslovni pokazatelji, ki pa še niso dovolj raziskani, da bi bili zanesljivi. Najpomembnejše so vrtače, ki so na uravnanem ozemlju pogoste, na znatno nagnjenem were therefore exposed to increased transpression and the effect of diverse successional tectonics. Since the Raša Fault trace is also laterally bent in the Sistiana Flexural Zone, in the apical part of the folding, i.e. in the area of Spodnja Branica, line »b« could, at least theoretically, split off from line »a« (Fig. 13). However, the Sistiana Flexural Zone axis is neither narrow nor precisely defined; in the broadest sense its influence towards the northwest could extend as far as the north-eastern border of the Raša Fault adjusting structure i.e. to the junction of the Tomačevo Fault with the Raša Fault (Fig. 13). In this case, line »b« could split off from line »a« already in the area of Volčja Draga village. The deformation of the flysch beds at the village of Brdo near Dornberk supports such a possibility (Fig. 13, point 1). To confirm the hypothesis, it would be necessary to carry out focused field and model research. In Figure 17, two options are indicated for the course of line »b« from Mt. Selivec to the boundary of the Raša Fault adjusting structure, »b« and »b'«.

The uplift of Mt. Selivec and the extreme uplift of Mt. Vremščica are represented by line »c« in Figure 17, which schematically follows their ridge and the Senadole saddle between the two elevations. The conditions on the profile in Figure 17 therefore show that the transpression reached its greatest effect in the Mt. Vremščica area.

In addition to the structural indicators that Mt. Selivec, Mt. Vremščica and Mt. Markiževa gora are anticlinal, or rather antiform deformations of the previously levelled karst surface, there are also karstological indicators that have not yet been sufficiently studied as to be considered reliable. The most important are dolines, which are common on flat land, yet absent or markedly rarer on a significantly tilted relief. Two tentative conclusions can be drawn from this: 1. dolines do not develop on slopes or only exceptionally under special conditions, and 2. dolines only develop on levelled relief and eventually disappear if the levelled relief tilts. The second assumption is more likely, because dolines are often found on antiform hinges, which is a kind of confirmation of what has been said, since the antiform hinge maintains a more or less horizontal (untilted) position, but there are no dolines or there are significantly fewer on the slopes. The rare dolines on the slopes could be the remnants of the larger ones from the previous peneplanation, while the smaller ones may have already disappeared. In this sense, we could interpret the situation on Mt. Markiževa gora above the village of Volče (Fig. 18): its north-eastern slope is conditioned by a fault, so it is steep and covered with

svetu jih ni ali pa so bistveno bolj redke. Iz tega je mogoče postaviti dva začasna sklepa: 1. vrtače se na pobočjih ne razvijejo ali le izjemoma kadar nastopijo posebni pogoji in 2. vrtače se razvijejo le na uravnanem svetu in sčasoma izginejo, če se uravnano ozemlje nagne. Verjetnejša je druga domneva, pogosto namreč najdemo vrtače na slemenih antiform, kar je svojevrstna potrditev povedanega, saj ohrani sleme antiforme več ali manj vodoravno lego, na pobočjih jih pa ni ali jih je bistveno manj. Redke vrtače na pobočjih bi lahko bile ostanki večjih vrtač prvotne uravnave, medtem ko so manjše morda že izginile. V tem smislu bi lahko interpretirali razmere na Markiževi gori nad Volčami (sl. 18), njeno severovzhodno pobočje je pogojeno s prelomom, zato je strmo in pokrito z deluvijem, jugozahodno pobočje pa položnejše, na njem je nekaj manjših vrtač, vendar bistveno manj kot spodaj na uravnanem Vrepolju pri Volčah, na slemenu pa sta dve večji vrtači. Lahko bi torej dejali, da so redke vrtače na jugozahodnem pobočju preostanek večjih vrtač, ki so obstajale pred dvigom. Pas ob Volčah in navzdol proti Košanskemu hribu je kultiviran in ni primeren za primerjavo. Preko Ravnika se na severovzhodni strani Markiževe gore vleče niz vrtač, ki kaže na brezstropo jamo (1), konča se ob severovzhodnem pobočju z veliko udorno tvorbo podobno zatrepu (2). Ta pokriva celotno severno pobočje in del grebena, kar pomeni, da je nastala po dvigu Markiževe gore in je verjetno posledica sekundarnih procesov, zato ne ruši predlagane interpretacije.

Vremščica in Selivec sta praktično brez večjih vrtač, obstajajo pa manjše, ki so na lidarju komaj zaznavne.

Razmeroma enostavna razlaga pa je manj prepričljiva za Sopado za katero smo ugotovili, da ni nastala zaradi tektonskega dviga temveč zaradi selektivne korozije, saj je Sopado dolgo časa prekrival pokrov flišnih kamnin, katerega ostanek je še viden ob Gabrškem prelomu v Brestovici pri Povirju (sl. 15, profil B – B). Če zanemarimo udornico Petnjak nad Brestovico, preseneča ena velika vrtača in nekaj manjših ter nizi vrtač v grapah. Vsi ti pojavi bi lahko nastali zaradi posebnih pogojev pri postopnem umikanju flišnega pokrova od slemena Sopade navzdol, vendar bi bilo treba to možnost še preučiti.

Korelacija

V coni povečane kompresije med črnokalsko anomalijo in Hrušico (sl. 11) so zaporedoma razvrščene naslednje strukturno-geomorfološke posebnosti: 1. deformirani severozahodni robovi deluvium, while the south-western slope is flatter with a few small dolines, but significantly fewer than further below, on the levelled Vrepolje field near Volče, and there are two larger dolines on the ridge. It could therefore be said that the rare dolines on the south-western slope are the remnants of larger dolines that existed before the uplift. The zone along Volče and down towards Mt. Košanski hrib is cultivated and not suitable for comparison. A series of dolines stretches across the Ravnik plane north of Mt. Markiževa gora and indicate an unroofed cave (1), ending on the north-eastern slope with a large collapse form similar to a steephead (2). It covers the entire northern slope and part of the ridge, which means that it was formed after the uplift of Mt. Markiževa gora and is probably the result of secondary processes, so it does not affect the proposed interpretation.

Mt. Vremščica and Mt. Selivec are practically free of larger dolines, but there are smaller ones that are barely detectable on the lidar.

A relatively simple explanation, however, is less convincing for Mt. Sopada, which we found to have been formed not by tectonic uplift but by selective corrosion, as Mt. Sopada was covered by flysch rocks for a long time, so flysch remnants can still be seen next to the Gabrk Fault at the village of Brestovica pri Povirju (Fig. 15, profile B – B). Ignoring the collapse doline Petnjak above Brestovica pri Povirju, one large and several smaller dolines and series of dolines in the ravines are surprising. All these phenomena could have formed due to special conditions during the gradual retreat of the flysch cover from the Mt. Sopada ridge down, but such a possibility should still be studied.

Correlation

In the zone of increased compression between the Črni Kal Anomaly and Mt. Hrušica (Fig. 11), the following structural-geomorphological peculiarities are sequentially classified: 1. the deformed north-western edges of the Brkini Synclinorium and the Čičarija Anticlinorium, 2. the Škocjan structural bend, which represents the highest part of the NW-tilted levelled karst surface (Fig. 12), 3. transpressive Selivec and Vremščica Anticlines (Fig. 15, profile B – B, profile C – C; Fig. 17) and 4. the Nanos part of the Nanos-Čaven antiform, which has a larger amplitude than the Čaven part. The interdependence of the described structural-geomorphological peculiarities is shown on the correlation diagram (Fig. 19), where their position on the common imaginary axis in the direction of N25° is given schematically. It is roughly perpendicular to the local trend of the larger Dinaric

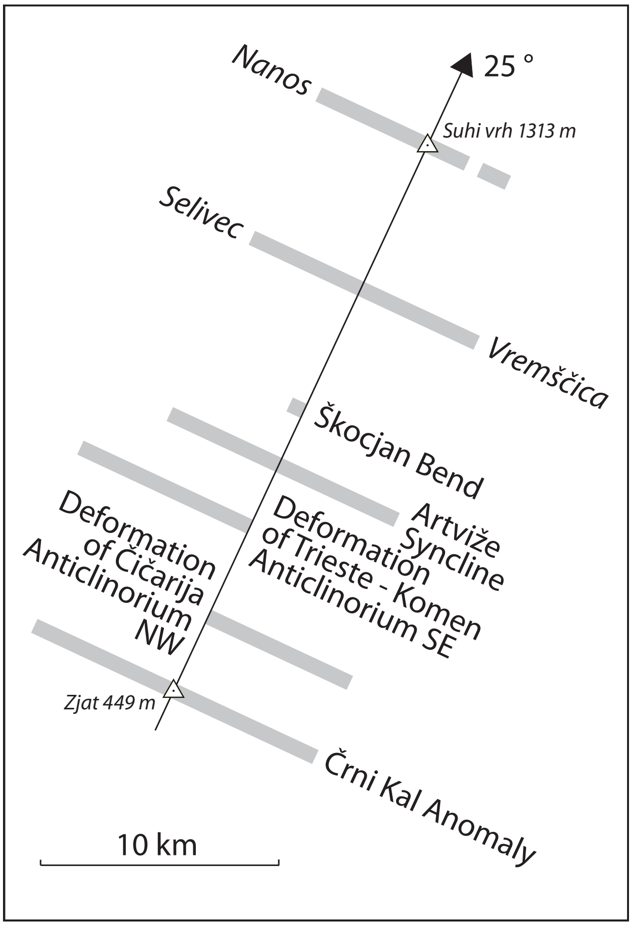


Fig. 19. Corelation diagram.
Sl. 19. Korelacijski diagram.

Brkinskega sinklinorija in Čičarijskega antiklinorija, 2. škocjanski pregib, ki predstavlja najvišji del proti NW nagnjene uravnave Krasa (sl. 12), 3. Selivška in Vremška transpresivna antiklinala (sl. 15, profil B – B, profil C – C; sl. 17) in 4. nanoški del nanoško-čavenske antiforme, ki ima večjo amplitudo od čavenskega dela. Soodvisnost opisanih strukturno-geomorfoloških posebnosti je prikazana na korelacijskem diagramu (sl. 19), kjer je shematsko podana njihova lega na skupni namišljeni osi v smeri 25°. Ta je približno pravokotna na tukajšnjo smer večjih dinarskih struktur in poteka med hribom Zjat (449 m) na Kraškem robu nad Podpečjo in najvišjim vrhom Nanosa, Suhim vrhom (1313 m). V spodnjem delu diagrama je prikazano vplivno območje črnokalske anomalije. Vse omenjene strukturno-geomorfološke posebnosti na korelacijskem diagramu ležijo v coni, ki je dolga okoli 40 km in široka okoli 10 km do 15 km. Zaradi prekrivanja strukturnih in geomorfoloških vrhuncev uvajamo namesto opisnega termina prečnodinarska cona povečane kompresije med črnokalsko anomalij in Hrušico, skrajšani termin traverza Kraški rob structures and runs between Zjat hill (449 m) on the Kraški rob above the village of Podpeč and the highest peak of Mt. Nanos, Mt. Suhi vrh (1313 m). The influence area of the Črni Kal Anomaly is shown in the lower part of the diagram.

