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# Structural meaning of the Sava folds

## Strukturni pomen Posavskih gub

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*Ključne besede:* meja Avstroalpin - Dinaridi - enota Tisa, Posavske gube, Slovenija

### Abstract

The Sava folds are situated in the triangle between the W-E striking **Periadriatic tectonic zone**, the NW-SE **Idrija tectonic zone**, and the WSW-ENE **Mid-Hungarian tectonic zone.** The forming of folds is associated with shaping of the intersecting area between two important tectonic zones called the **Idrija - Mid-Hungarian transsection zone** which is characterized by a typical parquet structure and by an absence of dominant direction of shear displacements. In this way in the triangular segment between the Idrija and Mid-Hungarian tectonic zones called by us the **Sava compressive wedge** a field of N-S directed increased normal tensions was formed that resulted into the folding of the W-E oriented Sava folds. Owing to folding the compressive wedge shortened in the N-S direction for about 20 km which led to the shift of the Periadriatic tectonic zone to the south, and to its narrowing.

The beginning of intense folding of Sava folds could not be more precisely determined as being younger than Miocene, or presumingly Pliocene. The compression is associated with folding and uplift of the compressive wedge and the forming of the antecedent valley of the Sava river between the Ljubljana and Krško basins. This means the process of compression was at work also in the Quaternary, and could be hypothetically active even at present.

### Kratka vsebina

Posavske gube so vmeščene v trikotnik med **Periadriatsko tektonsko cono** v smeri W-E, **Idrijsko tektonsko cono** v smeri NW-SE in **Srednjemadžarsko tektonsko cono** v smeri WSW-ENE. Nastanek gub je povezan z izoblikovanjem presečišča med Idrijsko in Srednjemadžarsko tektonsko cono, imenovanega **Idrijsko-Srednjemadžarska presečna cona** z značilno parketno zgradbo brez dominantne smeri strižnih premikov. Tako se je v trikotnem segmentu med Idrijsko in Srednjemadžarsko tektonsko cono, imenovanem **Savski kompresijski klin,** ustvarilo polje povečanih normalnih napetosti v smeri N-S, ki je povzročilo nastanek Posavskih gub v smeri W-E. Zaradi gubanja se je kompresijski klin v smeri N-S skrčil za okoli 20 km, kar se je odrazilo z usločitvijo Periadriatske tektonske cone proti jugu in z njenim zoženjem.

Začetka intenzivnega gubanja Posavskih gub ne moremo natančneje določiti, vsekakor pa je mlajše od miocena in ga domnevno postavljamo v pliocen, kompresijo povezujemo z gubanjem in z dviganjem kompresijskega klina ter nastankom antecedentne doline reke Save med Ljubljansko in Krško kotlino. To pomeni, da je proces komprimacije trajal še v kvartarju in bi bil hipotetično lahko dejaven še danes.

## Introduction

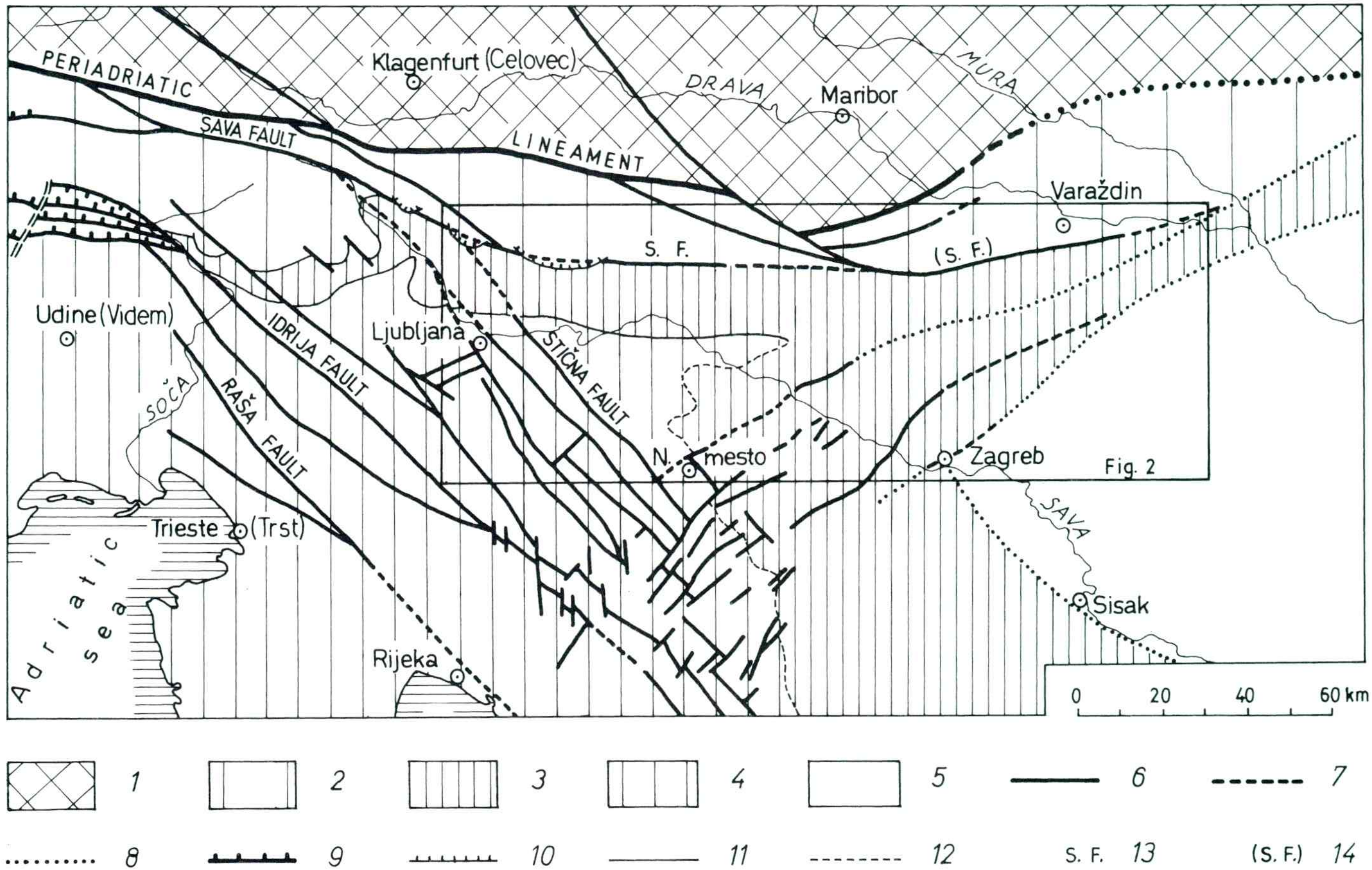
Between the Southern Alps and the External Dinarides along the middle course of the Sava river in Slovenia (fig. 1) a belt of folded beds is situated that was called by W i n k l e r (1923) the Sava folds. Earlier K o s s m a t (1913) used for this feature the term System of Sava folds. Characteristics of this belt are west-east striking folds with the wavelength of several hundreds of meters to ten kilometers and more, but with the amplitude of the largest hardly depassing two kilometers. In guidebooks to the Basic geologic map 1:100,000 several folds are listed. The more important are the Celje, Motnik, Laško, Planina-Desinice, Senovo, Bizeljsko-Zágorje, Brezina and Brdovec synclines and Pletovarje-Macelj, Trojane, Rudenica-Ivanjica, Litija, Orlica and Marija Gorica anticlines (fig. 2). The boundaries of Sava folds are not sharp. They extend westwards to the Ljubljana basin, in the east to Medvednica and Kalnik, in the north to Kamnik-Savinja Alps and eastern extension of Karavanke, and in the south they gradually fade out in External Dinarides south of Sava. Geologically they include Mesozoic beds of the Slovenian basin, Paleozoic and Mesozoic beds of the External Dinarides, Mesozoic beds of the Southern Alps and Tertiary beds of the Pannonian basin. The rocks of the Slovenian basin are attributed in the present article to the Internal Dinarides; this problem is, however, not the object of this treatise, so also a different attribution is possible. This problem is dealt with in the paper on tectonic subdivision of the considered territory (P l a c e r, 1998, this journal). In the structural sense the Sava folds consist from the bottom upwards of three structural levels. The first level is constituted of formationally not yet treated Carboniferous-Permian clastics and Middle Permian clastics of the Val Gardena Formation that were deposited on the first mentioned beds discordantly, and in places also of Triassic Werfen rocks. The second structural level that is overthrusted in the form of a large nappe, or several nappes, constitute the Permian, Triassic, Jurassic and Cretaceous beds that are developed in carbonate and clastic facies. A part of Jurassic and Cretaceous beds belong to the pelagic facies of the Slovenian basin. The third structural level is formed by the disconformably deposited, loosely cemented clastic and carbonate rocks of Tertiary age. K u š č e r (1967) on the ground of works of older researchers, among which B i t t n e r (1884) was the most important, and of his own observations meaningfully distinguished the Socka Formation with coal, marine clay called sivica, that he compared to Kiscell Formation, Govce Formation, Laško Formation and the Sarmatian beds. Locus typicus of the Socka Formation is Socka in Slovenian Styria where J e l e n et al. (1992) attributed it to Eocene age. The Socka Formation in Sava folds should have been deposited according to investigations during Middle or Late

Fig. 1. Neotectonic sketch map of the relationship between Eastern Alps and Dinarides

1 Eastern Alps; 2 Southern Alps; 3 Internal Dinarides; 4 External Dinarides; 5 Tisa unit; 6 Fault; 7 Fault - covered or approximately located; 8 Fault - covered and most approximately located; 9 Reverse fault, thrust; 10 Thrust of the Kamnik-Savinja Alps over Sava fault; 11 Thrust border of the Internal Dinarides; 12 Approximate sedimentation border of the Internal Dinarides; 13 Save fault - Celje fault after B u s e r (1978, 1979); 14 Sava fault - supposed line

Sl. 1. Neotektonska skica stičnega območja Vzhodnih Alp in Dinaridov

1 Vzhodne Alpe; 2 Južne Alpe; 3 Notranji Dinaridi; 4 Zunanji Dinaridi; 5 Enota Tisa; 6 Prelom; 7 Prelom - prekrit ali približno lociran; 8 Prelom - prekrit in grobo lociran; 9 Reverzni prelom, nariv; 10 Nariv Kamniško-Savinjskih Alp čez Savski prelom; 11 Narivna meja Notranjih Dinaridov; 12 Približna meja sedimentacije Notranjih Dinaridov; 13 Savski prelom - Celjski prelom po B u s e r j u (1978, 1979);14 Savski prelom - domnevna trasa


PERIADRIATIC
LINEAMENT
SAVA FAULT
Klagenfurt (Celovec)
DRAVA
MURA
Maribor
Varaždin
S. F.
(S. F.)
Udine (Videm)
Ljubljana
IDRIJA FAULT
STIČNA FAULT
RAŠA FAULT
SOČA
N. mesto
Zagreb
Fig. 2
SAVA
Trieste (Trst)
Adriatic sea
Sisak
Rijeka
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2
3
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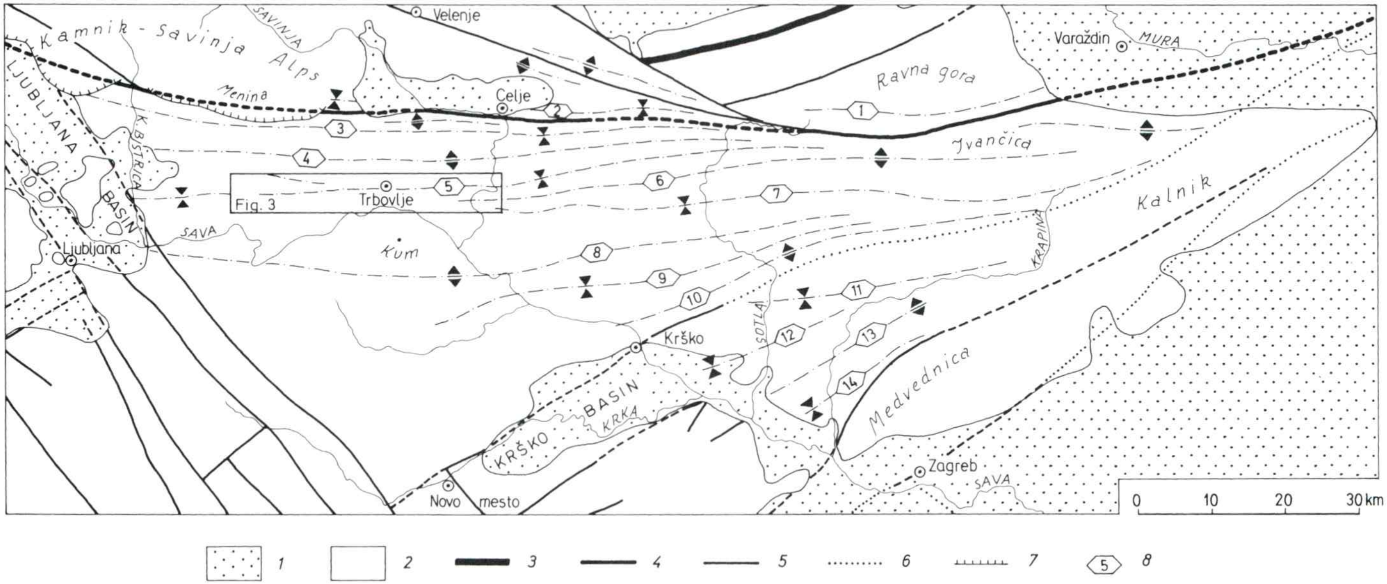