All of the mentioned structural-geomorphological features on the correlation diagram lie along a zone some 40 km long and 10 km to 15 km wide. Due to the overlap of structural and geomorphological peaks, instead of the descriptive term Transverse Dinaric zone of increased compression between the Črni Kal Anomaly and Mt. Hrušica«, we introduce the abbreviated term Kraški rob – Hrušica Traverse. For the sake of simplified use, we replaced the term Črni Kal Anomaly with the term Kraški rob (Žitko, 1990; Placer, 2007), with which it mainly overlaps (Fig. 11). The aforementioned zone of increased compression is not an exception within the Istra Pushed Area, as there is a disproportionately larger unit located in the hinterland of the South Istra Pushed Wedge. The Črni Kal Anomaly is a peculiarity, a special feature, which was the cause of the North Istra Extrusion Wedge formation. Without the discovery of the Črni Kal Anomaly and the zone of increased compression, we would not be able to explain the formation of Mt. Vremščica and other structural-geomorphological peculiarities in it, e.g. structural characteristics of the Škocjan Caves sinking area.

The Kraški rob - Hrušica Traverse spatially overlaps with the Senožče Folds Splitting Zone. The overlap is not accidental, as the Črni Kal Anomaly between the fronts of the Trieste - Komen and Čičarija Anticlinorium is an integral part of the Senožeče Folds Splitting Zone. If we look at the problem from the point of view of space shortening, the folds splitting zone is more (deformed) than the synclinorium and anticlinorium next to it (Fig. 9D), so the deformations are more pronounced in it.

In this article, we did not deal with the deformation kinematics of the north-western edges of the Brkini Synclinorium and the Čičarija Anticlinorium, which is related to the Črni Kal Anomaly. The exposed position of the Ravnik Anticlinorium could also be the result of increased compression, as it lies in the traverse zone. There are still some problems, but the tectonic geomorphology of the Istra Pushed Area is still in its infancy.

Formation of the North Istra Extrusion Wedge and South Istra Pushed Wedge

The main cause of the formation of the North Istra Extrusion Wedge and the South Istra Pushed Wedge is the structure of the border area between

- Hrušica. Izraz črnokalska anomalija smo zaradi poenostavljene rabe zamenjali s pokrajino Kraški rob (Žitko, 1990; Placer, 2007) s katero se v glavnem prekriva (sl. 11). Omenjena cona povečane kompresije ni izjema znotraj istrskega potisnega območja, saj se neprimerno večja nahaja v zaledju konice južnoistrskega potisnega klina, posebnost je črnokalska anomalija, ki je bila vzrok za njen nastanek. Brez odkritja črnokalske anomalije in cone povečane kompresije ne bi mogli razložiti nastanka Vremščice in drugih strukturno-geomorfoloških posebnosti v njej, npr. strukturnih značilnosti ponornega območja Škocjanskih jam.

Traverza Kraški rob - Hrušica se prostorsko prekriva s senožeško cono cepljenja gub. Prekrivanje ni slučajno, saj je črnokalska anomalija med čeloma Tržaško-Komenskega in Čičarijskega antiklinorija sestavni del senožeške cone cepljenja gub. Če gledamo na problem s strani krčenja prostora, je cona cepljenja gub bolj toga od sinklinorijev in antiklinorijev ob njej (sl. 9D), zato so deformacije tu povečane.

V tem članku se nismo ukvarjali s kinematiko deformacije severozahodnih robov Brkinskega sinklinorija in Čičarijskega antiklinorija, ki je povezana s črnokalsko anomalijo. Tudi izpostavljena lega Ravniškega antiklinorija bi lahko kazala na posledico povečane kompresije, saj leži v območju traverze. Problemov je še nekaj, vendar je tektonska geomorfologija istrskega potisnega območja šele v povojih.

Nastanek severnoistrskega iztisnega in južnoistrskega potisnega klina

Glavni vzrok nastanka severnoistrskega iztisnega klina in južnoistrskega potisnega klina je zgradba mejnega območja med Mikroadrijo in Dinaridi v Istri v katerem ima posebno vlogo črnokalska anomalija. Uvodoma si najprej oglejmo standardni horizontalni presek ene izmed manjših narivnih lusk, ki so sestavni del istrsko-furlanske narivno-podrivne cone (sl. 20). Vzorčna narivna luska je omejenega obsega. Njeno čelo ima obliko loka, zato se bočno izklinja, premik ob narivni ploskvi je največji v njenem srednjem delu, kjer se razvije čelna antiklinala, ki tone proti obema bokoma (sl. 20A), lahko pa se plasti preprosto naslanjajo na narivno ploskev brez izrazite čelne antiklinale (sl. 20B). Med narivanjem so zgornje luske s svojo težo izzvale nastanek spodnjih lusk, tako da se je izoblikoval splet lusk, ki je prikazan na sl. 20C. Iz tega sledi, da ležijo mlajše luske pod starejšimi. Taka zgradba je značilna za čičarijski del istrsko-furlanske

Microadria and the Dinarides in Istra, in which the Črni Kal Anomaly plays a special role. As an introduction, let us first take a look at the standard horizontal section of one of the smaller duplexes that are an integral part of the Istra-Friuli Thrust-Underthrust Zone (Fig. 20). The sample thrust duplex is limited in scope. Its front has the shape of an arch, so it curves laterally, and the offset along the thrust plane is largest in its central part, where a frontal anticline develops and its axis (gently) plunges towards both flanks (Fig. 20A), but the layers can simply rest on the thrust plane without a distinct frontal anticline (Fig. 20B). During thrusting, the upper duplexes provoked the formation of the lower scales with their weight, so that the scales-like network of duplexes was formed, which is shown in Fig. 20C. It follows that the younger scales lie below the older ones. Such a structure is typical for the Čičarija part of the Istra-Friuli Thrust-Underthrust Zone. The frontal anticlines (the duplex cores) are from the oldest layers that come to the surface, in our case Paleogene limestone.

The formation of the North Istra and South Istra Structural Wedges and their dynamic versions is shown schematically in Figure 21 in four sketches A, B, C and D. The first three show what happened in the Paleogene, the last one in the Neogene, which extended into the recent period.

Figure 21A shows the Trieste-Komen and Čičarija frontal Anticlines in the initial stage of the formation of the Trieste-Komen and Čičarija Anticlines. The two frontal anticlines had already shifted in the beginning, which is described in the chapter on thestructure of the External Dinaric Imbricated Belt.

Figure 21B shows the beginning of the development of a single thrust zone, when two anticlinoria formed from the two anticlines. From the present-day structure it can be concluded that there was no direct connection between the frontal thrusts of the two offset folds, but that a series of thrust duplexes of monotonous structure was formed between them, in which the north-western edges of the frontal anticlines of the Paleogene limestone were arranged in an echelon series. In the figure, the situation is simplified, whereby a situation developed where the envelope of the north-western flanks of the Paleogene limestone frontal anticlines was linear in two-dimensional space, and the subvertical plane or enveloping plane »E« in three-dimensional space. The spatial arrangement of frontal anticlines from Paleogene limestone can be compared to a stack of firewood, where the sawn surfaces of individual logs create a constructed plane. That this is possible is shown

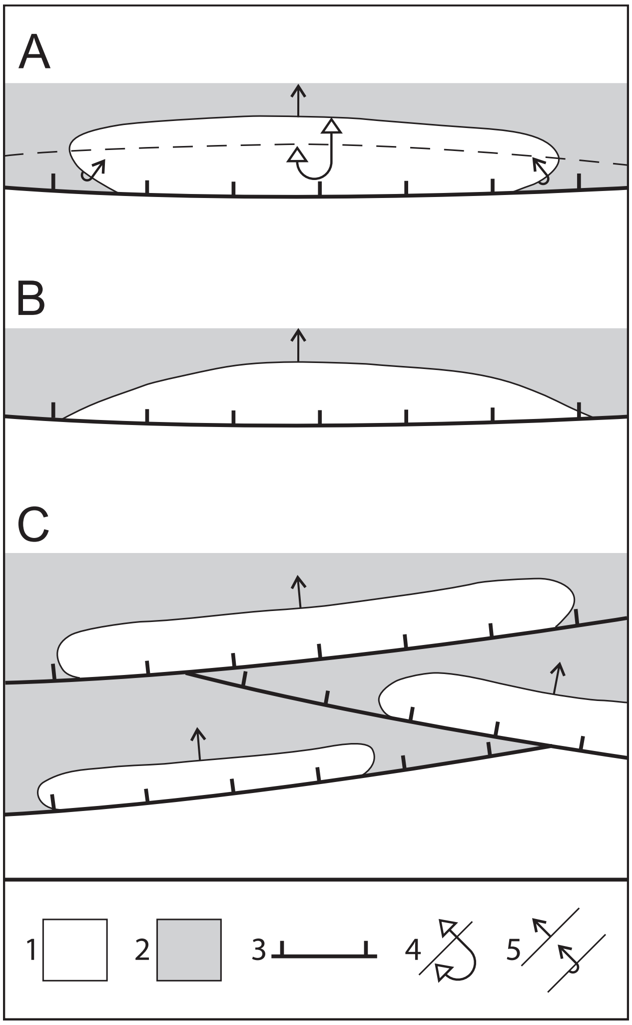


Fig. 20. Imbrication geometry: A. Ideal thrust sheet, variant with frontal anticline. B. Ideal thrust sheet, variant without frontal anticline. C. Imbricated zone (zone of multiple thrust sheets).

Sl. 20. Geometrija luskanja: A. Idealna narivna luska, varianta s čelno antiklinalo. B. Idealna narivna luska, varianta brez čelne antiklinale. C. Narivna cona iz narivnih lusk.

1 Carbonates / karbonati
2 Flysch / fliš
3 Thrust plane / narivna ploskev
4 Overturned Anticline / prevrnjena antiklinala
5 Bedding: normal, inverse / plasti: normalne, inverzne

narivno-podrivne cone. Čelne antiklinale so iz najstarejših plasti, ki izdanjajo na površje, v našem primeru je to paleogenski apnenec.

Nastanek severnoistrskega in južnoistrskega strukturnega klina ter njunih dinamskih izvedenk je shematsko prikazan na sliki 21 v skicah A, B, C in D, prve tri kažejo dogajanje v paleogenu, zadnja v neogenu, ki se je podaljšalo v recentno obdobje.

Na sliki 21A sta narisani Tržaško-Komenska in Čičarijska čelna antiklinala v začetni fazi nastajanja Tržaško-Komenskega in Čičarijskega antiklinorija. Čelni antiklinali sta bili zamaknjeni že v začetku, kar je opisano pri zgradbi Zunanjedinarskega naluskanega pasu.

in the structural diagram in Figure 6. Therefore, a special type of building was created, for which we proposed the term composite building.

Figure 21C shows the further development of the thrust structure. Erosion thrusts developed in front of the thrust zone front, such as the Isola Thrust, which initiated the formation of interlayer thrust surfaces in the flysch (Fig. 8). As the last thrust unit of the Dinarides in this area, the reverse Buje Fault, or the Buje Thrust Sheet, was formed, which has all the characteristics of the initial thrust unit, except that it is larger (Fig. 20). Five structural features indicate this:

1. The Savudrija-Buzet Anticline is the frontal anticline of the Buje Thrust Sheet, whose carbonate core is visible from the Savudrija peninsula to the Mirna valley before Buzet, where the limestone is covered by flysch layers in such a way that is typical for the carbonate cores of the initial thrust scales frontal folds in Figures 20A and 20C. The Savudrija-Buzet Anticline continues from Savudrija towards the northwest in the Gulf of Trieste seabed (Carulli, 2011, Fig. 3). The anticline is also indicated by the geophysical profile in the WSW-ENE direction (Busetti et al., 2012, Fig. 2). Figures 21C shows its presumed position at the time of its formation in the Paleogene.

2. The steep position of the reverse Buje Fault corresponds to the initial stage of thrust development.

3. Northeast verging reverse faults are visible in the cliff of the south-western coast of Strunjan Bay (Figs. 4A and 8). Judging by their position, they are related to the backthrusting in the hinterland of the Buje reverse Fault.

4. Thicker sub-horizontal layers of calcarenite are visible in the flysch cliff between Piran and Fiesa, i.e. in the uplifted block between the reverse Buje Fault and its backthrusts. Internal rotation is developed along the internal structures parallel to lamination in these layers via interlayer slips (Placer et al., 2010, fig. 19). The slips of the hanging wall beds are directed in a southwestern direction (Figs. 4A and 8). The data is not evidence of thrusting or underthrusting, but interlayer slipping could have been established only before the formation of the reverse Buje Fault and its backthrusts. The reverse Buje Fault is therefore related to the Paleogene thrusting. An interlayer thrust was discovered in the sub-horizontal bedding of the transitional marl between Paleogene limestone and flysch in Izola, which is the apparent equivalent of interlayer offsets in the cliff between Piran and Fiesa, which we named the Izola Thrust (Figs. 4A and 8).

Na sliki 21B je viden pričetek razvoja enotne narivne cone, ko sta iz antiklinal nastala antiklinorija. Iz današnje zgradbe je moč sklepati, da ni prišlo do neposredne povezave med čelnima narivoma obeh zamaknjenih gub, temveč, da je med njima nastal niz narivnih lusk monotone zgradbe, v katerih so se severozahodni robovi čelnih antiklinal iz paleogenskega apnenca razporedili v ešalonski niz. Na sliki so razmere poenostavljene, razvilo se je stanje, ko je ovojnica (envelopa) severozahodnih bokov čelnih antiklinal iz paleogenskega apnenca bila v dvodimenzionalnem prostoru lineara, v tridimenzionalnem prostoru pa subvertikalna planara ali ovojna ravnina (envelopna ravnina) »E«. Prostorsko razporeditev čelnih antiklinal iz paleogenskega apnenca lahko primerjamo s skladovnico drv, kjer žagane ploskve posameznih polen ustvarjajo konstruirano ravnino. Da je to mogoče je pokazano na strukturnem diagramu na sliki 6. Nastal je torej poseben tip zgradbe za katerega smo predlagali termin zložbena zgradba.

Na sliki 21C je prikazan nadaljnji razvoj narivne zgradbe. V predčelju narivne cone so se razvili erozijski narivi, kot npr. Izolski nariv, ki so injicirali nastanek medplastnih narivnih ploskev v flišu (sl. 8). Kot zadnja narivna enota Dinaridov na tem prostoru je nastal Bujski reverzni prelom, oziroma Bujska narivna luska, ki ima vse značilnosti inicialne narivne enote, le da je velikih dimenzij (sl. 20). Na to kaže pet strukturnih značilnosti:

1. Savudrijsko-Buzetska antiklinala je čelna antiklinala Bujske narivne luske, njeno karbonatno jedro je vidno od Savudrijskega polotoka do doline Mirne pred Buzetom, kjer karbonat prekrijejo flišne plasti na tak način, kot je značilno za karbonatna jedra čelnih gub inicialnih narivnih lusk na sliki 20A in 20C. Savudrijsko-Buzetska antiklinala se od Savudrije proti severozahodu nadaljuje v podmorju Tržaškega zaliva (Carulli, 2011, sl. 3). Na antiklinalo kaže tudi geofizikalni profil v smeri WSW – ENE (Busetti et al., 2012, sl. 2). Na sliki 21C je prikazana njena domnevna lega ob nastanku v paleogenu.

2. Strmi vpad Bujskega reverznega preloma ustreza inicialnemu stadiju razvoja nariva.

3. V klifu jugozahodne obale Strunjanskega zaliva so vidni reverzni prelomi, ki vergirajo proti severovzhodu (sl. 4A in sl. 8). Po prostorski legi sodeč, kažejo na povratno narivanje v zaledju Bujskega reverznega preloma.

4. V flišnem klifu med Piranom in Fieso, torej v dvignjeni grudi med Bujskim reverznim prelomom in njegovimi povratnimi narivi, so

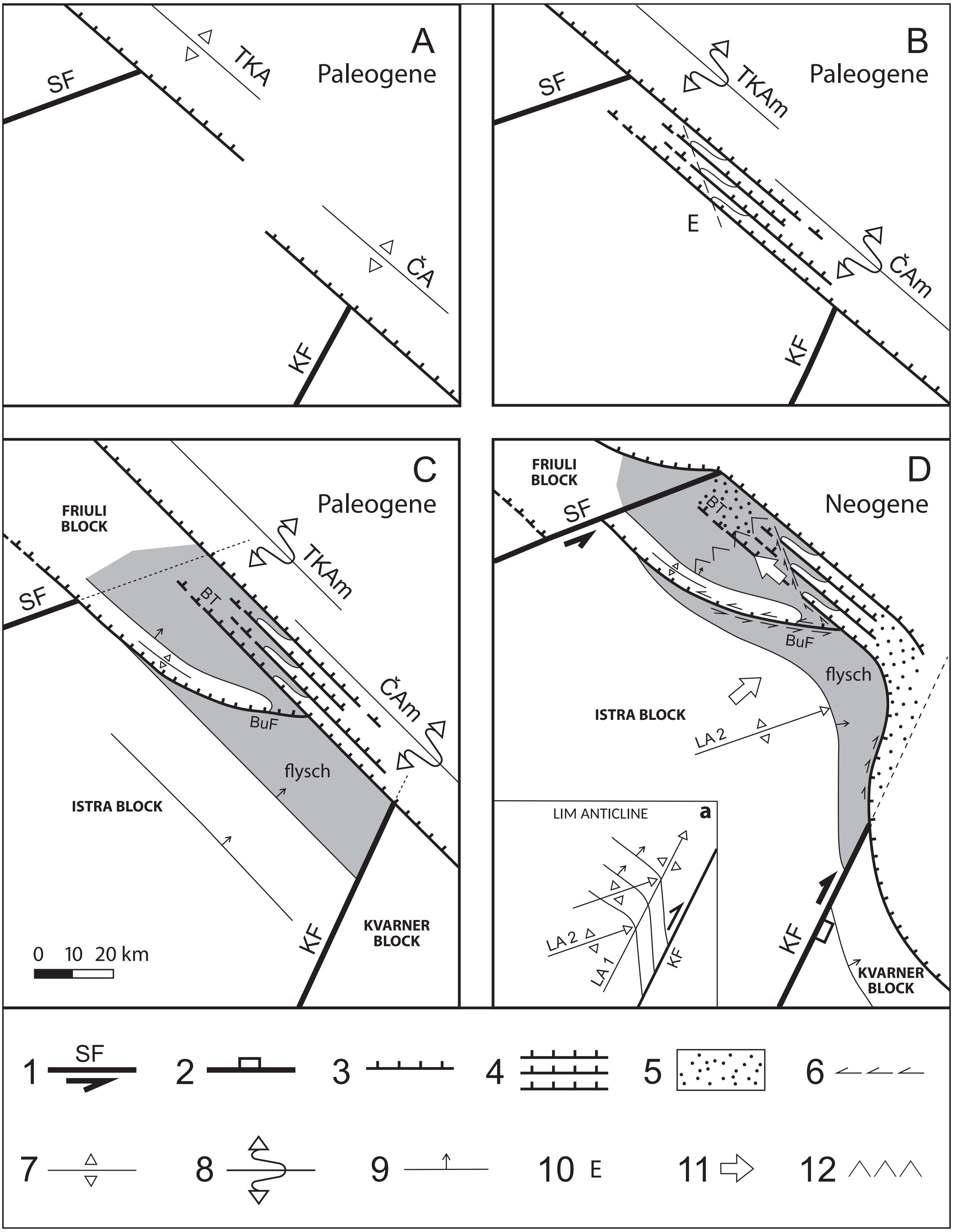


Fig. 21. Formation of the Črni Kal Anomaly, the North Istra Extrusion Wedge and the South Istra Pushed Wedge.
Sl. 21. Nastanek črnokalske anomalije, severnoistrskega iztisnega klina in južnoistrskega potisnega klina.