Fig. 2. Sava folds

1 Plioquaternary and Quaternary; 2 Paleozoic, Mesozoic, Tertiary; 3 Periadriatic lineament (Balaton l.); 4 Sava fault; 5 Fault; 6 Fault - covered and most approximately defined; 7 Thrust of the Kamnik-Savinja Alps over Sava fault; 8 Sava folds: (1) - Pletovarje-Macelj anticline, (2) - Celje syncline, (3) - Motnik syncline, (4) - Trojane anticline, (5) - Laško syncline, (6) - Rudnica-Ivančica anticline, (7) - Planina-Desinice syncline, (8) - Litija anticline, (9) - Senovo syncline, (10) - Orlica anticline, (11) - Bizeljsko-Z·gorje syncline, (12) - Brezina syncline, (13) - Marija Gorica anticline, (14) - Brdovec syncline

Sl. 2. Posavske gube

1 Pliokvartar in kvartar; 2 Paleozoik, mezozoik, terciar; 3 Periadriatski lineament (Balatonski l.); 4 Savski prelom; 5 Prelom; 6 Prelom - prekrit in grobo lociran; 7 Nariv Kamniško-Savinjskih Alp čez Savski prelom; 8 Posavske gube: (1) - Pletovarsko-Maceljska antiklinala, (2) - Celjska sinklinala, (3) - Motniška sinklinala, (4) - Trojanska antiklinala, (5) - Laška sinklinala, (6) - Rudniško-Ivanjiška antiklinala, (7) - Planinsko-Desiniška sinklinala, (8) - Litijska antiklinala, (9) - Senovška sinklinala, (10) - Orliška antiklinala, (11) - Bizeljsko-Z·gorska sinklinala, (12) - Brezinska sinklinala, (13) - Marijagoriška antiklinala, (14) - Brdovška sinklinala

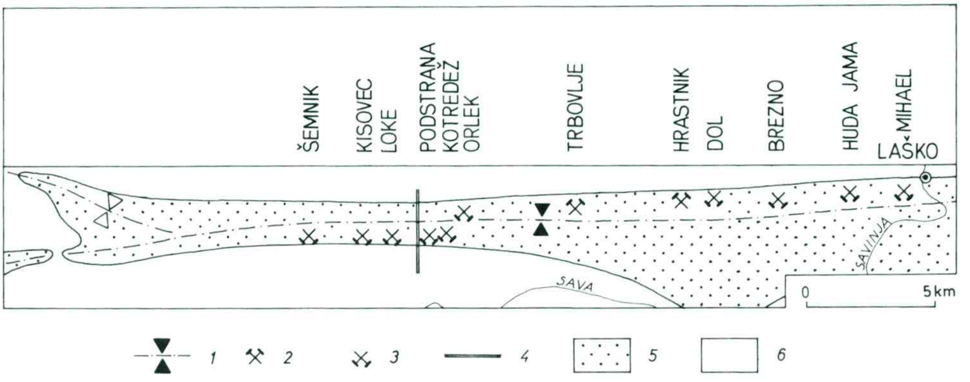



Fig. 3. Western part of the Laško syncline

1 Laško syncline; 2 Active colliery; 3 Abandoned colliery; 4 Cross - section on Fig. 4; 5 Tertiary; 6 Paleozoic and Mesozoic basement

Sl. 3. Zahodni del Laške sinklinale

1 Laška sinklinala; 2 Delujoči premogovnik; 3 Opuščeni premogovnik; 4 Profil na sl. 4; 5 Terciar; 6 Paleozojska in mezozojska podlaga

Oligocene, and was therefore called by the Jelen's group the Pseudosocka Formation. The deposition of Tertiary beds lasted with interruptions till the end of Sarmatian. The nappe structure was formed before the deposition of the Pseudosocka Formation. In the Sava folds intense folding started after the deposition of the Sarmatian beds.

Since the Pseudosocka beds are the best developed in the Trbovlje region, according to a Kuščer's suggestion the term Trbovlje Formation is proposed for them by us. In the following text this term will be used. In the sam line we consider that for unification of terms also the Sarmatian beds should be formationally determined. We propose for them the term Dol Formation named after the village Dol near Hrastnik where they could be studied in their totality.

In professional literature separating of western Sava folds west of the Ljubljana basin, and the eastern Sava folds east of it became customary. The extent of the eastern Sava folds is defined as just described, while the extent of the western folds is not clear. Most authors, among them also Kossmat, understand by this term the Polhov Gradec and Škofja Loka territory west of Ljubljana consisting of Paleozoic and Mesozoic beds. However, in this region no W-E trending folds occur that are the recognizable structural element of the Sava folds. Therefore in the present text the term Sava folds is a synonim for the eastern Sava folds, whereas for the western Sava folds we consider they do not exist in the structural sense.

At present the Tertiary beds occur in the Sava folds in cores of synclines, while in the cores of larger anticlines the Carboniferous-Permian clastics are found. The Tertiary beds of the Sava folds have been the object of study by many researchers owing to their economic interest. In the Trbovlje Formation an important coal seam up to 30 m thick occurs. Non industrial coal mining started in places in the 18th century already, and later, mostly in 19th century, mine workings in the Laško syncline at Šemnik, Kisovec, Loke, Zagorje, Orlek, Trbovlje, Hrastnik, Dol and Laško (Brezno, Huda jama and Mihael) (fig. 3) were opened, in the Motnik syncline at Motnik, Zabukovica, Štore and Pečovnik, and in the Senovo syncline at Senovo and in a few other places.

The last cycle of structural studies of the Laško syncline was performed in 1981 to 1991 on the initiative of the former Brown coal mines of Slovenia company in Trbovlje. At that time a detailed geologic map of the Laško syncline at the scale 1:5000 was made (fig. 2, 3). About 10 km mine adits in collieries Loke, Zagorje, Trbovlje, Hrastnik, Dol and Laško were then mapped, several kilometers of surface and mine drillings considered, and data from voluminous actual and historical archive materials in survey offices of active collieries included. The results of these studies is the kinematic model of the Laško syncline that indirectly illustrates also the structure and genesis of the entire Sava folds. In this contribution the deformation of the Laško syncline in a composite cross-section oriented N-S (fig. 3, 4) in the Zagorje area was shown as well as the resulting regional conclusions.

## Genesis of the actual structure of collieries in the Zagorje area

It became clear already after the first analyses of genesis of the Laško syncline that the deformations in Tertiary beds reflect the structure of older deformations in the basis of Tertiary. Therefore mapping of a broad belt of Mesozoic and Paleozoic beds was necessary as well as the reconstruction of circumstances before the deposition of the Oligocene beds. It turned out that the apparently so differing structures of individual coal deposits in the Laško syncline are a result of structural predisposition and different space relations between more or less ductile rocks in the pre-Tertiary basement, and not of different deformation styles.

Fig. 4 shows the genesis of the Laško syncline in the Zagorje area that contains the coal deposits at Kisovec, Loke, Podstrana, Kotredež and Orlek (fig. 3). The general situation before the deposition of the Trbovlje beds in the region of later Laško syncline is shown by cross-section in fig. 4a. On it the first and the second structural levels of the Sava folds are shown, separated by a well expressed obliquely cut thrust line against which lean from the north southwards gradually younger stratigraphic members of the second structural level from the Middle Permian clastics of the Val Gardena Formation in the north to Norian-Rhaetian Main Dolomite and Dachstein Limestone in the south. The nappe unit is of heterogeneous internal structure that is bivalent in the considered area. In the south occur in the base some Middle Triassic layered rocks, while the largest part of it consists of Middle Triassic, Upper Triassic and Lower Jurassic non bedded or indistinctly bedded dolomite and limestone with some discordantly deposited Upper Cretaceous limestone. In the north the nappe unit consists first of Middle Permian clastics of the Val Gardena Formation, followed by predominantly layered carbonate rocks of the Bellerophon and Werfen Formations, and dolomite of the Mendola Formation, and finally of abundant sequence of clastics of the Pseudozilja Formation of Ladinian and Cordevolian age (Kolar - Jurkovšek & Placer, 1987; Placer & Kolar - Jurkovšek, 1990) that originally, according to the fossil locality at the Celje castle (Teller, 1889) were attributed in their totality to the Langobardian age. On Triassic beds lie erosional remnants of discordantly deposited Cretaceous limestone. The Pseudozilja beds were consequently deposited near shore, parallel to the carbonate threshold, which is an extraordinary phenomenon from the geomechanic point of view. The lateral passage from the carbonate to clastic facies is seen in the Ravenska vas area.

The cross-section in fig. 4a is simplified to the measure as to enable understanding of deformational kinematics.

In Middle or in Late Oligocene ended a long time of erosion. The region started to subside slowly which resulted into forming of several depressions in the Sava folds region. In them initially the fresh water sedimentation started with a shorter period of swamping followed by the incursion of the Tertiary sea. In these depressions younger Tertiary beds always occupy an essentially larger extent than do the older ones which is possibly an indication of incipient folding and simultaneous sinking. The rate of sinking during Tertiary was not uniform. At times it even had alternating character as suggested by alternating marine and brackish environment, or transgressive and regressive depositional sequences with interruptions during the Sava phase between the Kiscell and Govce Formations, in the Styrian phase between the Govce and Laško Formations, and in the Moldavian-Attic phase between the Laško and Dol Formations. Among these phases the Sava phase is exceptionally weak, and is expressed only in places by a dispersion discordance. Somewhat more pronounced, but still dispersive, is the Styrian discordance, while the Moldavian-Attic is the strongest, displaying locally as the only one a clear angular component.

The situation at the end of deposition of Miocene beds in the region of later Laško syncline is shown in fig. 4b. At the first look it is obvious that the center of subsidence, and the design of the hinge of the Laško syncline were formed in the area of Pseudozilja Formation near the carbonate threshold, so that its south limb consists of prevailing non bedded carbonate beds, while the north limb of clastics of a higher degree of ductility.

After the Sarmatian times started an intense compression of the region that resulted into the uplift of the territory and thrust of the southern part of the basin on its northern half. This is the Novi Dol thrust, as named by Gregorač (1975) and commented by Kuščer & Mitrevski (1979). It follows from the detailed reconstruction of genesis of entire basin that the length of displacement of the thrusted mass along this thrust eastwards amounts at Laško to 2.5 kilometers, while it becomes westward shorter and shorter, so that it is in the Zagorje area only a few tens of meters, at most 100 meters. The effect of this thrust at Zagorje is shown in fig. 4c.

The mentioned displacement along the Novi Dol thrust is an indication of a temporally limited phase of compression. Then probably followed a time of stagnation and repeated compression. Alternation of compression and stagnation is the virtual component in the explanation of the genesisi of the Sava folds. At the end of this chapter it will be seen that the scenario could have been different, with the same succession of events, however.

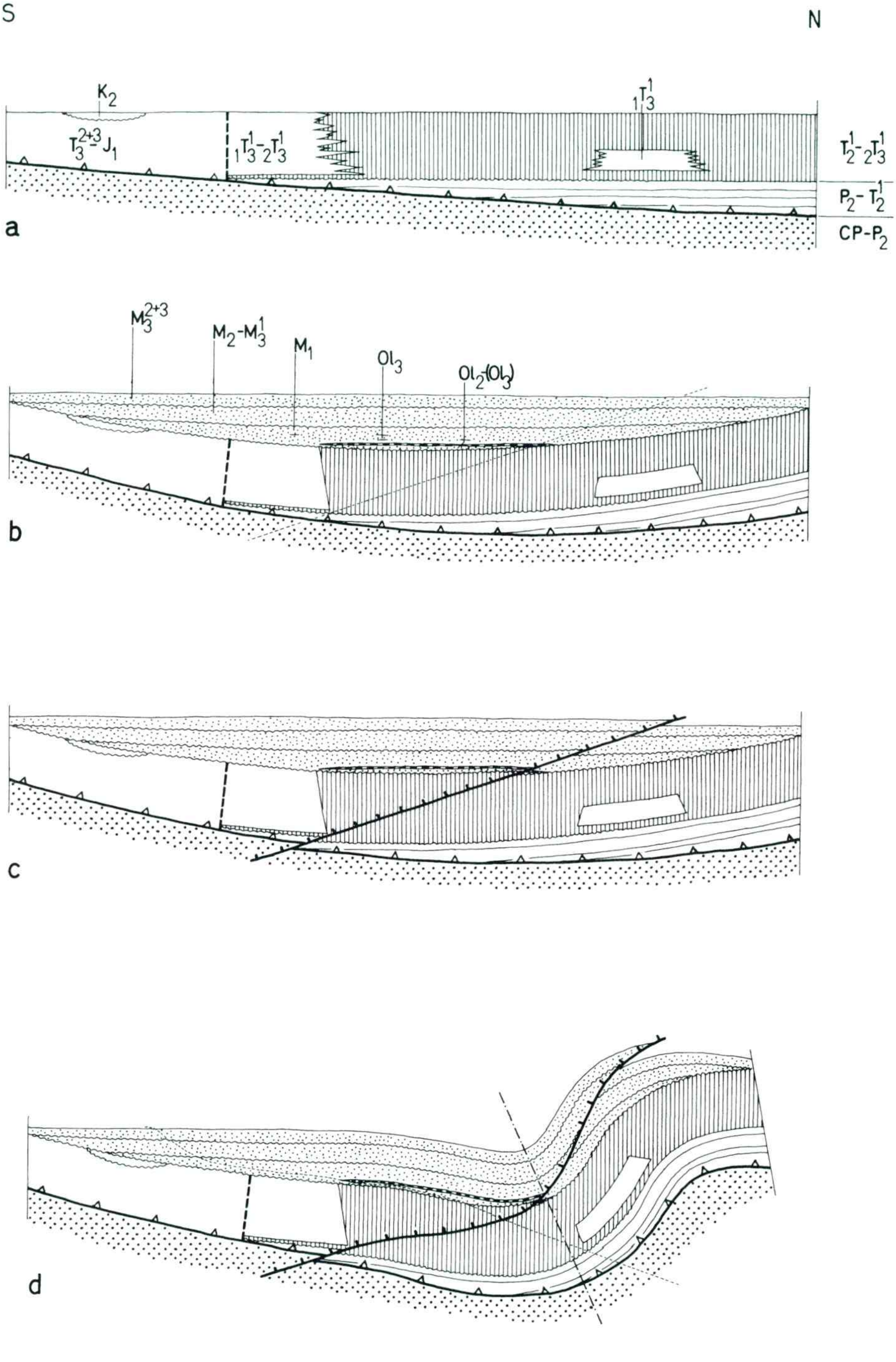
Regardless of these dilemmas it is possible to conclude from the deformational analysis of the entire Laško syncline that during the second phase of compression the area was first gently folded in asymmetric folds (fig. 4d). Then along the just formed predisposed zone that was directed parallel to the layers of the Trbovlje Formation in the south limb of the newly folded syncline the thrust plane was formed at which the north limb of the syncline was thrusted for 1500 to 2000 m southwards on its southern limb (fig. 4e). The Trbovlje Formation with coal seam was thrusted towards the south on the southerly lying carbonate threshold. At that the thrust front disintegrated into a number of nappes; the largest among them is the Kisovec horse (K). The considered overthrust from north to south is developed in the entire Laško syncline and is known as the Hrastnik thrust, after the town of Hrastnik. It was named by Gregorač (1975).