5. Folds are developed in the flysch between the reverse Buje Fault backthrusts and the Križ Thrust (Figs. 4A and 8). The Križ Thrust is a Paleogene structure associated with the interlayer Izola Thrust which represents an example of the interweaving of subhorizontal thrust planes in the flysch and interlayer thrust planes. The vergence of the folds in the intermediate space between the reverse Buje Fault backthrusts and the Križ Thrust is mirror-like. In this case, the symmetry is not evidence of simultaneous formation, but indicates that the older folds were formed together with the Križ Thrust. Later, when the reverse Buje Fault backthrusts were formed, the folds that create the impression of symmetry were also formed. A broader explanation is given in the description of Figure 8.

The Buje Thrust Sheet did not develop into a nappe thrust with a large offset along a subhorizontal or gently sloping thrust plane but remained as its aborted unit at the end of the Dinarides thrust. Its extreme south-eastern part is today the

vidne debelejše subhorizontalne plasti apnečevega peščenjaka. V njih je po internih strukturah vzporednih laminam, razvita interna rotacija, ki je nastala zaradi medplastnih zdrsov (Placer et al., 2010, sl. 19). Zdrsi krovninskih slojev so usmerjeni proti jugozahodu (sl. 4A in 8). Podatek ni dokaz za narivanje ali podrivanje, toda medplastno drsenje se je lahko uveljavilo samo pred nastankom Bujskega reverznega preloma in njegovih povratnih narivov. Povezujemo ga torej s paleogenskim narivanjem. V Izoli je bil v subhorizontalnih plasteh prehodnega laporja med paleogenskim apnencem in flišem odkrit medplastni nariv, ki je pojavni ekvivalent medplastnih premikov v klifu med Piranom in Fieso, imenovali smo ga Izolski nariv (sl. 4A in 8).

5. Med povratnimi narivi Bujskega reverznega preloma in Križnim narivnim prelomom so v flišu razvite gube (sl. 4A in 8). Križni narivni prelom je paleogenska struktura, povezujemo ga z Izolskim medplastnim narivnim prelomom, ki predstavlja

Paleogene thrusting:

A. Formation of shifted primal anticlines of the Trieste-Komen and Čičarija Anticlinoria and frontal reverse faults.

B. Anticlines develop into anticlinoria. A jump of movements from the frontal thrust of the Čičarija Anticlinorium to the frontal thrust of the Trieste-Komen Anticlinorium is formed via an echelon set of reverse faults. A stacked structure is formed (updated after Placer et al., 2010, Fig. 25 A). A composite building is created.

C. A segmented thrust zone is finally formed, the Buje Thrust Sheet is formed, which is the last (the most external) unit of the thrust structure of this part of the Dinarides with reverse Buje Fault in its front. The South Istra and North Istra Structural Wedges are formed (updated after Placer et al., 2010, Fig. 25 B).

Paleogensko narivanje:

A. Nastanek zamaknjenih izvornih antiklinal Tržaško-Komenskega in Čičarijskega antiklinorija ter čelnih reverznih prelomov.

B. Iz antiklinal se razvijeta antiklinorija. Oblikuje se preskok premikov s čelnega nariva Čičarijskega antiklinorija na čelni nariv Tržaško-Komenskega antiklinorija preko ešalonskega niza reverznih prelomov. Nastane zložbena zgradba (dopolnjeno po Placer et al., 2010, sl. 25 A).

C. Dokončno se oblikuje segmentirana narivna cona, nastane Bujska narivna luska, ki je zadnja enota narivne zgradbe tega dela Dinaridov. V njenem čelu Bujski reverzni prelom. Nastaneta južnoistrski in severniostrski strukturni klin (dopolnjeno po Placer et al., 2010, sl. 25 B).

Neogene underthrusting and pushing:

D. Formation of the South Istra Pushed and North Istra Extrusion Wedges.

Neogensko podrivanje in potiskanje:

D. Nastanek južnoistrskega potisnega in severnoistrskega iztisnega klina.

1 The segmented Microadria strike-slip faults: SF – Sisitiana Fault, KF - Kvarner Fault / zmični prelom segmentirane Mikroadrije: SF – Sesljanski prelom, KF – Kvarnerski prelom

2 Subsided fault block / ugreznjeno prelomno krilo

3 Paleogene thrust, reverse fault: BT – Buzet Thrust, BuF – reverse Buje Fault / paleogenski nariv, reverzni prelom: BT – Buzetski nariv, BuF – Bujski reverzni prelom

4 Paleogene thrust zone / paleogenska narivna cona

5 Neogene-recent Istra-Friuli Thrust-Underthrust Zone / neogensko-recentna istrsko-furlansla narivno-podrivna cona

6 Lateral slipping along primary thrust surfaces, along reverse faults and along envelope faults in the Črni Kal Anomaly / zmikanje po primarnih narivnih ploskvah, po reverznih prelomih in po ovojnih ali envelopnih prelomih v črnokalski anomaliji

7 Anticlines: TKA – Trieste-Komen Anticline, ČA – Čičarija Anticline, LA –Lim Anticline, a flanking asymetric fold along the Kvarner Fault (LA1 – axis in the axial plane, LA2 – axis in one of the bisector planes) / antiklinale: TKA – Tržaško-Komenska antiklinala, ČA – Čičarijska antiklinala, LA – Limska antiklinala, obprelomna asimetrična guba ob Kvarnerskem prelomu (LA1 – os v osni ravnini, LA2 – os v eni izmed simetralnih ravnin)

8 Anticlinoria: TKAm – Trieste-Komen Anticlinorium, ČAm – Čičarija Anticlinorium / antiklinoriji: TKAm – Tržaško-Komenski antiklinorij, ČAm – Čičarijski antiklinorij

9 Geological boundary, dip direction / geološka meja, smer vpada

10 Stacked structure / zložbena zgradba

11 Rellative offset direction / smer relativnega premikanja bloka

12 North Istra Extrusion Wedge extrusion boundary / meja izrivanja severnoistrskega iztisnega klina.

North Istra Structural Wedge. We assume that Microadria was already segmented in the Paleogene. This is indicated by the absence of the Oligocene in Istra, which is very likely related to the post-thrust uplift of Istra along the Kvarner Fault. From the above data, it follows that the South Istra Structural Wedge was also formed in the Paleogene.

In the Neogene, the movement of Istra, or rather this part of Microadria, towards the Dinarides began, which resulted in the development of pushing and underthrusting structures. The origin and direction of the deformations now change radically and run in the opposite direction of thrusting. In this process, the segmented Microadria faults also came to life, the most important of which are the Kvarner Fault and the Sistiana Fault in the territory under consideration, between which lies the Istra block. Structural mapping of the selected areas showed that the degree of thrusting and underthrusting of the Istra block increases from northwest to southeast, which is illustrated by the degree of tectonization of the Istra-Friuli Thrust-Underthrust Zone. This movement is smaller in the area of the Trieste parallelepiped, larger in the area of the North Istra Extrusion Wedge, and largest in the tip of the South Istra Pushed Wedge. Pushing and underthrusting is reflected in the formation of »pushed« reverse faults and in the folding of Paleogene thrust units. Both caused the uplift of the Kraški rob and the deformation of the Dinarides. The mechanism of folding and uplift of the Dinarides due to underthrusting and pushing of the Microadria has not yet been described in detail.

Sketch D (Fig. 21D) shows the hypothesis of the formation of the South Istra Pushed and North Istra Extrusion Wedges and envelope faults in the area of the Črni Kal Anomaly. The arcuate shape of the reverse Buje Fault trace and the resulting wedge-shaped south-eastern block should therefore have been designed already in the Paleogene (Fig. 21C). The Neogene movement of the Istra block towards the Dinarides provoked the development of the left-lateral strike-slip Sistiana and right-lateral strike-slip Kvarner Flexural Zones and the formation of pushed and underthrust zones. Within the Istra block itself, the wedge-shaped south-eastern part of the Buje Thrust Sheet provoked an extrusion process that did not follow the disjunctive boundaries of the wedge. Its south-western margin slipped along the newly formed strike-slip Zambratija Zone at the head of the Buje Thrust Sheet, while its north-eastern margin slipped along the newly formed dextral strike-slip zone in the enveloping plane of the Črni Kal Anomaly. The graphic in Figure 21D is a rough schematic of the reverse

primer prepletanja položnih narivnih ploskev v flišu in medplastnih narivnih ploskev. Vergenca gub v vmesnem prostoru med povratnimi narivi Bujskega reverznega preloma in Križnim narivnim prelomom, je zrcalna. Simetrija v tem primeru ni znak hkratnega nastanka, temveč kaže na to, da so starejše gube nastale skupaj s Križnim narivom, ob nastanku povratnih reverznih prelomov Bujskega reverznega preloma, pa so zatem nastale tudi gube, ki ustvarjajo podobo simetrije. Pri opisu sliki 8 je podana širša razlaga.

Bujska narivna luska se ni razvila v krovni nariv z daljšim premikom in položnejšim vpadom, temveč je ob zaključku narivanja Dinaridov ostala kot njihova abortirana enota. Njen skrajni jugovzhodni del predstavlja danes severnoistrski strukturni klin. Predpostavljamo, da je bila Mikroadrija v paleogenu že segmentirana, na to kaže odsotnost oligocena v Istri, kar je zelo verjetno povezano s postnarivnim dvigom Istre ob Kvarnerskem prelomu. Iz naštetih podatkov izhaja, da je bil v paleogenu zasnovan tudi južnoistrski strukturni klin.

V neogenu se je pričelo premikanje Istre, oziroma tega dela Mikroadrije, proti Dinaridom, v katerih so se zaradi tega razvile strukture potiskanja in podrivanja. Izvor in smer deformacij se sedaj radikalno spremenita in potekata v nasprotni smeri narivanja. V tem procesu oživijo tudi prelomi segmentirane Mikroadrije, pomembnejša med njimi sta na obravnavanem ozemlju Kvarnerski in Sesljanski prelom med katerima leži istrski blok. Strukturno kartiranje izbranih območij je pokazalo, da se stopnja potiskanja in podrivanja istrskega bloka povečuje od severozahoda proti jugovzhodu. To se najlepše vidi v stopnji porušenosti istrsko-furlanske narivno-podrivne cone. Na območju tržaškega paralelepipeda je manjša, na območju severnoistrskega iztisnega klina večja, največja na območju konice južnoistrskega potisnega klina. Potiskanje in podrivanje se odraža v nastajanju potisnih reverznih prelomov in v gubanju paleogenskih narivnih enot. Oboje je povzročilo dvig kraškega roba in deformacijo Dinaridov. Mehanizem gubanja in dviganja Dinaridov zaradi podrivanja in potiskanja Mikroadrije še ni bil podrobneje opisan.