The displacement along the Hrastnik thrust was probably followed by a phase of stagnation which was replaced by repeated intense folding (fig. 4f) with various results in the synclinal limbs. In the northern limb the thrust plane of the Novi Dol thrust was tilted upwards, and it dips actually steeply southwards. The intrastratal slips as a consequence of folding took place here in Pseudozilja clastics. In the non-bedded to thick bedded dolomite of the southern carbonate threshold in the southern limb the effect of folding was manifested by forming of reverse faults owing to extrusions from the core of the fold (the Borovnik fault). These faults are directed close to nonexistent layer planes, or they present the reactivation of already existent discontinuities. With progressing folding the displacement along these faults increased. The characteristic steep dolomite horses in the southern limb od the Laško syncline at Zagorje and west from it were formed; some of them reach to the surface (Ocepkov vrh, Smrekovec, Borovnik), others do not. In the latter instance they always presented a hidden danger for unexpected water inrushes into the collieries when coming too close to them with mine workings.

West of Zagorje the Laško syncline became compressed into a subvertical isoclinal fold. When folding was not possible any more the thrust of the Upper Triassic carbonate rocks south of the Laško syncline on its southern limb was formed, as shown by fig. 4g (the Čolnišče thrust). It is true, at Zagorje the Laško syncline is not isoclinal, but this detail is an indication of the formation of the embryonic scheme of the Čolnišče thrust in the area of the isoclinal fold, beyond the considered corss-section. In the footwall of the Čolnišče thrust In Tertiary beds of the southern border of the Tertiar basin the perithrust folds were formed. The already mentioned Kisovec horse (K) at the front of the Hrastnik thrust now became folded to the Kisovec lateral basin, as it was called in the mining practice. The structural feature between this basin and the Borovnik fault was formed into the Loke lateral basin.

The profil in fig. 4g is synthetic, combining the actual situation in the area of Kisovec, Loke, Zagorje, Podstrana and Orlek, as established by detailed surface mapping, and mapping of mine workings and surface and underground drillings. In the Kisovec lateral basin (K) the pits of Podstrana and Kisovec were developed, in the Loke lateral basin and in a part of the southern flank of the principal basin the Loke pit, and in the principal basin the pits Kotredež and Orlek. The reconstruction of the kinematic development of the Laško syncline in the Zagorje area is based on numerous factographic structural data, so a high degree of confidence can be attributed to it. The conceptually equal reconstructions of coal deposits of Šemnik, Trbovlje, Hrastnik and Laško (pits of Brezno, Huda jama, Mihael) that we already did are based on the same structural starting point and the same degree of compression, but they led to different end effects. They resulted into various structures of individual deposits as a result of either the dominance of folding, or of one of the three phases of thrusting.

Before going to conclusions, I would like to draw attention to a different view of reconstruction, as announced earlier. The genesis of the present structure consisting of thrusting first from the south, and then from the north, and from the south again, and folding, can be kinematically explained also withouth the periods of stagnation between the periods of compression. The idea can be derived as a continuum of thrusting and folding, first by thrusting from south northwards (fig. 4c) accompied by synchronous asymmetric folding (fig. 4d). At a sufficient steep northern limb of the syncline the thrusting capability along the Novi Dol thrust died away. With this, in the southern limb the conditions for forming of a new predisposed plane along beds of the Trbovlje Formation became fulfilled, and the thrust plane of the Hrastnik thrust formed with the southward thrusting along it to take place (fig. 4d, 4e). At simultaneous thrusting and folding the Hrastnik thrust can be active as long as owing


S
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CP-$P_2$
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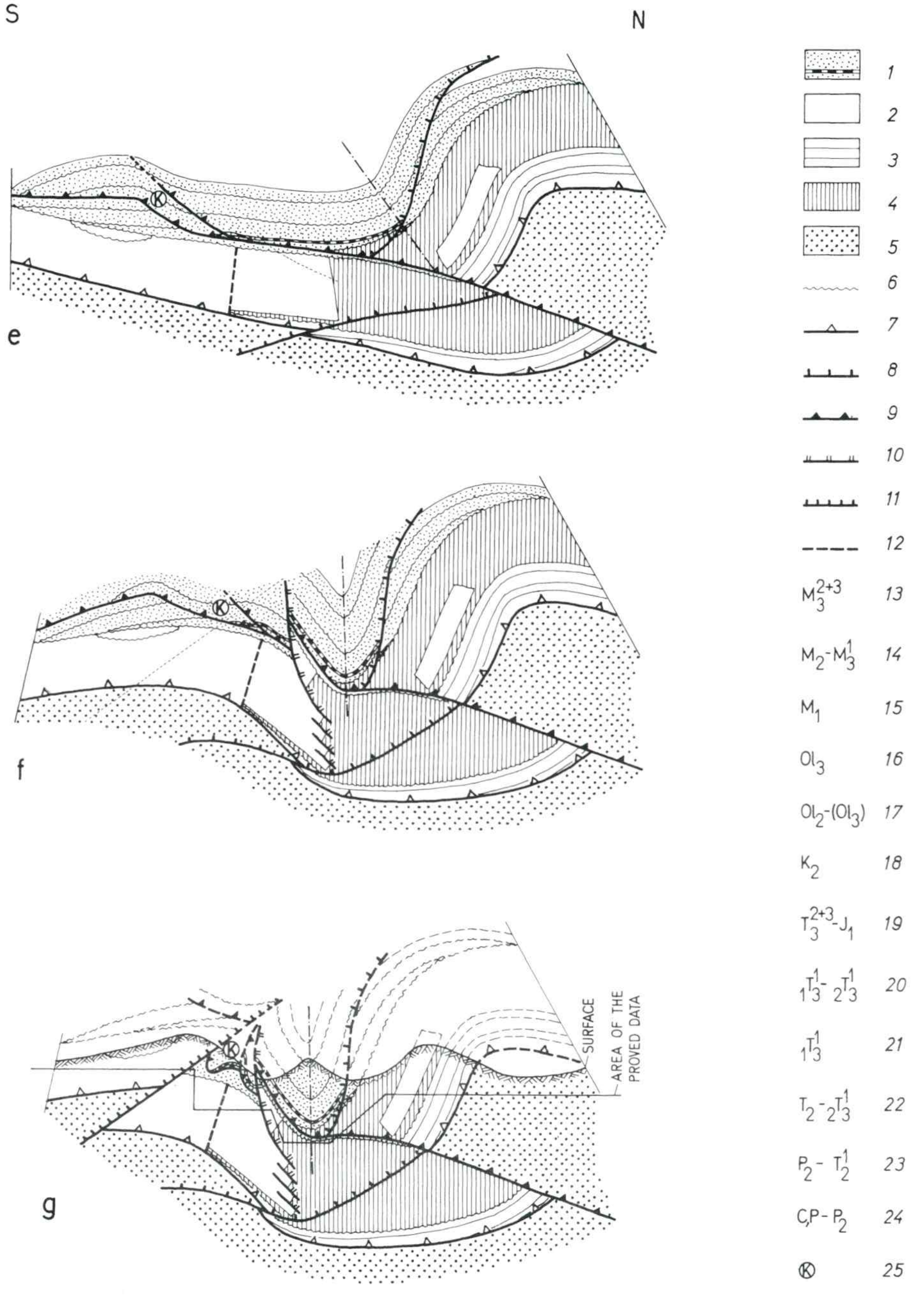
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M3 2+3 13
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Ol3 16
Ol2-(Ol3) 17
K2 18
T3 2+3-J1 19
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T2-2T3 1 22
P2-T2 1 23
C,P-P2 24
K 25
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to folding its thrust plane becomes so steep that no further movements along it can occur (fig. 4f). When the fold becomes isoclinal, or somewhat earlier, develops the Čolnišče thrust along which the southern flank of the Laško syncline is thrusted from the south northwards (fig. 4g). In all this the role of older fault planes that must have existed in the Mesozoic nappe before the deposition of the Tertiary beds should not be neglected. These cannot be etablished in detail, and therefore the described model cannot be very consistent with the real situation. The original dip of thrust planes in the model on fig. 4 is consistent with analysis of the factographic data.

Here we have the kinematic reconstruction of a tectonic process for which the sequence of events is not questionable nor are the starting and the final structure as well as the intermediate stages of evolution. Questionable is, however, the dynamics of the process that could be studied and its theory understood only by model investigations.

Tectonic processes in Tertiary on the territory of the Laško syncline, and indirectly also in the Sava folds, could be arranged in a sequence of consecutive events but without accurate dating of them. The oldest and at the same time the most impressive tectonic element in the considered territory is the extended nappe unit of prevailing Triassic rocks on Carboniferous-Permian and Val Gardena clastics. The structure has been proved by numerous tectonic windows, semiwindows and a clear oblique section, and it comprises the entire Sava folds. Its existence extends back to times before

Fig. 4. Genesis of the Laško syncline

a - Geologic section. The end of the Paleogene hiatus; b - Geologic section. End of Miocene; c - Origin of Novi Dol thrust; d - Asymmetric folding; e - Origin of Hrastnik thrust; f - Last phase of folding. Origin of Borovnik reverse fault; g - Origin of Čolnišče thrust. Synthetic section across the region of collieries Podstrana, Kisovec, Loke, Kotredež and Orlek

1 Tertiary clastic rocks of high ductility, coal; 2 Triassic massive rocks of low ductility; 3 Permian, Triassic and Cretaceous bedded rocks of medium ductility; 4 Triassic clastic rocks of high ductility; 5 Carboniferous and Permian clastic rocks of high ductility; 6 Unconformity; 7 Nappe basal plane; 8 Novi Dol thrust; 9 Hrastnik thrust; 10 Borovnik reverse fault; 11 Čolnišče thrust; 12 Supposed fault; 13 Dol Formation; 14 Laško Formation; 15 Govce Formation; 16 Kiscell Formation; 17 Trbovlje Formation; 18 Upper Cretaceous bedded limestone and marl; 19 Norian, Rhaetian and Lower Jurassic very thick bedded and massive carbonate rocks; 20 Cordevolian and Julian massive and very thick bedded carbonate rocks. Counterpart of the Pseudozilja Formation; 21 Reef of the Cassian dolomite; 22 Ladinian and Carnian clastics, pyroclastics and bedded limestones of the Pseudozilja Formation; 23 Partly Val Gardena clastic rocks and Upper Permian, Lower Triassic and Anisian bedded carbonate rocks and mudstones; 24 Carboniferous - Permian clastics and Middle Permian (Val Gardena Formation) clastics; 25 Kisovec horse

Sl. 4. Geneza Laške sinklinale

a - Geološki profil ob koncu paleogenskega hiata; b - Geološki profil ob koncu miocena; c - Nastanek Novodolskega nariva; d - Asimetrično gubanje; e -Nastanek Hrastniškega nariva; f - Zadnja faza gubanja. Nastanek Borovniškega reverznega preloma; g - Nastanek Čolniškega nariva. Sintetični profil čez območje premogovnikov Podstrana, Kisovec, Loke, Kotredež in Orlek

1 Visoko duktilne terciarne klastične kamnine, premog; 2 Nizko duktilne triasne neplastnate kamnine; 3 Srednje duktilne plastnate permske, triasne in kredne kamnine; 4 Visoko duktilne triasne klastične kamnine; 5 Visoko duktilne karbonske in permske klastične kamnine; 6 Diskordanca; 7 Narivna ploskev pokrova; 8 Novodolski nariv; 9 Hrastniški nariv; 10 Borovniški reverzni prelom; 11 Čolniški nariv; 12 Domnevni prelom; 13 Dolska formacija; 14 Laška formacija; 15 Govška formacija; 16 Kiscellska formacija; 17 Trboveljska formacija; 18 Zgornjekredni plastnat apnenec in lapor; 19 Norijski, retijski in spodnjejurski debeloplastnati in masivni karbonati; 20 Cordevolski in julski masivni in debeloplastnati karbonati. Ekvivalent Psevdoziljske formacije; 21 Greben iz cassijanskega dolomita; 22 Ladinijski in karnijski klastiti, piroklastiti in plastnati apnenci Psevdoziljske formacije; 23 Delno grödenski klastiti in zgornjepermski, spodnjetriasni in anizijski plastnati karbonati in meljevci; 24 Karbonskopermski klastiti in klastiti Grödenske formacije; 25 Kisovška luska

Middle or Late Oligocene. The internal structure of this nappe is not understood sufficiently to allow discussions on the directions of thrusting. There is even the possibility of existence of several nappes.