Na skici D (sl. 21D) je podana hipoteza nastanka južnoistrskega potisnega in severnoistrskega iztisnega klina ter ovojnih ali envelopnih prelomov v območju črnokalske anomalije. Ločna oblika Bujskega reverznega preloma in iz tega izhajajoča klinasta oblika njegovega jugovzhodnega boka, naj bi bila torej zasnovana že v

Buje Fault area, so it also appears in Figure 22. The formation of the South Istra Pushed Wedge is therefore the result of the movement of the North Istra Extrusion Wedge. The amount of displacement along the edges of the North Istra Extrusion Wedge is the same, but it is asymmetric along the edges of the South Istra Pushed Wedge; along the strike-slip Zambratija Zone it is equal to the displacement of the North Istra Extrusion Wedge and is relatively small, while it is incomparably larger along the strike-slip Kvarner Fault. This is externally reflected in the formation of the extensive sigmoidal structure of the Kvarner Flexural Zone and the asymmetric Lim Anticline.

The dynamics of this process are also confirmed by recent GNSS (Global Navigation Satellite System) data, according to which the part representing the South Istra Pushed Wedge is moving north-northeast, i.e. parallel to the Kvarner Fault (Brancolini et al., 2019, fig. 1). A large asymmetrical anticlinal fold, called the Lim Anticline, developed along the Kvarner Fault. Its asymmetrical structure is presented in Fig. 21D, sketch a; the axis in the axial plane is marked as LA1; and the axis in one of the symmetry planes is marked as LA2, and there are as many of these as there are layers. Due to a gentle bedding dip it is easy to determine anticline axis on the geological map only in the symmetry plane of the unconformity between the Eocene carbonates and clastites (Fig. 21D, fold LA2; Fig. 2), while the axis of the LA1 axial plane can only be constructed. When interpreting the current shape of the Lim Anticline it is also necessary to take into account the deformation due to movement along the left-lateral strike-slip Zambratija Zone. The Lim Anticline shape (Figs. 2 and 3) is therefore a combination of a flanking fold along the right-lateral strike-slip Kvarner Zone and the left-lateral strike-slip Zambratija Zone.

By describing the role of the reverse Buje Fault, or the Buje Thrust Sheet it is, in the dynamic scheme of Istra, possible to answer the question of where the border of the Dinarides lies northwest of the Kvarner Fault. Formally, it would lie along the reverse Buje Fault, which is the most distal thrust of the Dinarides which, however, did not experience its full development. Which is why the Buje Thrust Sheet became a part of Microadria in the process of its underthrusting. Thus, the formal thrust boundary of the Dinarides in eastern Istra represents the south-western or external edge of the Istra-Friuli Thrust-Underthrust Zone, and in the area of the Gulf of Trieste its north-eastern or inner edge. The Kvarner Fault extends to the external edge, the Sistiana Fault to the internal edge, and with this the

paleogenu (sl. 21C). Neogensko premikanje istrskega bloka proti Dinaridom je izzvalo razvoj sesljanske levozmične in kvarnerske desnozmične upogibne cone ter nastajanje potisne in podrivne cone. Znotraj samega bloka je klinasta oblika jugovzhodnega dela Bujske narivne luske izzvala proces iztiskanja, ki pa ni sledil disjunktivnim mejam klina. Njegov jugozahodni rob je zdrsel po novonastali zambratijski levozmični coni ob čelu Bujske narivne luske, severovzhodni rob pa po novonastali desnožnični coni v envelopni ravnini črnokalske anomalije. Grafika na sl. 21D je v območju Bujskega reverznega preloma grobo shematska, tako je tudi na sl. 22. Nastanek južnoistrskega potisnega klina je torej posledica premika severnoistrskega iztisnega klina. Velikost premika ob robovih severnoistrskega iztisnega klina je enaka, ob robovih južnoistrskega potisnega klina pa je asimetrična; ob zambratijski levozmični coni je enaka premiku severnoistrskega iztisnega klina in sorazmerno majhna, ob Kvarnerskem desnozmičnem prelomu pa neprimerljivo večja. Ta se navzven odraža v nastanku obsežne sigmoidalne zgradbe kvarnerske upogibne cone in Limske asimetrične obprelomne antiklinale.

Dinamiko tega procesa potrjujejo tudi recentni podatki GNSS (Global Navigation Satellite System) po katerih se del, ki predstavlja južnoistrski potisni klin, premika proti severo-severovzhodu, torej vzporedno s Kvarnerskim prelomom (Brancolini et al., 2019, sl. 1). Razvila se je obsežna obprelomna guba, oziroma obprelomna antiklinala, ki smo jo poimenovali Limska. Njena zgradba je asimetrična (sl. 21D, skica a), os v osni ravnini je označena z LA1, os v eni izmed simetrijskih ravnin pa z LA2, teh je toliko kolikor je plasti. Na površinski karti Istre je zaradi blagega vpada plasti mogoče hitro in enostavno določiti le os v simetralni ravnini diskordančnega stika med eocenskimi karbonati in eocenskimi klastiti (sl. 21D, guba LA2; sl. 2), medtem ko je mogoče os osne ravnine LAl le konstruirati. Pri razlagi sedanje oblike gube pa je potrebno upoštevati tudi deformacijo zaradi premika ob zambratijski levozmični coni, Limska antiklinala na slikah 2 in 3 je torej kombinacija obprelomne gube ob kvarnerski desnozmični coni in zambratijski levozmični coni.

Z opisom vloge Bujskega reverznega preloma, oziroma Bujske narivne luske, v dinamični shemi Istre, je mogoče dati odgovor na vprašanje, kje poteka meja Dinaridov severozahodno od Kvarnerskega preloma. Formalno po Bujskem reverznem prelomu, ki je skrajni zunanji nariv

Črni Kal Anomaly acquires a meaning that must be investigated from other aspects as well, e.g. sedimentological. At the moment, we can only suggest that the informal and temporary boundary between the Dinarides and the Adriatic promontory runs along the Črni Kal Anomaly.

Considering the offset between the Trieste-Komen and the Čičarija Anticlinoria, which caused the Črni Kal Anomaly, we believe that the Istra-Friuli Thrust-Underthrust Zone is only so wide in the Istra block. The Zone should therefore be narrower northwest of the Sistiana Fault, but this aspect has not yet been investigated.

Dynamic model

A structural geometry of the Istra block and the south-western part of the Istra Pushed Area sketch is presented in Figure 22. At first glance, the relation between the autochthon (*sensu stricto* and *sensu lato*), that is, Microadria, and the Dinarides is noticeable. The only original deformations of the autochthon *sensu stricto* are the Sistiana and Kvarner Faults, both of which lie transversely to Dinaridov, vendar ta ni doživel popolnega razvoja. Zato je Bujska narivna luska v procesu podrivanja Mikroadrije postala njen aktivni del. Tako predstavlja formalno narivno mejo Dinaridov v vzhodni Istri jugozahodni ali zunanji rob istrsko-furlanske narivno podrivne cone, na območju Tržaškega zaliva pa njen severovzhodni ali notranji rob. Kvarnerski prelom sega do zunanjega roba, Sesljanski prelom do notranjega roba, s tem pa dobi črnokalska anomalija pomen, ki ga je treba raziskati tudi z drugih vidikov, npr. sedimentološkega. V tem trenutku lahko le predlagamo, da poteka neformalna in začasna meja med Dinaridi in jadranskim predgorjem po črnokalski anomaliji.

Glede na zamik med Tržaško-Komenskim in Čičarijskim antiklinorijem, zaradi katerega je nastala črnokalska anomalija, menimo, da je istrsko-furlanska narivno-podrivna cona tako široka le na območju istrskega bloka. Severozahodno od Sesljanskega preloma naj bi bila torej ožja, vendar je v tem smislu še neobdelana.

Fig. 22. Dynamic model of the Kraški rob - Hrušica Traverse formation.
Sl. 22. Dinamski model nastanka traverze Kraški rob - Hrušica.

1 Thrusting classification: autochthon *sensu stricto*, autochthon *sensu lato*, allochthon / narivna razčlenitev: avtohton *sensu stricto*, avtohton *sensu lato*, alohton

2 External Dinaric Thrust Belt boundary / meja Zunanjedinarskega narivnega pasu

3 A thrust (plane) in the External Dinaric thrust boundary zone: BuF – reverse Buje Fault, BT – Buzet Thrust / nariv v coni narivne meje Dinaridov: BuF – Bujski reverzni prelom, BT – Buzetski narivni prelom

4 Istra-Friuli Thrust-Underthrust Zone / istrsko-furlanska narivno-podrivna cona

5 Črni Kal Anomaly, the informal boundary between autochthon *sensu lato* and allochthon / črnokalska anomalija, neformalna meja avtohtona *sensu lato* in alohtona

6 The segmented Microadria strike-slip faults: SF – Sistiana Fault, KF – Kvarner Fault / zmični prelom segmentirane Mikroadrije: SF – Sesljanski prelom, KF – Kvarnerski prelom

7 Secondary subsided block of the Kvarner Fault / sekundarno ugreznjeno krilo Kvarnerskega preloma

8 Right lateral strike-slip longitudinal faults: RF – Raša Fault, IF – Idrija Fault / dinarski desnozmični longitudinalni prelom: RF – Raški prelom, IF – Idrijski prelom

9 Direction of secondary strike-slip movement / smer sekundarnega zmikanja

10 Axis of the flexural zone and the inferred position of the Sistiana and Kvarner Faults beneath nappe units of the External Dinarides: SFZ – Sistiana Flexural Zone, KFZ – Kvarner Flexural Zone / os upogibne cone in domnevna lega Sesljanskega in Kvarnerskega preloma pod narivnimi enotami Zunanjih Dinaridov: SFZ – sesljanska upogibna cona, KFZ – kvarnerska upogibna cona

11 Anticline: LA2 – Lim Anticline (axis in one of the bisector planes), SbA – Savudrija- Buzet Anticline, ViA – East Istra Anticline / 11 antiklinala: LA2 – Limska antiklinala (os po eni od simetralnih ravnin), SbA – Savudrijsko-Buzetska antiklinala, ViA – vzhodnoistrska antiklinala

12 Anticlinorium, synclinorium: a – Trieste-Komen Anticlinorium, b – Čičarija Anticlinorium, c – Ravnik Anticlinorium, d – Vipava Synclinorium, e – Brkini Synclinorium / 12 antiklinorij, sinklinorij: a – Tržaško-Komenski antiklinorij, b – Čičarijski antiklinorij, c – Ravniški antiklinorij, d – Vipavski sinklinorij, e – Brkinski sinklinorij