The second important event is the deposition of Oligocene and Miocene sediments characterized by rhythmicity that is predisposed by the Sava, Styrian and Moldavian-Attic discordances of which each consecutive was stronger and more distinct.

Folding of the Sava folds continued after Sarmatian since these beds are included into folding.

The terminal part of deformations of the considered region is connected with a weak neotectonic reactivation of certain NW-SE striking faults. All compressive deformations after Miocene, from folding to NW-SE striking faults, formed at orientation of the principal maximal axis of regional tension state in the approximate N-S direction.

## Previous investigations and comparison with results of regional studies

Now, after knowing the newest schematic views of the structure and genesis of the Laško syncline, the previous studies should be reviewed. The first integral overview of geology of the Laško syncline and its surroundings was presented by B i t t n e r (1884). The structure of the Sava folds was understood by Bittner as a simple sequence of folded and interrupted by discordances Paleozoic, Mesozoic and Cenozoic beds, and in the same way also by T e l l e r (1907) who used Bittner's data for construction of the Celje-Radeče sheet of the basic geologic map of Austro-Hungarian monarchy. The idea of the nappe structure was first expressed by W i n k l e r (1923). He assumed an extended nappe of carbonate rocks of the External Dinarides being thrusted northwards on the Sava folds region. In this frame he considered the carbonate rocks threshold that is an equivalent of the Pseudozilja Formation a part of the External Dinarides, and the Pseudozilja beds themselves a part of the outer zone of the Southern Alps. K u š č e r (1967) who investigated in detail the surroundings of Zagorje resumed Bittner's and Teller's concept on the non-problematic succession of Paleozoic, Mesozoic and Cenozoic beds in the Sava folds.

During the mapping for the Basic geologic map of Yugoslavia at 1:100,000 new divergences of opinions arouse. The essential part of the Sava folds territory is covered by three sheets of the basic geologic map, Ljubljana, Celje and Rogatec, and they were interpreted by different authors. The result are two different tectonic concepts. The central part of the Sava folds, comprising also the central part of the Laško syncline, was investigated on the Celje sheet by B u s e r (1978, 1979). He established at the beginning of Helvetian, at the time of the Styrian phase, first folding of the territory, and then forming of extensive overthrust faults. The Sava folds themselves were folded to their final shape in Pliocene. The overthrusting should have been directed from north southwards; he did not mentioned the thrusting distances (fig. 5a). The proofs for the age of overthrusting he found in wedging out of thrust planes at the Styrian discordance. In spite of extensive overthrust structure Buser considered that the Sava folds continuoulsy pass to the External Dinarides. A similar standpoint was advocated also by A n i č i ć & J u r i š a (1985a, 1985b) who mapped the sheet Rogatec east of the Celje sheet. The idea of forming of the overthrusts in Helvetian should be refused owing to the absence of folded beds below the Styrian discordance. According to our observations, this discordance is of dispersion type, and on

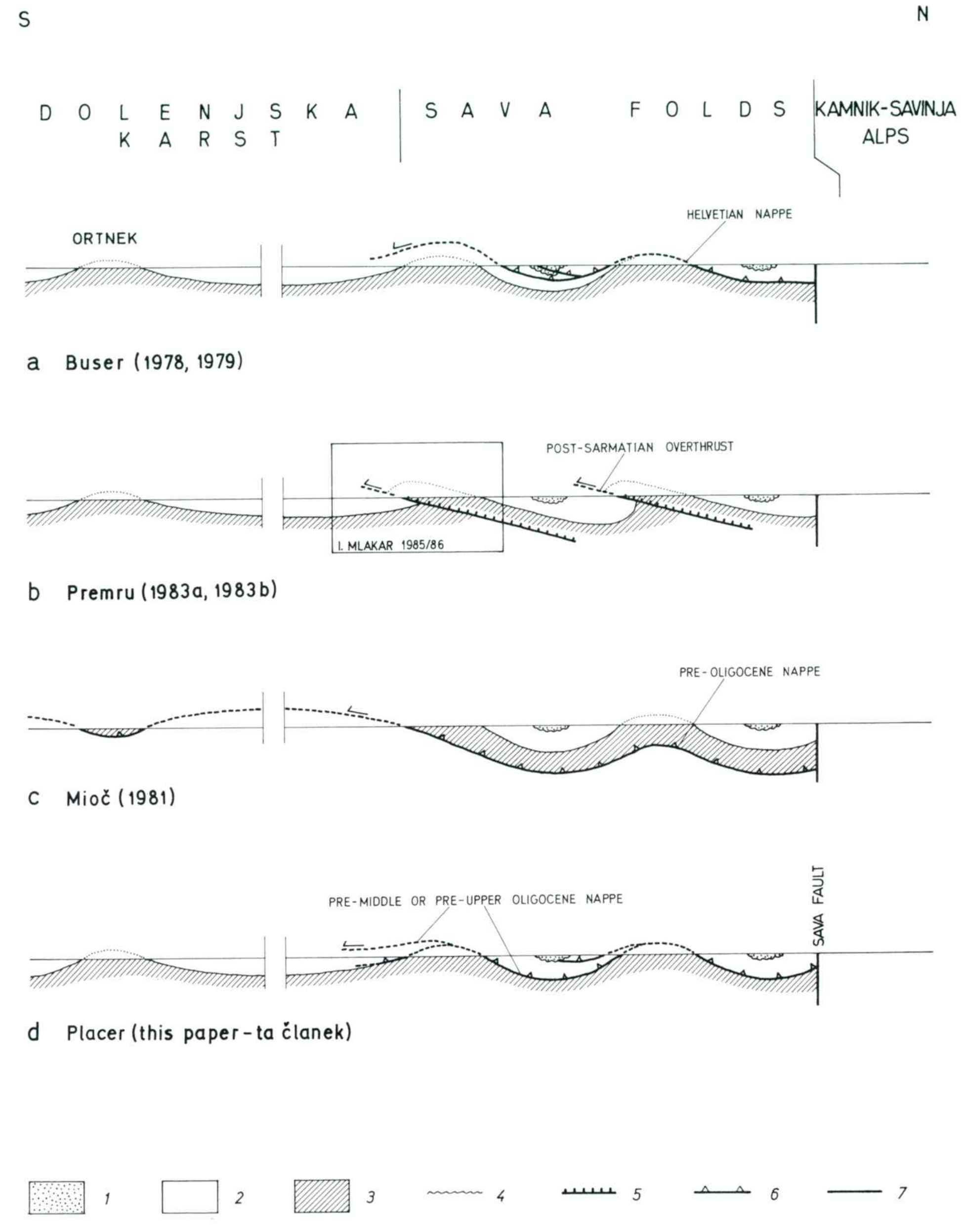



Fig. 5. Schematic presentation of hypotheses on the structure of Sava folds
1 Tertiary; 2 Mesozoic; 3 Upper Paleozoic; 4 Unconformity; 5 Overthrust; 6 Nappe basal plane; 7 Fault

Sl. 5. Shematski prikaz hipotez o zgradbi Posavskih gub
1 Terciar; 2 Mezozoik; 3 Zgornji paleozoik; 4 Diskordanca; 5 Nariv; 6 Narivna ploskev pokrova; 7 Prelom

the sheet of Ljubljana even the Helvetian beds are preserved (P r e m r u, 1983a, 1983b). The boundaries of nappes nowhere cut the Oligocene and Lower Miocene beds. The Mesozoic beds are nowhere thrusted at overthrusts on Oligocene and Lower Miocene beds.

On the geologic map of the Ljubljana sheet and in inedependent papers P r e m r u (1974, 1975, 1980, 1983a, 1983b) defended an entirely different structural concept. According to his opinions, the Sava folds in Paleogene and Neogene went through three phases of thrusting. The oldest phase during which first folding and then thrusting took place he dated at the boundary between Oligocene and Tortonian, and it could be observed in the western part of the eastern Sava folds. The next most expressed phase in which also folding and thrusting happened lived between the end of Sarmatian and beginning of Pliocene. To the youngest thrusting in Quaternary he attributed only local importance. All described deformations were the result of increased tensions in the N-S direction. In the most important folding and thrusting between Sarmatian and Pliocene the overturned and disrupted folds formed out of which resulted the extended thrusts whose southward movements amounted to between 8 and 19 km. The Sava folds were consequently folded during that phase. Each thrust unit should consist of an overturned anticline in the front of the thrust, and of a syncline in the back. The Paleozoic beds of the Sava folds should have been thrusted on the External Dinarides (fig. 5b). The most recent thrusting in Quaternary shoud be, however, somewhere directed also northwards. The described scheme cannot be accepted for several reasons. It is obvious that in the Sava folds the planes of nappes or overthrusts are folded together with the Sava folds, a fact taken in consideration by Buser and, as seen later, also by Mioč. There are no proofs on wider thrusting of Paleozoic and Mesozoic beds on the Tertiary ones, except for local deformations as the Hrastnik and Čolnišče thrusts. Certain thrust plains drawn by Premru are according to our observations entirely normal or discordant geologic boundaries, as evidened also by other geologists that mapped this territory (K u š č e r, 1962, 1967, 1975; B u s e r, 1978, 1979). A justified objection against Premru's interpretation of thrust structure of the Sava folds was published by K u š č e r (1975). Premru's concept of the relationship of Sava folds to the External Dinarides was adapted also by M l a k a r (1985/86).

In this concept an interesting idea was raised by M i o č (1976, 1981) who took part in mapping the sheets of Celje and also Ribnica and Novo mesto south of the Sava folds. He introduced the term Sava nappe that would comprise the entire Sava folds. The structure should consist of two structural stages. The lower consists of Carboniferous-Permian clastics, and the upper one of Mesozoic rocks separated from the Paleozoic ones by smaller thrusts (fig. 5c). The nappe should have been thrusted from the north southwards on the External Dinarides before Oligocene. The Permian clastics in the surroundings of Ortnek, on the carbonate platform of the External Dinarides south of the Sava folds should represent tectonic klippes that are erosional remnants of the Sava nappe. However, the data from the Basic geologic map, sheet Ribnica (B u s e r, 1969, 1974) and control visits in the field do not confirm this concept. The Middle Permian beds are overlain here discordantly by Lower Triassic and younger beds so that the idea of tectonic klippes is groundless. Besides, these beds lie predominantly in valleys, and represent simply erosional windows. It is a fact that up to the present nobody has ever proved or seen east of Ljubljana basin a thrust of Carboniferous-Permian clastics on the Mesozoic beds of the External Dinarides. The Carboniferous-Permian clastics lie consistently below them. The constructions by Mioč, Premru and Mlakar are hypothetic, and they are derived from the situation west of the Ljubljana basin where the Carboniferous-Permian beds are indubitably thrusted on the Mesozoic rocks of the External Dinarides. The thrusted position of the belt of Carboniferous-Permian beds on the Mesozoic ones between Orle and Gabrovka is a local deformation.

## Discussion

We try to show with the present contribution that detailed studies in the Sava folds on 1:5000 indicated a different structure of the territory at the contact between the Southern Alps and the External Dinarides as suggested by the regional investigations in the frame of the Basic geologic map on 1:100,000. This means that the synoptic smaller scale maps in so complex circumstances as those in the region between the Southern Alps and the External Dinarides are not appropriate for detailed study of structure of this region. Therefore we commented only the authors that directly studied the Sava folds, and not numerous researchers that included the Alpine-Dinaric region into their regional or global syntheses. We consider that the understanding of key structural details for the mentioned region is still unsufficient for allowing a serious synthesis. On the basis of new data and confirmed results of older researchers the following conclusions can be reached at present on the structure of the Sava folds (fig. 5d):

**1.** All three structural stages of the Sava folds (1. Carboniferous-Permian clastics and in places also Permian and Lower Triassic beds, 2. Mesozoic beds, 3. Tertiary beds) are mappably and kinematically founded. The first and the second stages are separated by an extended overthrust plane, and between the second and the third stage occurs a well expressed discordance plane that formed after a long erosion period before the Middle or the Late Oligocene.

**2.** The Carboniferous-Permian beds of the Sava folds are a constituting part of the External Dinarides, as considered already by B u s e r (1978, 1979). There is no direct or indirect proof on thrusting of these beds southwards on the carbonate platform of the External Dinarides east of the Ljubljana basin.

**3.** The overthrusting of Mesozoic rocks in the Sava folds took place before the Middle or the Late Oligocene, and its thrust plane had in its starting position the property of a detachment. The direction of overthrusting has not been determined analytically yet. Nevertheless a large horizontal displacement, possibly several tens, perhaps a few hundreds of kilometers, can justifiedly be assumed. A large distance between the original positions of the rocks of the first ad the second structural stages can be deduced from the circumstances in cross-section in fig. 4a. The position of the Upper Triassic Main Dolomite and Dachstein Limestone on the Carboniferous - Permian beds that can be observed in several tectonic windows in the southern flank of the Laško syncline is a good indication for it.

**4.** For the Pseudosocka beds we propose the term **Trbovlje Formation** after the town of Trbovlje, and for Sarmatian beds **Dol Foramtion** after the village Dol near Hrastnik. The typical profiles of the Trbovlje and Dol Formations will have yet to be selected and described.