13 Area of the Kraški rob - Hrušica Traverse / območje traverze Kraški rob - Hrušica

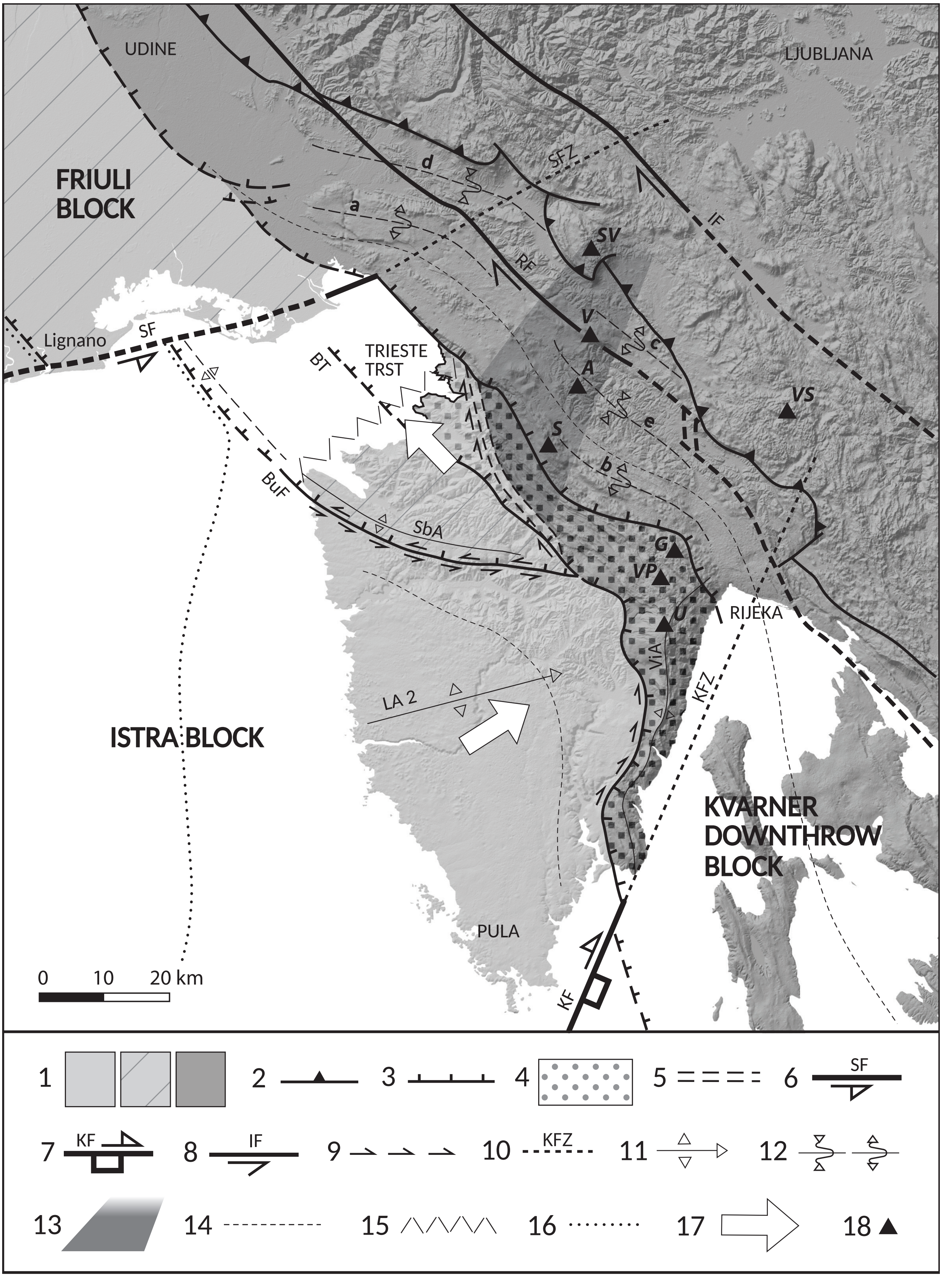
14 Structural-geomorphological trajectory / strukturno-geomorfološka trajektorija

15 North Istra Extrusion Wedge limit of extrusion / meja izrivanja severnoistrskega iztisnega klina

16 External boundary of the Mesozoic carbonate platform / zunanja meja mezozojske karbonatne platforme

17 Relative direction of movement of the South Istra Pushed and North Istra Extrusion Wedges / relativna smer premikanja južnoistrskega potisnega in severnoistrskega iztisnega klina

18 Exposed peaks: SV– Mt. Suhi vrh (1313 m), V – Mt. Vremščica (1027 m), A – Mt. Ajdovščina (804 m) and Mt. Artviže (817 m), S – Mt. Slavnik (1028 m), U – Mt. Učka (1394 m), VP – Mt. Veliki Planik (1272 m), G – Mt. Gomila (1241 m), VS – Mt. Veliki Snežnik (1796 m) / izpostavljeni vrhovi: SV – Suhi vrh (1313 m), V – Vremščica (1027 m), A – Ajdovščina (804 m) in Artviže (817 m), S – Slavnik (1028 m), U – Učka (1394 m), VP – Veliki Planik (1272 m), G – Gomila (1241 m), VS – Veliki Snežnik (1796 m).



UDINE
LJUBLJANA
FRIULI BLOCK
SFZ
IF
RF
SV
V
A
VS
S
d
a
c
e
b
Lignano
SF
BT
TRIESTE
TRST
BuF
SbA
G
VP
U
RIJEKA
ViA
KFZ
LA 2
ISTRA BLOCK
KVARNER DOWNTHROW BLOCK
PULA
0 10 20 km
KF
1
2
3
4
5
6 SF
7 KF
8 IF
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10 KFZ
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the Dinarides, while the reverse Buje Fault, or rather the Buje Thrust Sheet, is part of the Dinaric thrust structure, which became part of the autochton (*sensu lato*) in the Neogene-recent pushing and subthrusting phase of the Microadria towards the Dinarides. The Sistiana and Kvarner Faults do not intersect the Dinarides, but only extend to the Istra-Friuli Thrust-Undrerthrust Zone. The Sistiana and Kvarner Flexural Zones have developed in their extensions in the Dinarides. The first is simpler and weaker, but can be followed on a digital relief model at least 50 km into the Dinarides. The second one is considerably stronger and forms an extensive flexural zone of sigmoidal shape, but its extent in the Dinarides is difficult to determine. According to a rough estimate, it extends at least 70 km to 80 km into the Dinarides. In its extension, the Idrija Fault is not bent in the same way as in the extension of the Sistiana Flexural Zone. Discussion of this issue is beyond the scope of this article; here it is sufficient to explain that the Idrija Fault is segmented in the area of the karst fields southeast of Mt. Hrušica and in this sense has not yet been investigated in detail, therefore its trace in Figures 1 and 22 is drawn dashed.

The course of the Sistiana Fault in the Gulf of Trieste is not clear. Carulli (2011, fig. 3) hypothetically stretched it from Sistiana Bay towards the southwest, based on the structural map of the contact between the carbonates and the flysch in the subsea of the Gulf of Trieste, which is based on the geophysical profiles. Carulli (2011) was guided by a saddle in the hinge of the Savudrija-Buzet Anticline extension drawn on the structural map. Determination of the Sistiana Flexural Zone in the External Dinarides to 60–56° (Placer et al., 2021b) offered a hypothetical possibility that the fault trace runs along the north-western edge of the extension of the Savudrija-Buzet Anticline, where Carulli (ib.) assumed the Aquilea Fault. According to this variant, there is a possibility that the Sistiana Fault runs from Sistiana Bay towards the west-southwest to the mentioned edge of the Savudrija-Buzet Anticline and continues along the south-western slope of the Friuli Mesozoic Carbonate Platform in the Lignano area. Such an interpretation could also mean that the previously uniform Mesozoic carbonate platform margin was cut along the Sistiana Fault, and its south-southeastern part was moved together with the Istra block towards the Dinarides. In our opinion, the Aquileia Fault does not exist; the structural anomaly on the north-western margin of the Trieste-Komen Anticlinorium, to which Carulli linked the Aquileia Fault, is, according to our yet unpublished research, similar to the structural anomaly between

Dinamski model

Na sliki 22 je skicirana strukturna geometrija istrskega bloka in jugozahodni del istrskega potisnega območja. Že na prvi pogled je opaziti povezavo med avtohtonom (*sensu stricto* in *sensu lato*), torej Mikroadrijo in Dinaridi. Izvorni deformaciji avtohtona *sensu stricto* sta le Sesljanski in Kvarnerski prelom, oba ležita prečno na Dinaride, medtem ko je Bujski reverzni prelom, oziroma Bujska narivna luska, del dinarske narivne zgradbe, ki pa je v fazi neogensko-recentnega potiskanja in podrivanja Mikroadrije proti Dinaridom, postala del avtohtona (*sensu lato*). Sesljanski in Kvarnerski prelom ne sekata Dinaridov, temveč segata le do istrsko-furlanske narivno-podrivne cone, v Dinaridih sta se v njunih podaljških razvili sesljanska in kvarnerska upogibna cona. Prva je enostavnejša in šibkejša, vendar jo je mogoče na digitalnem modelu reliefa slediti vsaj 50 km v notranjost Dinaridov. Druga je bistveno močnejša in tvori obsežno upogibno cono sigmoidalne oblike, ki pa ji je težko določiti doseg v Dinaridih. Po grobi oceni sega vanje vsaj 70 km do 80 km. V njenem podaljšku Idrijski prelom ni upognjen tako kot v podaljšku sesljanske upogibne cone. Razprava o tem vprašanju presega okvir tega članka, tu zadostuje pojasnilo, da je Idrijski prelom na območju kraških polj jugovzhodno od Hrušice segmentiran in v tem smislu še ni detajlno raziskan, zato je njegova trasa na slikah 1 in 22 narisana črtkano.