**5.** If looking at the Sava folds from a broader angle, already at the first glance an unusual correspondence between the regional geometry of neotectonic deformations of the considered region, and the extension of the Sava folds can be established (fig. 1, 2). They are, as a matter of fact, placed in a triangle between the neotectonically active tectonic zones, the Periadriatic tectonic zone in the north, the Idrija tectonic zone in southwest, and the Mid-Hungarian tectonic zone in south-southeast, as schematically shown in fig. 6. The network of neotectonic faults on fig. 1 is taken from the sheets of the Basic geologic map of Yugoslavia on 1:100,000, and for the region of the Sava folds the results of the author's research were taken in consideration. Before proceeding, a few terms used in the text should be defined. The term **Periadriatic tectonic zone** was used by Jelen et al. (1997) for deformations that are genetically associated with shear displacements along the Periadriatic lineament. In the kinematic sense here is considered the belt between the Periadriatic lineament and the Sava fault that forms the southern boundary of this zone. The Sava fault is understood in the sense of a unique fault plane that relies its classic course in the upper Sava valley, the Celje fault and the accurately still undetermined course east of Celje (Placer, 1996) towards the Šoštanj fault that passes near Velenje, fig. 2, and then between Ravna gora and Ivančica towards east-ortheast. The criteria of neotectoinic activity are deformations as described by researchers of the Jelen's group. The characteristics of the Periadriatic tectonic zone is its southward bending in the region of the Sava folds. The **Mid-Hungarian tectonic zone** comprises the WSW-ENE oriented faults about between Orlica and southeast foot of Medvednica, and is understood in the sense of Csontos et al. (1992). The criterion of neotectonic activity of this zone are deformed axes of the Sava folds shown in fig. 2 and the Quaternary tectonic activity as described by Prelogović & Cvijanović (1976). The Mid-Hungarian tectonic zone leans on the Periadriatic tectonic zone northeast of Kalnik. The **Idrija tectonic zone** comprises the dominant faults in the northwestern part of the External Dinarides in the NW-SE direction, approximately between the Raša and Stična faults according to Buser (1976). Its central structure is the Idrija fault. The criterion for neotectonic activity along these faults is of morphostructural nature. The Idrija tectonic zone consists of two parts that are separated by the Idrija fault. In the northeastern, or its inner part (a on fig. 6), the faults lean at the rim of the zone on the Sava fault, while between the latter and the Idrija fault they more or less pinch out within the overthrust of the eastern Julian Alps. In the southwestern or outer part (a on fig. 6) in the region of the western Julian Alps the faults of this zone, comprising the Idrija fault, transform from wrench into oblique reverse faults according to a scheme described among others also by Carulli et al. (1990). In the region of the Sava folds, within the mentioned triangle the faults striking NW-SE and WSW-ENE cut the Tertiary sedimentary rocks to an insignificant degree, or do not cut them at all.

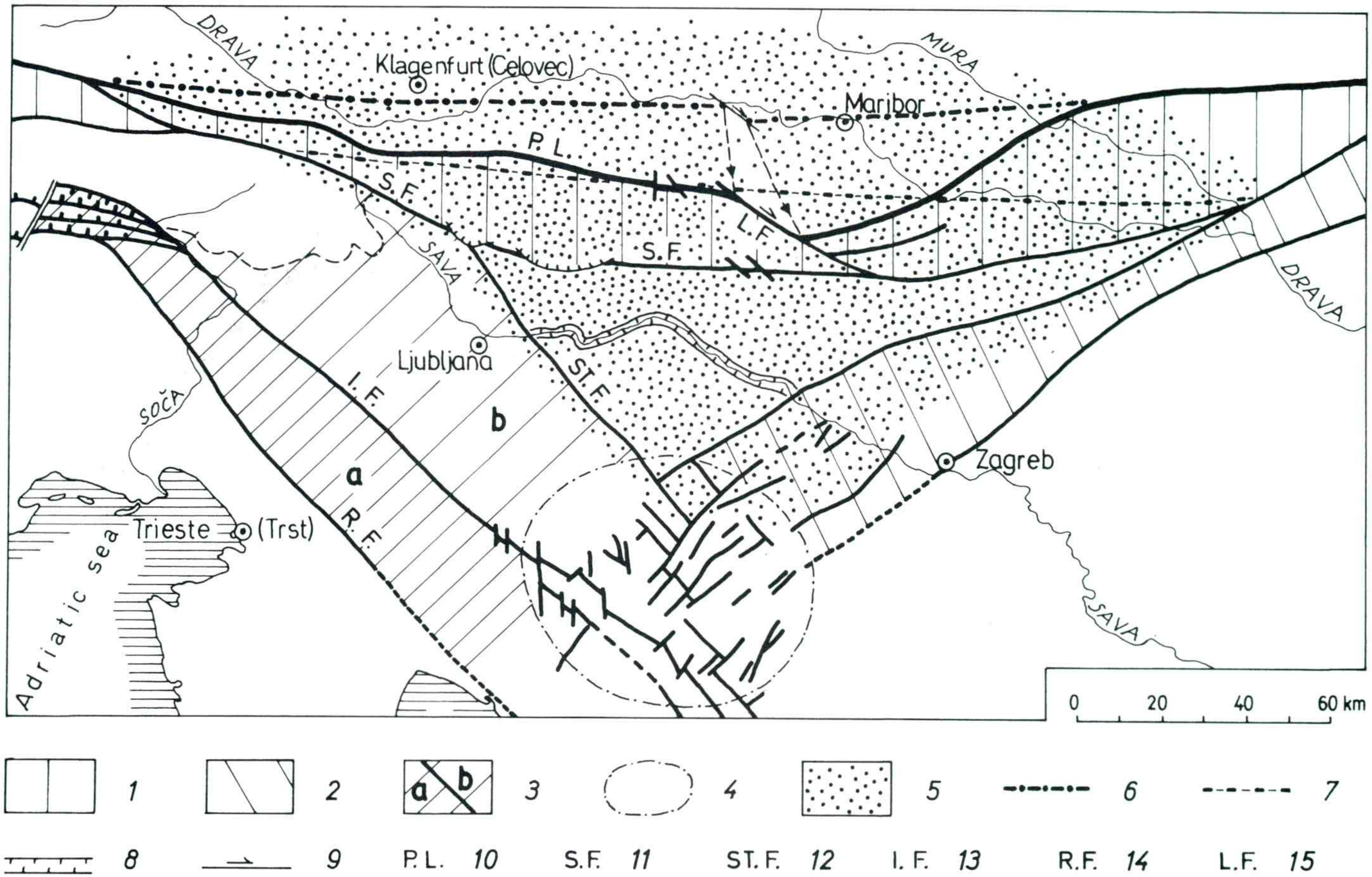
The inner part of the Idrija and Mid-Hungarian tectonic zones cut in the extended

Fig. 6. Sketch of the supposed Sava campressive wedge extension

1 Periadriatic tectonic zone; 2 Mid-Hungarian tectonic zone; 3 Idrija tectonic zone, a - outer part, b - inner part; 4 Idrija-Mid-Hungarian transsection zone; 5 Sava compressive wedge; 6 Primary position of the Periadriatic lineament; 7 Primary position of the Sava fault; 8 Sava gorge; 9 Primary position of the Labot (Lavant) fault; 10 Periadriatic lineament; 11 Sava fault; 12 Stična fault; 13 Idrija fault; 14 Raša fault; 15 Labot (Lavant) fault

Sl. 6. Skica domnevnega obsega Savskega kompresijskega klina

1 Periadriatska tektonska cona; 2 Srednjemadžarska tektonska cona; 3 Idrijska tektonska cona, a - zunanji del, b - notranji del; 4 Idrijsko-Srednjemadžarska presečna cona; 5 Savski kompresijski klin; 6 Prvotna lega Periadriatskega lineamenta; 7 Prvotna lega Savskega preloma; 8 Savska soteska; 9 Prvotna lega Labotskega preloma; 10 Periadriatski lineament; 11 Savski prelom; 12 Stiški prelom; 13 Idrijski prelom; 14 Raški prelom; 15 Labotski prelom


DRAVA
Klagenfurt (Celovec)
MURA
Maribor
P.L.
S.F.
L.F.
S.F.
SAVA
Ljubljana
ST.F.
b
I.F.
a
R.F.
SOČA
Trieste
(Trst)
Adriatic sea
Zagreb
DRAVA
SAVA
0 20 40 60 km
1
2
a b
3
4
5
6
7
8
9
P.L. 10
S.F. 11
ST.F. 12
I.F. 13
R.F. 14
L.F. 15

**Idrija- Mid-Hungarian transsection zone** in which the Mid-Hungarian tectonic zone pinches out in the southwest, whereas the continuation of the Idrija tectonic zone southeastward is not clear. The boundaries of the Sava folds are not sharp since they do not follow distinct faults, but are marked by gradual fading out intensity of folding in the mentioned tectonic zones (fig. 2). In the west we presume that this happens below the alluvial deposits of the Ljubljana basin that shows similarly to the faults of the Idrija tectonic zone the NW-SE strike. Therefore the fading out cannot be observed, although west of the Ljubljana basin no more folds occur that could be compared to the Sava folds.

In the east the Sava folds slowly pinch out in the Mid-Hungarian tectonic zone in which they also change their striking from W-E to WSW-ENE. This actually happens already outside the north-northwestern border of this zone. In the north the folds in places occur also north of the Sava fault, e.g. the Pletovarje-Macelj anticline. It follows from the described geometry of disjunctive and plicative elements of the structure that the region between the Idrija and Mid-Hungarian tectonic zones represents a compressive wedge in which along with the regional orientation of the principal maximum tension of approximate direction N-S south of the Periadriatic tectonic zone the Sava folds were formed. The feature is called by us the **Sava compressive wedge** (fig. 6). The extent of this compressive wedge was estimated according to those deformations that are relied with the tension state in the wedge itself. In the southwest it presumably extended somewhat across the Stična fault, in the south-southeast to the center of the Mid-Hungarian tectonic zone, while the northern boundary could not be established. Only formally it was drawn somewhat more to the north of the original position of the Periadriatic lineament which will be discussed below.

Considering the definition of the Sava compressive wedge, the following preliminary conclusions can be formulated:

**A.** The reason for formation of the Sava compressive wedge we see in the development of the Idrija - Mid-Hungarian transsection zone with the expressive parquet structure in which the dominant shear direction cannot be established. This means that the compressive wedge came into being in a period of stagnation of intensive shear movements in the inner part of the Idrija and in the Mid-Hungarian tectonic zones.

**B.** The bending of the Sava folds at the Mid-Hungarian tectonic zone and within it is well expressed, whereas this phenomenon could not be proved along or within the Idrija tectonic zone. We suppose the reasion for this in the asymmetry of the Sava compressive wedge the south-southeastern flank of it being more exposed to influences of the newly created tensional state than its southwestern flank.

**C.** Next to folding the influence of compression of the region in the Sava compressive wedge resulted also into the general uplift of the entire wedge. This can be observed in the antecedent character of the Sava gorge between the Ljubljana and the Krško basins, and in the Plioquaternary gravel that is at present within the wedge uplifted to 450 m above the actual level of the Sava river (Čolnišče above Zagorje, Završje below Kum), while the same gravel beyond the boundaries of the wedge occurs only little uplifted above the Sava, regardless of local anomalies, e.g. Libna at Krško.

**D.** The fourth characteristics is the bending of the Periadriatic tectonic zone southwards owing to shortening of space in the Sava compressive wedge. The extent of the total shortening was estimated on the basis of data on genesis of the Laško syncline in fig. 4 to about 6.5 km. Since into the construction in fig. 4 also the south limb of the Trojane and part of the northern limb of the Litija anticlines are included, the total shortening of the compressive wedge south of the Sava fault can be determined by addition of all synclines. Along the axis of the wedge occur in the N-S direction two synclines: the Tuhinj and Laško synclines that have about equal sizes, and suffered probably also similar shortenings, which amounts to narrowing for 13 km. If adding to this also the somewhat smaller shortening of the Planina-Desenice and Senovo synclines more eastwards from it, and a few smaller ones, it could be estimated that the largest shortening of the compressive wedge south of the Sava fault is about 20 km. It follows thereof that the shortening of territory in the axis of the wedge caused a bending and shift of the Periadriatic tectonic zone for 20 km southwards, in the flanks gradually less and less, to the zero shift close to the corners. These are situated for the level of the Sava fault west of the Kamnik-Savinja Alps and northeast of Kalnik. Folding is more intense in areas with more rocks of higher ductility (Carboniferous-Permian, Val Gardena, Pseudozilja and Tertiary clastics), and less intense at the top of the wedge where Mesozoic carbonate beds prevail. There also the Periadriatic tectionic zone became narrower.

**E.** Along with forming of the Idrija - Mid-Hungarian transsection zone was necessary for the genesis of the Sava folds also the reorientation of tension conditions from the dextral shear character, over transpressive to normal ones oriented perpendicular to the Periadriatic tectonic zone in direction N-S, in probable connection with a rotation of wider dimensions. As deformations of the new tension state we consider next to the folds south of the Sava fault and partly within the tectonic zone also the wrench faults oriented NW-SE that cut the Periadriatic lineament and the Sava fault, and were recapitulated from data by Mioč & Žnidarčič (1977), Mioč et al. (1983), Polinski & Eisbacher (1992) and Krystyn et al. (1994). Among them is the most important the Labot (Lavant) fault that was most probably designed already during the initial stage of shortening of the Sava compressive wedge which is shown in fig. 6 by the initial shearing of the Periadriatic lineament in the original position. The process can be explained by the arching effect, with extension in the direction of the Periadriatic tectonic zone, and with the influence of the Pohorje massif of competent rocks on the strike-slipping.

The bending of the Periadriatic tectonic zone must have resulted along with the described influences also to inherited movements along already existent mechanic discontinuities of tectonic or sedimentary origin. Therefore more attention will have to be paid to these phenomena. At this point we would like to draw attention to the paper by Jelen et al. (1997) in which the dextral progressive transpression along the Sava fault that ought to continue even at present is established. If transpression really exists it could be of secondary importance and of local extent only owing to arching effects of the bending of the Periadriatic tectonic zone, but of no regional importance. With respect to their ascertaining that the last intense shear movements occurred 6 million years ago, this means at the end of Miocene, we believe that the conditions for forming of the Sava compressive wedge were realized in Pliocene, so that the process of folding and compression of the territory could have lasted into the Quaternary, as indicated by Plio-Quaternary gravel on Čolnišče and at Završje, high above the gorge of the Sava river. The question whether the recent movements are a continuation of these processes should become the object of future research.

The proposed neotectonic geometric scheme is still in the stage of intense investigations, in spite of several sufficiently firm facts. Therefore many relationships between the mentioned structural elements are not yet unequivocally explained. This is especially true for the relationship between the southern boundary of the Periadriatic tectonic zone, resp. the Sava fault and the Mid-Hungarian tectonic zone, that is studied by Jelen's group in a broader geotectonic context, and for the question of genesis of the Idrija-Mid-Hungarian transsection zone.

## Strukturni pomen Posavskih gub

### Uvod

Med Južnimi Alpami in Zunanjimi Dinaridi leži ob srednjem toku reke Save v Sloveniji (sl. 1) pas nagubanih kamnin, ki ga je W i n k l e r (1923) poimenoval Posavske gube, že prej pa je K o s s m a t (1913) za isto strukturo uporabil izraz Savski sistem gub. Značilnost tega pasu so gube potekajoče v smeri zahod-vzhod, z valovno dolžino od nekaj sto metrov do deset kilometrov in več, amplituda pri največjih pa doseže največ dva kilometra. V tolmačih Osnovne geološke karte 1:100.000 je navedenih več gub; pomembnejše so Celjska, Motniška, Laška, Planinsko-Desiniška, Senovška, Bizeljsko-Z·gorska, Brezinska in Brdoveška sinklinala ter Pletovarsko-Maceljska, Trojanska, Rudeniško-Ivanjiška, Litijska, Orliška in Marijagoriška antiklinala (sl. 2). Meje Posavskih gub niso ostre, na zahodu segajo do Ljubljanske kotline, na vzhodu do Medvednice in Kalnika, na severu do Kamniško-Savinjskih Alp in vzhodnega podaljška Karavank, na jugu pa počasi zamrejo v Zunanjih Dinaridih južno od Save. V geološkem smislu vključujejo mezozojske kamnine Slovenskega bazena, paleozojske in mezozojske kamnine Zunanjih Dinaridov, mezozojske kamnine Južnih Alp ter terciarne kamnine Panonskega bazena. Kamnine Slovenskega bazena prištevamo v tem članku k Notranjim Dinaridom, vendar to vprašanje ni predmet te razprave, zato dopuščamo tudi drugačno uvrstitev. S tem problemom se ukvarjamo v prispevku o tektonski rajonizaciji obravnavanega ozemlja (P l a c e r, 1998, ta revija). V strukturnem smislu sestoje Posavske gube od spodaj navzgor iz treh strukturnih etaž. Prvo tvorijo formacijsko še neobdelani karbonskopermski klastiti in srednjepermski klastiti Grödenske formacije, ki so na prve odloženi diskordantno ter ponekod tudi werfenske kamnine. Drugo strukturno etažo, ki je na prvo narinjena v obliki obsežnega pokrova ali več pokrovov, tvorijo permske, triasne, jurske in kredne kamnine, razvite v karbonatnih in klastičnih faciesih. Del jurskih in kredne plasti pripadajo pelagičnemu fasiesu Slovenskega bazena. Tretja strukturna etaža je iz diskordantno odloženih, slabo vezanih, klastičnih in karbonatnih kamnin terciarne starosti. K u š č e r (1967) je na podlagi del starejših raziskovalcev, od katerih je najpomembnejši B i t t n e r (1884) in lastnih opazovanj smiselno ločil Soteško formacijo s premogom, morsko glino - sivico, ki jo je primerjal s Kiscellsko formacijo, Govško formacijo, Laško formacijo in sarmatske plasti. Locus tipicus Soteške formacije je kraj Socka na Slovenskem Štajerskem, kjer so J e l e n et al. (1992) ugotovili, da je eocenske starosti. Soteška formacija v Posavskih gubah pa naj bi po dosedanjih raziskavah nastala v srednjem ali zgornjem oligocenu, zato jo Jelenova skupina imenuje Psevdosoteška formacija. Sedimentacija terciarnih plasti je s prekinitvami trajala do konca sarmata. Krovna zgradba se je izoblikovala pred odložitvijo Psevdosoteške formacije. Posavske gube so se pričele intenzivno gubati po odložitvi sarmatskih plasti.

Ker so psevdosoteške plasti najlepše razvite na območju Trbovelj, predlagamo zanje, po Kuščerjevi sugestiji, termin Trboveljska formacija. V nadaljevanju bomo uporabljali ta izraz. Podobno menimo, da je zaradi poenotenja potrebno formacijsko opredeliti tudi sarmatske plasti, zato zanje predlagamo termin Dolska formacija po kraju Dol pri Hrasniku, kjer bi jih mogli v celoti raziskati.

V strokovni literaturi se je uveljavilo ločevanje na Zahodne Posavske gube, zahodno od Ljubljanske kotline in na Vzhodne Posavske gube, vzhodno od tod. Medtem ko je obseg Vzhodnih Posavskih gub definiran kot smo ga opisali, je obseg Zahodnih nejasen. Večina avtorjev razume, tako kot Kossmat, pod tem terminom Polhograjsko in Škofjeloško ozemlje zahodno od Ljubljane, zgrajeno iz paleozojskih in mezozojskih kamnin, vendar na tem območju ni v smeri W-E potekajočih gub, ki so spoznavni strukturni element Posavskih gub. Zato je v tem prispevku termin Posavske gube sinonim za Vzhodne Posavske gube, medtem ko za Zahodne menimo, da v strukturnem smislu ne obstojajo.

Danes nastopajo terciarne plasti Posavskih gub v jedrih sinklinal, medtem ko v jedrih večjih antiklinal izdanjajo karbonskopermski klastiti. Terciarne kamnine Posavskih gub so zaposlovale že mnoge raziskovalce zaradi ekonomskih vzrokov, saj se v Trboveljski formaciji nahaja pomemben sloj rjavega premoga, ki doseže debelino do 30 m. Neindustrijsko odkopavanje premoga se je ponekod pričelo že v 18. stoletju, sčasoma, pretežno v 19. st., pa so se razvili rudarski obrati v Laški sinklinali v Šemniku, Kisovcu, Lokah, Zagorju, Orleku, Trbovljah, Hrastniku, Dolu in Laškem (Brezno, Huda jama in Mihael) (sl. 3), v Motniški sinklinali v Motniku, Zabukovici, Štorah in Pečovniku, v Senovški sinklinali v Senovem in še ponekod. Zadnji ciklus strukturnih raziskav Laške sinklinale je bil opravljen v letih od 1981 do 1991 na pobudo takratnega podjetja Rudniki rjavega premoga Slovenije v Trbovljah. Tedaj smo izdelali detajlno geološko karto Laške sinklinale v merilu 1:5000 (sl. 2, sl. 3). Skartirali smo okoli 10 km rovov v rudnikih Loke, Zagorje, Trbovlje, Hrastnik, Dol in Laško, obdelali nekaj kilometrov površinskih in jamskih vrtin ter obsežno aktualno in zgodovinsko arhivsko gradivo v jamomernicah obstoječih rudnikov. Rezultat teh raziskav je kinematski model Laške sinklinale, ki posredno pojasnjuje tudi zgradbo in genezo celotnih Posavskih gub. V tem prispevku smo prikazali deformacijo Laške sinklinale v kombiniranem profilu v smeri N-S (sl. 3, sl. 4) na območju Zagorja in regionalne zaključke, ki iz tega sledijo.

## Geneza sedanje zgradbe premogišč na območju Zagorja

Že pri prvih analizah geneze Laške sinklinale je postalo jasno, da so deformacije v terciarnih kamninah odsev zgradbe in starejših deformacij v podlagi terciarja. Zato je bilo treba skartirati tudi široko ozemlje mezozojskih in paleozojskih kamnin ter rekonstruirati razmere pred pričetkom sedimentacije oligocenskih skladov. Pokazalo se je, da je na videz tako različna zgradba posameznih premogišč v Laški sinklinali posledica strukturnega predrisa in različnih prostorskih odnosov med bolj in manj duktilnimi kamninami v podlagi terciarja, ne pa različnih stilov deformiranja.

Na sl. 4 je prikazana geneza Laške sinklinale na območju Zagorja, ki vključuje premogišča v Kisovcu, Lokah, Podstrani, Kotredežu in Orleku (sl. 3). Splošne razmere tik pred odložitvijo trboveljskih plasti na prostoru kasnejše Laške sinklinale ponazarja profil na sl. 4a. V njem sta vidni prva in druga strukturna etaža Posavskih gub, ki ju loči izrazit krovni poševni rez, na katerega se od severa proti jugu naslanjajo vedno mlajši stratigrafski členi druge strukturne etaže od srednjepermskih klastitov Grödenske formacije na severu do noriško retijskega glavnega dolomita in dachsteinskega apnenca na jugu. Krovna enota ima heterogeno notranjo zgradbo, ki je na opisanem območju zgrajena bivalentno. Na jugu je v podlagi nekaj srednjetriasnih plastnatih kamnin, pretežni del pa je iz srednjetriasnega, zgornjetriasnega in spodnjejurskega neplastnatega ali slabo plastnatega dolomita in apnenca z nekaj diskordantno odloženega zgornjekrednega apnenca. Na severu pa je krovna enota sestavljena najprej iz srednjepermskih klastitov Grödenske formacije, nato pretežno iz plastnatih karbonatov Belerofonske in Werfenske formacije in dolomita Mendolske formacije ter končno iz obsežne skladovnice klastitov Psevdoziljske formacije ladinijske in cordevolske starosti (Kolar-Jurkovšek & Placer, 1987; Placer & Kolar-Jurkovšek, 1990), ki so bili prvotno po najdišču fosilov na celjskem gradu (Teller, 1889) uvrščeni v celoti le v langobardsko dobo. Na triasnih kamninah ležijo erozijske krpe diskordantno odloženega krednega apnenca. Psevdoziljske plasti so se torej odlagale blizu obale, vzporedno ob karbonatnem pragu, kar je v geomehanskem smislu izjemen pojav. Lateralni prehod iz karbonatnega v klastični facies je viden na območju Ravenske vasi.

Profil na sl. 4a je poenostavljen toliko, kolikor je potrebno za razumevanje kinematike deformiranja.

V srednjem ali v zgornjem oligocenu se je končalo dolgo obdobje erozije. Območje se je pričelo polagoma pogrezati, zaradi česar je na območju Posavskih gub nastalo nekaj depresij, v katerih se je najprej uveljavila sladkovodna sedimentacija s krajšim obdobjem zamočvirjenja, nakar je vanje vdrlo terciarno morje. V teh depresijah zavzemajo mlajše terciarne plasti vedno bistveno večjo površino od starejših, kar kaže morda na začetke gubanja in hkratno pogrezanje. Grezanje skozi terciar ni bilo enakomerno, včasih je imelo celo nasprotni predznak, saj se menjavata morsko in brakično okolje, oziroma transgresijski in regresijski nizi sedimentacije s prekinitvami v savski fazi med Kiscellsko in Govško formacijo, v štajerski fazi med Govško in Laško formacijo in v moldavsko-atiški fazi med Laško in Dolsko formacijo. Od teh faz je savska izjemno šibka in se izraža le ponekod z disperzijsko diskordanco. Nekoliko izrazitejša, vendar še vedno disperzijska, je štajerska diskordanca, medtem ko je moldavsko-atiška najmočnejša in ima ponekod edina tudi jasno kotno komponento.

Stanje ob koncu sedimentacije miocenskih plasti na prostoru kasnejše Laške sinklinale kaže sl. 4b. Že na prvi pogled je očitno, da je jedro grezanja, oziroma zasnova temena Laške sinklinale, nastalo na območju Psevdoziljske formacije blizu karbonatnega praga, tako da je njeno južno krilo pretežno iz neplastnatih karbonatov, severno pa iz klastitov z višjo stopnjo duktilnosti.

Po sarmatski dobi je nastopilo intenzivno stiskanje prostora, ki se je odrazilo v dvigu ozemlja in v narivu južne polovice bazena na severno polovico. Po Novem Dolu je to Novodolski nariv, ki ga je poimenoval Gregorač (1975), komentirala pa Kuščer & Mitrevski (1979). Iz detajlne rekonstrukcije geneze celotnega bazena vemo, da znaša dolžina premika narinjene grude ob tem narivu na vzhodu pri Laškem okoli dva kilometra in pol, proti zahodu je premik vedno manjši, na območju Zagorja pa znaša le še nekaj deset metrov do največ 100 m. Učinek tega nariva v Zagorju kaže sl. 4c.

Omejen premik ob Novodolskem narivu kaže na časovno omejeno obdobje komprimacije. Tej je verjetno sledilo obdobje stagnacije in ponovno komprimacija. Menjavanje komprimacije in stagnacije je virtualna komponenta razlage geneze Posavskih gub, ob koncu tega poglavja bomo videli, da bi bilo lahko tudi drugače, vendar pri enakem zaporedju dogodkov.