Potek Sesljanskega preloma v Tržaškem zalivu ni jasen. Carulli (2011, sl. 3) ga je na podlagi strukturne karte stika med karbonati v podlagi in flišem v podmorju Tržaškega zaliva, ki je bila izdelana s pomočjo geofizikalnih profilov, hipotetično potegnil od Sesljanskega zaliva proti jugozahodu. Za vodilo mu je služilo sedlo v temenu podaljška Savudrijsko-Buzetske antiklinale, ki se je izrisala na strukturni karti. Potem, ko je bila določena smer sesljanske upogibne cone v Zunanjih Dinaridih, ki znaša okoli 60° do 65° (Placer et al., 2021b), se je ponudila hipotetična možnost, da poteka po severozahodnem robu podaljška Savudrijsko-Buzetske antiklinale, kjer je Carulli (ib.) domneval Oglejski prelom. Po tej varianti obstaja možnost, da poteka Sesljanski prelom od Sesljanskega zaliva proti zahodu-jugozahodu do omenjenega roba Savudrijsko-Buzetske antiklinale in se nadaljuje po jugozahodnem pobočju Furlanske mezozojske karbonatne platforme na območju Lignana (Lignano). Taka interpretacija pa bi lahko tudi pomenila, da je bil ob Sesljanskem prelomu prej enotni rob mezozojske karbonatne platforme the Čičarija and Trieste-Komen Anticlinorium in the Val Glinščica/Rosandra area, only that the Trieste-Komen Anticlinorium meets a similar unit in the northwest, which is covered by fluvial deposits on the Friuli Plain. If the proposed interpretation of the Sistiana Fault trace turns out to be correct, it could represent the agreed boundary between the Adriatic and Friuli Mesozoic Carbonate Platforms. This assumption is supported by the consistency of the strike-slip direction along the Sistiana Flexural Zone and along the proposed route of the Sistiana Fault. The offset in both cases is left-lateral. The assumption that the Sistiana Fault has not been active recently (Placer et al., 2021b) speaks only in favour of the proposed hypothesis.

The location of the Kvarner Fault in the Adriatic Sea subsea was well determined by Špelić et al. (2021). At the same time, we must draw attention to the subsided block of the Microadria on the east-south-eastern side of the Kvarner Fault, with which the Kvarner islands, belonging to the External Dinaric Imbricated Belt, also subsided and which we have named the Kvarner block. It is the result of the Paleogene and Neogene-recent Microadria activities southeast of the Kvarner Fault, description of which exceeds the scope of this article. The formation of the East Istrian Anticline is also related to this same scheme (Korbar et al., 2020).

Formation of the Istra Pushed Area and the two flexural zones is therefore related to the movement of the Istra block towards the Dinarides. The difference in the size of the flexural zones and the submarine response of the Sistiana and Kvarner Faults shows that northwest of the Kvarner Fault the Istra block is only the most exposed object of this part of the Microadria, while the second in the series is the Friuli block. The Sistiana Fault is therefore less important than the Kvarner Fault. Based on this, we believe that the Kvarner Fault divides the Microadria into the Po and Adriatic segments. This assumption is also supported by the fact that southeast of the Kvarner Flexural Zone there is no structure that would surpass it in terms of size and importance, at least in the middle Adriatic area. The Istra block is therefore the most eastward-pushed part of the Po segment of the Microadria.

Three dynamic units lie opposite the Dinarides: the Trieste parallelepiped, the North Istra Extrusion Wedge, and the South Istra Pushed Wedge in the Istra Block. The formation of the Kraški rob - Mt. Hrušica Traverse can be explained by the blocking of the lateral extrusion of the North Istra Extrusion Wedge towards the Trieste parallelepiped. We assume that the Extrusion Wedge was therefore compressed and acted as a rigid

presekan, njegov jugo-jugovzhodni del pa premaknjen skupaj z istrskim blokom proti Dinaridom. Oglejski prelom po našem mnenju ne obstaja, strukturna anomalija na severozahodnem obrobju Tržaško-Komenskega antiklinorija, na katero je Carulli vezal Oglejski prelom, je po naših, vendar še neobjavljenih raziskavah, podobna strukturni anomaliji med Čičarijskim in Tržaško-Komenskim antiklinorijem na območju Glinščice, le da se tu stikata Tržaško-Komenski antiklinorij in podobna enota na severozahodu, ki pa je prekrita z naplavinami Furlanske nižine. Če se predlagana interpretacija poteka Sesljanskega preloma izkaže za pravilno, bi ta lahko predstavljal dogovorno mejo med Jadransko in Furlansko mezozojsko karbonatno platformo. V prid tej domnevi govori skladnost smeri zmika ob sesljanski upogibni coni in ob predlagani trasi Sesljanskega preloma. V obeh primerih je levi. Domneva, da Sesljanski prelom recentno ni aktiven (Placer et al., 2021b), govori le v prid predlagane hipoteze.

Lego Kvarnerskega preloma v podmorju Jadranskega morja so dobro določili Špelić et al. (2021). Ob tem moramo opozoriti na ugreznjeni blok Mikroadrije na vzhodno-jugovzhodni strani Kvarnerskega preloma s katerim so se ugreznili tudi Kvarnerski otoki, ki pripadajo Zunanjedinarskemu naluskanemu pasu. Poimenovali smo ga kvarnerski blok. Gre za posledico paleogenske in neogensko-recentne dejavnosti Mikroadrije jugovzhodno od Kvarnerskega preloma, katere opis presega okvir tega članka. S tem je povezan tudi nastanek Vzhodnoistrske antiklinale. O tej problematiki so pisali Korbar et al. (2020).

Nastanek istrskega potisnega območja in obeh upogibnih con je torej povezan s premikom istrskega bloka proti Dinaridom. Razlika v velikosti upogibnih con in podmorske odzivnosti Sesljanskega in Kvarnerskega preloma kaže, da je severozahodno od Kvarnerskega preloma istrski blok le najbolj izpostavljen objekt tega dela Mikroadrije, drugi v nizu je furlanski blok. Sesljanski prelom je torej manj pomemben od Kvarnerskega preloma. Glede na to menimo, da Kvarnerski prelom deli Mikroadrijo na padski in jadranski segment. Tej domnevi ustreza tudi podatek, da jugovzhodno od kvarnerske upogibne cone vsaj v območju srednjega Jadrana ni strukture, ki bi jo prekašala po velikosti in pomenu. Istrski blok je torej najbolj proti vzhodu potisnjeni del padskega segmenta Mikroadrije.

V istrskem bloku ležijo nasproti Dinaridom tri dinamske enote, tržaški paralelepiped, severnoistrski iztisni klin in južnoistrski potisni insert between the active Microadria and the passive Dinarides, in which stress state trajectories grew thicker transversely to their direction. Specific deformations occurred in the area of thickening, presented on the correlation diagram in Figure 19. The lateral boundaries of the zones of these deformations are not sharp, but gradually die out more slowly toward the northwest and more quickly toward the southeast. The visible area of influence of the Kraški rob-Mt. Hrušica Traverse is 10 to 15 km wide and about 40 km long.

It is necessary to prove the assumption about the formation of the traverse experimentally, and to determine the mutual influence of three factors: the blocking of the North Istra Extrusion Wedge, the Črni Kal Anomaly, and the Senožeče Folds Splitting Zone.

The presented dynamic model should work from the beginning of the movement of the Microadria towards the Dinarides. More broadly, the process is related to the anticlockwise rotation of the Microadria (Weber et al., 2006), which is expressed in two components, in the hinterland of the Istra block, transpressive and shear (Placer et al., 2010). The question arises as to which status is recently active. Whether it is a transpressive or shear phase could only be determined from focal mechanisms and targeted surface surveys. However, it should be taken into account that one activity does not exclude the other, only that one is the prevailing one and the other is parallel, i.e., relieves the burden. It follows from the field data that the role of the Sistiana Fault in the recent dynamics is not important (Placer et al., 2021b), but the assumption needs to be proven. The presented dynamic model forms the basis for focused geodetic measurements.

The proposed dynamic model is supported by the following structural-geomorphological indicators: in the area of the Kraški rob-Mt. Hrušica Traverse, in addition to Mt. Selivec (619 m) and Mt. Vremščica (1027 m), are also the highest peaks of Mt. Nanos (Mt. Suhi vrh 1313 m), the north-western part of Brkini (Mt. Ajdovščina 804 m, Mt. St. Servul 817 m, above Artviže village) and the north-western part of Čičarija (Mt. Slavnik 1028 m). The existence of the South Istra Pushed Wedge is confirmed by the highest peaks of Mt. Učka (Mt. Vojak 1394 m), Čičarija (Mt. Veliki Planik 1272 m, Mt. Gomila 1241 m) and Snežnik hills (Mt. Veliki Snežnik 1796 m). In terms of geomorphology, the Čičarija Anticlinorium generally rises gradually from the northwest (Mt. Reva by Kozina 587 m) to the southeast (Mt. Veliki Planik). Mt. Slavnik, only some 7 km from Mt. Reva, would therefore be an anomaly if it did not lie in the area of the Kraški

klin. Nastanek traverze Kraški rob - Hrušica je moč razložiti z blokado bočnega izrivanja severnoistrskega iztisnega klina proti tržaškemu paralelepipedu. Domnevamo, da se je iztisni klin zaradi tega komprimiral in deloval kot trd vložek med aktivno Mikroadrijo in pasivnimi Dinaridi, v katerih so se prečno na njihovo smer zgostile trajektorije napetostnega stanja. V območju zgostitve so nastale specifične deformacije, ki so predstavljene na korelacijskem diagramu na sliki 19. Bočne meje območij teh deformacij niso ostre, temveč postopoma zamirajo proti severozahodu počasneje in jugovzhodu hitreje. Vidno vplivno območje traverze Kraški rob - Hrušica je široko okoli 10 km do 15 km, v dolžino pa sega okoli 40 km.

Domnevo o nastanku traverze je potrebno eksperimentalno dokazati, pri tem pa določiti medsebojne vplive treh dejavnikov: blokade severnoistrskega iztisnega klina, črnokalske anomalije in senožeške cone cepljenja gub.

Predstavljeni dinamski model naj bi deloval vse od pričetka pomikanja Mikroadrije proti Dinaridom. Širše je proces povezan z rotacijo Mikroadrije v nasprotni smeri urinega kazalca (Weber et al., 2006), kar se v zaledju istrskega bloka, izraža v dveh komponentah, transpresivni in zmični (Placer et al., 2010). Postavlja se vprašanje, katero stanje je recentno dejavno. Ali gre za transpresivno ali zmično fazo bi se dalo ugotoviti le iz potresnih mehanizmov in z usmerjenimi površinskimi raziskavami. Treba pa je upoštevati, da ena aktivnost ne izključuje druge, le da je ena glavna, druga pa vzporedna, oziroma razbremenilna. Iz terenskih podatkov izhaja, da vloga Sesljanskega preloma v recentni dinamiki ni pomembna (Placer et al., 2021b), vendar je potrebno domnevo dokazati. Predstavljeni dinamski model je osnova za usmerjene geodetske meritve.