Ne glede na dileme moremo iz analize deformacije celotne Laške sinklinale ugotoviti, da se je v drugi fazi komprimacije območje najprej rahlo asimetrično nagubalo (sl. 4d), nato pa se je ob novonastali predisponirani coni, ki je potekala po plasteh Trboveljske formacije v južnem krilu novonastale sinklinale, formirala narivna ploskev ob kateri se je severno krilo sinklinale narinilo za 1500 m do 2000 m proti jugu na njeno južno krilo (sl. 4e). Trboveljska formacija s premogom se je narinila proti jugu na južni karbonatni prag. Pri tem je čelo nariva razpadlo na več lusk; največja med njimi je Kisovška luska (K). Obravnavani nariv od severa proti jugu je razvit v celotni Laški sinklinali in je poznan kot Hrastniški nariv po kraju Hrastnik. Poimenoval ga je G r e g o r a č (1975).

Premiku ob Hrastniškem narivu je verjetno sledila faza stagnacije in nato ponovno intenzivno gubanje (sl. 4f), ki se je v krilih sinklinale različno odražalo. V severnem krilu se je narivna ploskev Novodolskega nariva postavila pokonci in vpada danes strmo proti jugu. Medplastni zdrsi zaradi gubanja so se tu dogajali v psevdoziljskih klastitih. V južnem krilu pa se je v neplastnatem do debeloplastnatem zrnatem dolomitu južnega karbonatnega praga manifestiral učinek gubanja z nastankom reverznih prelomov zaradi izrivanja v jedru gube (Borovniški prelom). Ti ležijo blizu lege neobstoječih plastnic, ali pa gre morebiti za reaktivacijo že obstoječih diskontinuitet. Z nadaljnjim gubanjem se je premik ob teh prelomih še povečal. Nastale so značilne strme dolomitne luske v južnem krilu Laške sinklinale v Zagorju in zahodno od tod, od katerih segajo nekatere do površja (Ocepkov vrh, Smrekovec, Borovnik), druge pa ne. V slednjem primeru so te vedno predstavljale skrito nevarnost za nenadejane vdore vode v jamske prostore, če so se jim z rudarskimi deli preveč približali.

Zahodno od Zagorja se je Laška sinklinala stisnila v subvertikalno izoklinalno gubo. Ko gubanje ni bilo več mogoče se je izoblikoval nariv zgornjetriasnih karbonatov južno od Laške sinklinale na njeno južno krilo kot kaže sl. 4g (Čolniški nariv). V Zagorju Laška sinklinala sicer ni izoklinalna, vendar ta podrobnost kaže le na to, da je embrionalna zasnova Čolniškega nariva nastala izven obravnavanega profila na območju izoklinalne gube. V talninski grudi Čolniškega nariva so v terciarnih plasteh južnega roba terciarne kadunje nastale obnarivne gube. Že omenjena Kisovška luska (K) s čela Hrastniškega nariva se je sedaj nagubala v Kisovško stransko kadunjo, kot so jo poimenovali v rudarski praksi. Struktura med to kadunjo in Borovniškim prelomom pa se je izoblikovala v Loško stransko kadunjo.

Profil na sl. 4g je sintetičen in združuje sedanje razmere na območju Kisovca, Lok, Zagorja, Podstrane in Orleka, ugotovljene na podlagi detajlnega površinskega kartiranja, kartiranja rudarskih del ter površinskih in jamskih vrtin. V Kisovški stranski kadunji (K) sta bili jami Podstrana in Kisovec, v Loški stranski kadunji in v delu južnega krila glavne kadunje je bila jama Loke, v glavni kadunji sta se razvili jami Kotredež in Orlek. Rekonstrukcija kinematskega razvoja Laške sinklinale na območju Zagorja temelji na številnih strukturnih faktografskih podatkih, tako da moremo govoriti o kinematski rekonstrukciji visoke stopnje verjetnosti. Smiselno enake rekonstrukcije premogišč v Šemniku, Trbovljah, Hrastniku in Laškem (Brezno, Huda jama, Mihael), ki smo jih že opravili, imajo enako strukturno izhodišče, enako stopnjo komprimacije, vendar različne končne efekte. Ti se izražajo z različno zgradbo posameznih premogišč, ki je nastala ali z dominacijo gubanja ali ene od treh faz narivanja.

Preden preidemo na zaključke naj opozorimo na drugačen vidik rekonstrukcije, ki smo ga že napovedali. Genezo sedanje strukture ali narivanje najprej z juga, nato s severa in ponovno z juga ter gubanje je mogoče kinematsko razložiti tudi brez obdobij stagnacije med obdobji komprimacije. Idejo je mogoče izpeljati kot kontinuum narivanja in gubanja in sicer najprej narivanje od juga proti severu (sl. 4c) in hkratno asimetrično gubanje (sl. 4d). Pri dovolj strmem severnem krilu sinklinale zamre sposobnost narivanja ob Novodolskem narivu. S tem se v južnem krilu ustvarijo pogoji za nastanek nove predisponirane ploskve po plasteh Trboveljske formacije in formira se narivna ploskev Hrastniškega nariva, ob kateri pride do narivanja od severa proti jugu (sl. 4d, 4e). Ob hkratnem narivanju in gubanju živi Hrastniški nariv toliko časa, dokler se zaradi gubanja njegova narivna ploskev toliko ne usloči, da premikanje ob njej ni več mogoče (sl. 4f). Ko postane guba izoklinalna, ali pa nekoliko prej, se razvije Čolniški nariv, ob katerem je južno krilo Laške sinklinale narinjeno od juga proti severu (sl. 4g). Pri vsem tem ne smemo zanemariti vloge starejših prelomnih ploskev, ki so gotovo obstajale v mezozojskem pokrovu pred pričetkom usedanja terciarnih plasti. Teh ne moremo podrobno poznati, zaradi česar predstavljeni model ne more biti povsem v skladu z naravnimi razmerami. Prvotni vpad narivnih ploskev v modelu na sl. 4 je usklajen z analizo faktografskih podatkov.

Pred seboj imamo torej kinematsko rekonstrukcijo nekega tektonskega dogajanja, katerega zaporedje dogodkov ni sporno, sporna nista tudi izhodiščna in končna zgradba in vmesne stopnje razvoja. Sporna pa je dinamika dogajanja, ki bi jo bilo mogoče proučevati in ji dati teoretično podlago le z modelnimi raziskavami.

Tektonska dogajanja v terciarju na območju Laške sinklinale in posredno tudi Posavskih gub, je mogoče razvrstiti v lestvico zaporednih dogodkov, medtem ko se njihove natančnejše starosti še ne da določiti. Najstarejši in hkrati najmarkantnejši tektonski element na obravnavanem ozemlju je obsežna krovna enota iz pretežno triasnih kamnin na karbonskopermskih in grödenskih klastitih, ki je dokazana s številnimi tektonskimi okni, polokni in izrazitim poševnim rezom ter zavzema celotne Posavske gube. Nastala je pred srednjim ali zgornjim oligocenom. Notranja zgradba pokrova še ni dovolj proučena, da bi lahko razpravljali o smeri narivanja, obstoja pa tudi možnost, da je pokrovov več.

Drugi pomemben dogodek je sedimentacija oligocenskih in miocenskih sedimentov, za katere je značilna ritmičnost, ki je podana s savsko, štajersko in moldavsko-atiško diskordanco, od katere je vsaka naslednja močnejša in bolj izrazita.

Gubanje Posavskih gub se je dogajalo po sarmatu, ker so te plasti vključene v gubanje.

Sklepni del deformiranja obravnavanega prostora je povezan s šibko neotektonsko oživitvijo nekaterih prelomov v smeri NW-SE. Vse deformacije stiskanja prostora po miocenu od gubanja do prelomov NW-SE so nastale pri orientaciji glavne maksimalne osi regionalnega napetostnega stanja približno v smeri N-S.

## Dosedanje raziskave in primerjava z rezultati regionalnih raziskav

Sedaj ko poznamo najnovejši shematski pogled na zgradbo in genezo Laške sinklinale, se je potrebno ozreti na dosedanje raziskave. Prvi je celovit pregled geološke zgradbe Laške sinklinale in njenega obrobja podal B i t t n e r (1884). Zgradbo Posavskih gub sta tako Bittner kot pozneje T e l l e r (1907), ki je za izdelavo osnovne geološke karte avstro-ogrske monarhije v merilu 1:75.000, list Celje-Radeče, uporabil Bittnerjeve podatke, razumela kot običajno zaporedje nagubanih in z diskordancami prekinjenih paleozojskih, mezozojskih in kenozojskih kamnin. Idejo o krovni zgradbi je prvi izrazil W i n k l e r (1923), vendar je sklepal na obsežni pokrov karbonatnih kamnin Zunanjih Dinaridov narinjen proti severu na območje Posavskih gub, tako da je karbonatni prag, ki je ekvivalent Psevdoziljske formacije smatral za del Zunanjih Dinaridov, same psevdoziljske plasti pa je prišteval k Južnim Alpam oziroma njihovi Zunanji coni. K u š č e r (1967), ki je detajlno obdelal okolico Zagorja, je povzel Bittnerjevo in Tellerjevo idejo o neproblematičnem zaporedju paleozojskih, mezozojskih in kenozojskih skladov v Posavskih gubah.

Pri kartiranju v okviru Osnovne geološke karte Jugoslavije v merilu 1:100.000, pa je prišlo do novih razhajanj. Bistveni del ozemlja Posavskih gub prekrivajo trije listi Osnovne geološke karte in sicer Ljubljana, Celje in Rogatec, ki so jih interpretirali različni avtorji; rezultat sta dva različna tektonska koncepta. Osrednji del Posavskih gub, oziroma osrednji del Laške sinklinale, je na listu Celje obdelal B u s e r (1978, 1979) in ugotovil, da se je v helvetiju v času štajerske faze ozemlje najprej nagubalo, nato pa so nastali obsežni krovni narivi. Same Posavske gube naj bi se dokončno nagubale v pliocenski dobi. Narivanje naj bi bilo usmerjeno od severa proti jugu; dolžine narivanja ni omenil (sl. 5a). Starost krovnega narivanja je dokazoval z izklinjanjem narivnic ob štajerski diskordanci. Kljub obsežni narivni zgradbi Buser meni, da Posavske gube neproblematično prehajajo v Zunanje Dinaride. Enako stališče je zagovarjal tudi A n i č i ć & J u r i š a (1985a, 1985b), ki je kartiral list Rogatec vzhodno od lista Celje. Misel, da bi krovni narivi nastali v helvetiju je treba zavrniti, saj pod štajersko diskordanco ni nagubanih plasti. Po naših opazovanjih je ta diskordanca disperzijska, na listu Ljubljana pa so helvetske plasti po P r e m r u j u (1983a, 1983b) celo ohranjene. Meje pokrovov nikjer ne sekajo oligocenskih in spodnjemiocenskih plasti. Mezozojske plasti niso nikjer ob krovnih narivih narinjene na oligocenske in spodnjemiocenske.

Na listu Ljubljana in v samostojnih razpravah je P r e m r u (1974, 1975, 1980, 1983a, 1983b) zagovarjal povsem drugačen koncept zgradbe. Posavske gube so po njem v paleogenu in neogenu doživele tri faze narivanja. Starejša faza, v kateri je prišlo najprej do gubanja in nato do narivanja je nastala na meji med oligocenom in tortonom, vidna pa naj bi bila v zahodnem delu Vzhodnih Posavskih gub. Naslednja najbolj izrazita faza, v kateri se je tudi uveljavilo gubanje in narivanje, je živela med koncem sarmata in začetkom pliocena. Najmlajše narivanje v kvartarju naj bi imelo le lokalni pomen. Vse opisane deformacije naj bi nastale zaradi povečanih napetosti v smeri N-S. V najpomembnejši fazi gubanja in narivanja med sarmatom in pliocenom so nastale prevrnjene in pretrgane gube, iz katerih so se razvili obsežni narivi s premikom proti jugu, katerih dolžino je ocenil na 8 do 19 km. Posavske gube naj bi se torej nagubale v tej fazi. Vsaka narivna enota naj bi bila zgrajena iz prevrnjene antiklinale v čelu nariva in sinklinale v začelju. Paleozojske plasti Posavskih gub pa naj bi bile narinjene na Zunanje Dinaride (sl. 5b). Najmlajše narivanje v kvartarju naj bi bilo ponekod usmerjeno tudi proti severu. Opisani shemi ne moremo pritrditi zaradi več vzrokov. V Posavskih gubah je očitno, da so narivne ploskve pokrovov ali narivov nagubane skupaj s Posavskimi gubami, kar sta upoštevala Buser in kot bomo videli tudi Mioč. Nikjer nimamo dokazov o obsežnejšem narivanju paleozojskih in mezozojskih plasti na terciarne, razen pri lokalnih deformacijah kot sta npr. Hrastniški in Čolniški nariv. Nekatere narivne ploskve, ki jih riše Premru, so po naših opazovanjih povsem normalne ali diskordančne geološke meje, kar potrjujejo tudi drugi geologi, ki so to območje kartirali (K u š č e r, 1962, 1967, 1975; B u s e r, 1978, 1979). Upravičen ugovor proti Premrujevi interpretaciji narivne zgradbe Posavskih gub je objavil K u š č e r (1975). Premrujev koncept odnosa Posavskih gub do Zunanjih Dinaridov je povzel tudi M l a k a r (1985/86).