Predlagani dinamski model podpirajo naslednji strukturno-geomorfološki kazalci: v območju traverze Kraški rob - Hrušica ležijo poleg Selivca (619 m) in Vremščice (1027 m), tudi najvišji vrhovi Nanosa (Suhi vrh 1313 m), severozahodnega dela Brkinov (Ajdovščina 804 m, Sv. Servul v Artvižah 817 m) in severozahodnega dela Čičarije (Slavnik 1028 m). Obstoj južnoistrskega potisnega klina potrjujejo najvišji vrhovi Učke (Vojak 1394 m), Čičarije (Veliki Planik 1272 m, Gomila 1241 m) in Snežniškega hribovja (Veliki Snežnik 1796 m). Čičarijski antiklinorij se v geomorfološkem smislu na splošno polagoma dviguje od severozahoda (Reva pri Kozini 587 m) proti jugovzhodu (Veliki rob – Mt. Hrušica Traverse. Mt. Veliki Snežnik lies in a structural block that has risen extremely high above the landscape. According to OGK, sheet Ilirska Bistrica, this process was helped along by the appropriate shape of the block, which probably narrows in depth in a wedge-shaped manner. In the intermediate space between the Snežnik hills and Čičarija lies the Brgudsko podolje (plane), a compressional trench. A complex view of the geomorphology of the Istra Pushed Area will be given in the following discussion.

The importance and existence of the Črni Kal Anomaly is also reflected in the geomorphology of the Istra Pushed Area, with important structural lines of this zone running parallel to the anomaly: the north-eastern boundary of the Istra-Friuli Thrust-Underthrust Zone, the north-western part of the Čičarija Anticlinorium axis, and the north-western part of the Brkini Synclinorium axis. Everything is nicely reflected in the course of the structural-geomorphological trajectories between the Sistiana and Kvarner Flexural Zones. In this scheme, the unresponsiveness of the Raša Fault stands out in the area of the Kraški rob - Hrušica Traverse, and there are two reasons for this: the Raša Fault was formed at a late stage in the development of the Istra Pushed Area (Placer et al., 2021b), and part of the lateral bending was compensated for by the formation of transpressive Vremščica Anticline.

The presented deformation model covers only Istra and its immediate hinterland, i.e. the Istra Block and the area of the External Dinaric Imbricated Belt between the Sistiana and Kvarner Flexural Zones. The area of the External Dinaric Thrust Belt is not covered in the discussion.

Conclusion

Istra is part of the Dinaric promontory (Microadria) on which the External Dinarides are thrusted. Thrusting of the Dinarides ended in the middle of Paleogene, and in the middle of Neogene, the movement of the Microadria towards the Dinarides began, which continues today. Istra lies in the Istra Block, which moved significantly towards the Dinarides between the left-lateral strike-slip Sistiana and right-lateral strike-slip Kvarner Faults. As it moved, it pushed the Dinarides in front of it, creating a large-scale arc-like structure called the Istra Pushed Area.

Part of the movement of the Microadria towards the Dinarides was also compensated by underthrusting, which took place and is still active along newly formed reverse faults. Along these, the hanging block was raised, and the Paleogene thrust planes within it were anticlinally folded. The

Planik), Slavnik, le okoli 7 km od Reve, bi bil torej anomalija, če ne bi ležal v območju traverze Kraški rob - Hrušica. Veliki Snežnik leži v strukturnem bloku, ki se je ekstremno dvignil nad pokrajino. Po podatkih OGK, list Ilirska Bistrica, je k temu pripomogla ustrezna oblika bloka, ki se v globino verjetno klinasto zožuje. V vmesnem prostoru med Snežniškim hribovjem in Čičarijo leži Brgudsko podolje, ki je kompresijski jarek. Kompleksen pogled na geomorfologijo istrskega potisnega območja bo podan v naslednji razpravi.

Pomen in obstoj črnokalske anomalije se odraža tudi v geomorfologiji istrskega potisnega območja, vzporedno z anomalijo potekajo pomembne strukturne linije tega območja: severovzhodna meja istrsko-furlanske narivno-podrivne cone, severozahodni del osi Čičarijskega antiklinorija in severozahodni del osi Brkinskega sinklinorija. Vse se lepo odraža v poteku strukturno-geomorfoloških trajektorij med sesljansko in kvarnersko upogibno cono. V tej shemi izstopa neodzivnost Raškega preloma v območju traverze Kraški rob - Hrušica, vendar obstajata za to dva razloga, Raški prelom je nastal v poznem stadiju razvoja istrskega potisnega območja (Placer et al., 2021b), del bočnega upogiba se je kompenziral z nastankom Vremške transpresivne antiklinale.

Predstavljeni deformacijski model zajema le Istro in njeno neposredno zaledje, torej istrski blok in območje Zunanjedinarskega naluskanega pasu med sesljansko in kvarnersko upogibno cono. Območje Zunanjedinarskega narivnega pasu v razpravi ni zajeto.

Sklep

Istra je del dinarskega predgorja (Mikroadrija) na katerega so narinjeni Zunanji Dinaridi. Narivanje Dinaridov se je zaključilo sredi paleogena, sredi neogena pa se je pričelo premikanje Mikroadrije proti Dinaridom, ki traja še danes. Istra leži v istrskem bloku, ki se je med levozmičnim Sesljanskim in desnozmičnim Kvarnerskim prelomom, ekstremno premaknil proti Dinaridom. Med premikanjem je Dinaride potiskal pred seboj, da je nastala obsežna ločna struktura imenovana istrsko potisno območje.

Del premikanja Mikroadrije proti Dinaridom se je kompenziral tudi s podrivanjem, to se je dogajalo in se še vedno dogaja, ob novonastalih reverznih prelomih, ob katerih se je krovninsko krilo dvignilo, paleogenske narivne ploskve v njem pa so se antiklinalno usločile. Cona podrivanja se v Istri na površju prekriva z mejo underthrusting zone in Istra on the surface overlaps with the Dinarides boundary, so it makes sense to speak of a thrust-underthrust zone (Istra-Friuli Thrust-Underthrust Zone). On the surface the Sistiana and Kvarner Faults only extend as far as the mentioned thrust-underthrust zone, and further to the northeast they continue under the units of the Dinaric thrust structure, so only the lateral and vertical response of the movements along both faults under the thrust units is visible on the surface. In the extension of the Sistiana Fault, a relatively simple Sistiana Flexural Zone was formed, while in the extension of the Kvarner Fault a complicated and far more extensive Kvarner Flexural Zone in the form of a large sigmoid was formed. This lends the Kvarner Fault exceptional importance in the breakdown of the Microadria block, which is why we think it divides it into its Po and Adriatic segments. The Istra block is the farthest eastward-pushed part of the Microadria Po segment.

The Istra block has a hybrid structure, consisting of the autochthonous *sensu stricto* and the aborted Buje Thrust Sheet, which was part of the Dinarides during the thrusting period and became a connected part of the Microadria (autochthonous *sensu lato*) during the underthrusting period. The Karški rob – Mt. Hrušica Traverse, which lies in the Istra Pushed Area transversely to the Dinarides, was created as a result of the hybrid structure of the Istra block. Its geomorphologically most prominent deformation is Mt. Vremščica.

Mt. Vremščica is a transpressive anticline that rose from the levelled karst surface. Its formation is a challenge for the study of the geomorphology of karst areas.

The direction of the Sistiana Flexural Zone indicates the course of the Sistiana Fault in the seabed of the Gulf of Trieste from Sistiana to the west-southwest. According to such course, it can be assumed that the external boundary of the Mesozoic carbonate platform in the area of Lignano is transversally shifted along the Sistiana Fault. If so, the Sistiana Fault could represent an agreed boundary between the Friuli and Adriatic Mesozoic Carbonate Platforms.

The hydrographic network of Istra is specific and entirely subordinated to the deformations of the South Istra Pushed and North Istra Extrusion Wedges. The Classical Karst (territory between the Gulf of Trieste and the Ljubljana Marshes) lies entirely in the Istra Pushed Area, where the development of the hydrographic network is mainly related to the deformations of shortening caused by the Neogene to recent movement of Istra towards the Dinarides.

Dinaridov, zato je smiselno govoriti o narivno-podrivni coni (istrsko-furlanska narivno-podrivna cona). Sesljanski in Kvarnerski prelom segata na površju le do omenjene narivno-podrivne cone, naprej proti severovzhodu pa se nadaljujeta pod enotami dinarske narivne zgradbe, zato je na površju viden le bočni in vertikalni odziv premikov ob obeh prelomih pod narivnimi enotami. V podaljšku Sesljanskega preloma je nastala razmeroma enostavna sesljanska upogibna cona, v podaljšku Kvarnerskega preloma pa komplicirana in po dimenzijah dosti obsežnejša kvarnerska upogibna cona v obliki velike sigmoide. Ta daje Kvarnerskemu prelomu v blokovni razčlenitvi Mikroadrije izjemen pomen, zato menimo, da jo deli na njen padski in jadranski segment. Istrski blok je najdlje proti vzhodu potisnjeni del padskega segmenta Mikroadrije

Istrski blok ima hibridno zgradbo, sestavljen je iz avtohtona *sensu stricto* in abortirane Bujske narivne luske, ki je bila v obdobju narivanja del Dinaridov, v obdobju podrivanja pa je postala priključeni del Mikroadrije (avtohton *sensu lato*). Traverza Kraški rob - Hrušica, ki leži v istrskem potisnem območju prečno na Dinaride, je nastala zaradi hibridne zgradbe istrskega bloka. Njena geomorfološko najbolj izstopajoča deformacija je Vremščica.

Vremščica je transpresivna antiklinala, ki se je dvignila iz uravnanega kraškega površja. Njen nastanek je izziv za študij geomorfologije kraških območij.

Smer sesljanske upogibne cone nakazuje potek Sesljanskega preloma v podmorju Tržaškega zaliva od Sesljana proti zahodu-jugozahodu. Na podlagi tega je moč domnevati, da je zunanja meja mezozojske karbonatne platforme na območju Legnana (Legnano) prečno premaknjena ob Sesljanskem prelomu. Če je tako, bi Sesljanski prelom lahko predstavljal dogovorno mejo med Furlansko in Jadransko mezozojsko karbonatno platformo.

Hidrografska mreža Istre je specifična in povsem podrejena deformacijam južnoistrskega potisnega in severnoistrskega iztisnega klina. Klasični kras (ozemlje med Tržaškim zalivom in Ljubljanskim barjem) leži v celoti v istrskem potisnem območju, kjer je razvoj hidrografske mreže pretežno povezan z deformacijami krčenja prostora, ki jih je izzvalo neogensko do recentno pomikanje Istre proti Dinaridom.

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