V tem kontekstu je zanimiva ideja M i o č a (1976, 1981), ki je sodeloval pri kartiranju lista Celje pa tudi Ribnica in Novo mesto južno od Posavskih gub. Uvedel je termin Savski pokrov, ki naj bi zajemal celotne Posavske gube. Sestavljen naj bi bil iz dveh strukturnih etaž. Spodnja naj bi bila iz karbonskopermskih klastitov, zgornja pa iz mezozojskih kamnin, ki so od paleozojskih ločene z manjšimi narivi (sl. 5c). Pokrov naj bi bil narinjen od severa proti jugu na Zunanje Dinaride, nastal pa naj bi pred oligocenom. Permski klastiti v okolici Ortneka na karbonatni platformi Zunanjih Dinaridov južno od Posavskih gub naj bi predstavljali tektonske krpe, ki so erozijski ostanki Savskega pokrova. Vendar podatki Osnovne geološke karte, list Ribnica (B u s e r, 1969, 1974) in kontrolnih ogledov na terenu tega ne potrjujejo, saj tukaj na srednjepermskih plasteh ležijo diskordantno odložene spodnjetriasne in mlajše plasti, tako da je ideja o tektonskih krpah brez osnove, poleg tega pa ležijo te plasti pretežno v dolinah in preprosto predstavljajo erozijska okna. Dejstvo je, da nihče doslej ni vzhodno od Ljubljanske kotline dokazal ali videl nariva karbonskopermskih klastitov na mezozojske sklade Zunanjih Dinaridov, temveč ležijo karbonskopermski klastiti dosledno pod njimi. Konstrukcije Mioča, Premruja in Mlakarja so hipotetične in izhajajo iz razmer zahodno od Ljubljanske kotline, kjer so karbonskopermske plasti nedvomno narinjene na mezozojske kamnine Zunanjih Dinaridov. Narivna lega pasu karbonskopermskih plasti na mezozojskih med Orlami in Gabrovko predstavlja lokalno deformacijo.

## Razprava

S tem prispevkom skušamo pokazati, da so detajlne raziskave v Posavskih gubah v merilu 1:5000 nakazale drugačno zgradbo ozemlja na stiku med Južnimi Alpami in Zunanjimi Dinaridi, kot so jo dale regionalne raziskave v okviru Osnovne geološke karte v merilu 1:100.000. To pomeni, da pregledne karte v tako zamotanih razmerah, kot je prostor med Južnimi Alpami in Zunanjimi Dinaridi niso primerne za poglobljen študij zgradbe tega prostora. Zato smo tudi komentirali le tiste avtorje, ki so neposredno raziskovali Posavske gube, ne pa tudi številnih raziskovalcev, ki so alpsko-dinarski prostor vključevali v regionalne in globalne sinteze, saj menimo, da je poznavanje ključnih strukturnih detajlov z omenjenega prostora še premajhno, da bi lahko izdelali resnejšo sintezo. Na podlagi novih podatkov in potrjenih ugotovitev starejših raziskovalcev lahko v tem trenutku o zgradbi Posavskih gub zaključimo naslednje (sl. 5d):

**1.** Vse tri strukturne etaže Posavskih gub (1. karbonskopermski klastiti ter ponekod tudi permski in spodnjetriasni skladi, 2. mezozojske plasti, 3. terciarne plasti) so kartografsko in kinematsko utemeljene. Prva in druga sta ločeni z obsežno krovno narivno ploskvijo, med drugo in tretjo pa je izrazita diskordančna ploskev, ki je nastala po dolgem obdobju erozije pred srednjim oziroma zgornjim oligocenom.

**2.** Karbonskopermske plasti Posavskih gub so sestavni del Zunanjih Dinaridov, tako kot je menil že B u s e r (1978, 1979). O narivanju teh plasti proti jugu na karbonatno platformo Zunanjih Dinaridov vzhodno od Ljubljanske kotline ni nobenega neposrednega ali posrednega dokaza.

**3.** Krovno narivanje mezozojskih kamnin v Posavskih gubah je nastalo pred srednjim ali zgornjim oligocenom, njegova krovna narivna ploskev pa je imela v izhodiščni legi lastnost ločilne ploskve (decollement, detachment). Smer narivanja še ni analitično ugotovljena. Kljub strokovno še neugotovljeni smeri narivanja pa upravičeno domnevamo na velik horizontalni premik, ki bi utegnil znašati več deset, morda več sto kilometrov. Na veliko prvotno medsebojno oddaljenost kamnin prve in druge strukturne etaže je mogoče sklepati po razmerah v profilu na sl. 4a. Lega zgornjetriasnega glavnega dolomita in dachsteinskega apnenca na karbonskopermskih skladih, ki jo je mogoče opazovati v nekaj tektonskih oknih v južnem krilu Laške sinklinale, je dober dokaz za to.

**4.** Za psevdosoteške plasti predlagamo termin **Trboveljska formacija** po kraju Trbovlje, za sarmatske plasti pa **Dolska formacija** po kraju Dol pri Hrastniku. Tako naj bi imeli v Laški sinklinali Trboveljsko, Kiscellsko, Govško, Laško in Dolsko formacijo. Tipična profila Trboveljske in Dolske formacije bo treba še določiti in opisati.

**5.** Če pogledamo na Posavske gube s širšega zornega kota, opazimo že na prvi pogled nenavadno skladnost med regionalno geometrijo neotektonskih deformacij obravnavanega prostora in razprostranjenostjo Posavskih gub (sl. 1, sl. 2). Te so pravzaprav vmeščene v trikotnik med neotektonsko aktivne tektonske cone in sicer Periadriatsko tektonsko cono na severu, Idrijsko tektonsko cono na jugozahodu in Srednjemadžarsko tektonsko cono na jugo-jugovzhodu, kar je shematsko prikazano na sl. 6. Mreža neotektonskih prelomov na sl. 1 je povzeta po listih Osnovne geološke karte Jugoslavije 1:100.000, za območje Posavskih gub pa smo upoštevali podatke lastnih raziskav. Preden nadaljujemo naj nekoliko podrobneje definiramo uporabljene termine. Izraz **Periadriatska tektonska cona** so uporabili Jelen et al. (1997) za deformacije, ki so genetsko povezane s strižnimi premiki ob Periadriatskem lineamentu. V kinematskem smislu prištevamo sem pas med Periadriatskim lineamentom in Savskim prelomom, ki je južna meja te cone. Savski prelom razumemo v smislu enotne prelomne ploskve, ki povezuje njegovo klasično traso v Zgornjesavski dolini, Celjski prelom in natančno še nedoločeno traso vzhodno od Celja (Placer, 1996) do Šoštanjskega preloma, ki poteka mimo Velenja, sl. 2, nato pa med Ravno goro in Ivančico proti vzhodu-severovzhodu. Kriteriji neotektonske aktivnosti so deformacije, kot jih opisujejo raziskovalci Jelenove skupine. Značilnost Periadriatske tektonske cone je, da je na območju Posavskih gub usločena proti jugu. **Srednjemadžarska tektonska cona** zajema prelome v smeri WSW-ENE približno med Orlico in jugovzhodnim podnožjem Medvednice in jo razumemo v smislu Csontos et al. (1992). Kriterij neotektonske aktivnosti te cone so deformirane osi Posavskih gub, prikazane na sl. 2 in kvartarna tektonska aktivnost kot jo podajata Prelogović & Cvijanović (1976). Srednjemadžarska tektonska cona se naslanja na Periadriatsko tektonsko cono severovzhodno od Kalnika. **Idrijska tektonska cona** vključuje dominantne prelome v severozahodnem delu Zunanjih Dinaridov v smeri NW-SE, približno med Raškim in Stiškim prelomom po Buserju (1976). Njena osrednja struktura je Idrijski prelom. Kriterij neotektonske aktivnosti ob teh prelomih je morfostrukturne narave. Idrijska tektonska cona je sestavljena iz dveh delov, ki ju loči Idrijski prelom. V severovzhodnem ali njenem notranjem delu (b na sl. 6) se prelomi ob robu cone naslanjajo na Savski prelom, med temi in Idrijskim prelomom pa se bolj ali manj izklinjajo znotraj pokrova Vzhodnih Julijskih Alp. V jugozahodnem ali zunanjem delu (a na sl. 6) se na območju Zahodnih Julijskih Alp prelomi te cone skupaj z Idrijskim transformirajo iz zmičnih v poševne reverzne prelome po shemi, ki jo med drugimi podajajo Carulli et al. (1990). Na prostoru Posavskih gub znotraj omenjenega trikotnika prelomi smeri NW-SE in WSW-ENE le v neznatni meri ali pa sploh ne sekajo terciarnih sedimentnih kamnin.

Notranji del Idrijske in Srednjemadžarska tektonska cona se sekata v obsežni **Idrijsko-Srednjemadžarski presečni coni** v kateri se izklinja Srednjemadžarska tektonska cona proti jugozahodu medtem ko je nadaljevanje Idrijske tektonske cone proti jugovzhodu nejasno. Meje Posavskih gub niso ostre, ker ne potekajo po določenih prelomih, temveč se intenzivnost gubanja v omenjenih tektonskih conah postopoma manjša (sl. 2). Na zahodu domnevamo, da se to dogodi pod aluvialnimi naplavinami Ljubljanske kotline, ki ima tako kot prelomi Idrijske tektonske cone smer NW-SE, zato samega zamiranja ne moremo opazovati, vendar vzhodno od Ljubljanske kotline ni več gub, ki bi jih lahko vzporejali s Posavskimi.

Na vzhodu se Posavske gube polagoma izklinijo v Srednjemadžarski tektonski coni, v kateri spremenijo tudi smer od W-E proti WSW-ENE, kar pa se pravzaprav zgodi že zunaj severo-severozahodne meje te cone. Na severu se gube ponekod pojavljajo tudi severno od Savskega preloma, npr. Pletovarsko-Maceljska antiklinala. Iz opisane geometrije disjunktivnih in plikativnih elementov zgradbe moremo sklepati, da predstavlja območje med Idrijsko in Srednjemadžarsko tektonsko cono kompresijski klin, v katerem so se pri regionalni orientaciji glavne maksimalne napetosti približno v smeri N-S južno od Periadriatske tektonske cone izoblikovale Posavske gube. Imenujemo ga **Savski kompresijski klin** (sl. 6). Obseg kompresijskega klina smo določili na podlagi tistih deformacij, ki jih povezujemo z napetostnim stanjem v samem klinu. Na jugozahodu je domnevno segal nekaj čez Stiški prelom, na jugo-jugovzhodu do srede Srednjemadžarske tektonske cone, severne meje pa ni mogoče določiti. Zgolj formalno smo jo potegnili nekaj severneje od prvotne lege Periadriatskega lineamenta, o čemer bomo spregovorili nekoliko pozneje.

Glede na definicijo Savskega kompresijskega klina moremo postaviti naslednje preliminarne sklepe:

**A.** Vzrok za izoblikovanje Savskega kompresijskega klina vidimo v nastanku Idrijsko-Srednjemadžarske presečne cone z izrazito poudarjeno parketno zgradbo, v kateri ne moremo določiti dominantne strižne smeri. To pomeni, da se je kompresijski klin razvil v obdobju stagnacije intenzivnejših strižnih premikov v notranjem delu Idrijske in v Srednjemadžarski tektonski coni.

**B.** Zavijanje Posavskih gub ob Srednjemadžarski tektonski coni in znotraj nje je izrazito, medtem ko tega pojava ob ali v Idrijski tektonski coni nismo mogli dokazati. Menimo, da leži vzrok v asimetriji Savskega kompresijskega klina, saj je njegovo jugo-jugovzhodno krilo bolj izpostavljeno vplivom novonastalega napetostnega stanja kot jugozahodno krilo.

**C.** Poleg gubanja se je vpliv stiskanja prostora v Savskem kompresijskem klinu izrazil tudi v splošnem dviganju celotnega klina, kar opazujemo v antecedentnem značaju Savske soteske med Ljubljansko in Krško kotlino in v pliokvartarnem produ, ki je danes znotraj klina dvignjen do 450 m nad današnji nivo reke Save (Čolnišče nad Zagorjem, Završje pod Kumom), medtem ko je isti prod izven kompresijskega klina v splošnem le malo dvignjen nad Savo, če izvzamemo lokalne anomalije, npr. Libna pri Krškem.

**D.** Četrta značilnost je usločitev Periadriatske tektonske cone proti jugu zaradi skrčenja prostora v Savskem kompresijskem klinu. Velikost celotnega skrčka smo ocenili na podlagi podatkov geneze Laške sinklinale na sl. 4, ki znaša okoli 6,5 km. Ker je v konstrukcijo na sl. 4 vključeno tudi južno krilo Trojanske in del severnega krila Litijske antiklinale, je mogoče celotni skrček kompresijskega klina južno od Savskega preloma določiti s seštevkom vseh sinklinal. Po osi klina nastopata v smeri N-S dve sinklinali: Tuhinjska in Laška, ki sta približno podobnih dimenzij in imata verjetno tudi podobna skrčka, kar pomeni zožitev za 13 km. Če pa temu prištejemo še skrček Planinsko-Desiniške in Senovške sinklinale nekoliko vzhodneje od tod, ki ni tolikšen in še nekaj manjših, menimo, da znaša največji skrček kompresijskega klina južno od Savskega preloma okoli 20 km. Iz tega sledi, da je zoženje prostora v osi klina povzročilo usločitev in pomik Periadriatske tektonske cone za 20 km proti jugu, v bokih pa postopoma manj do ničelnega premika v bližini oglišč. Ti se za nivo Savskega preloma nahajata zahodno od Kamniško-Savinjskih Alp in severovzhodno od Kalnika. Gubanje je intenzivnejše tam, kjer je več kamnin visoke duktilnosti (karbonskopermski, grödenski, psevdoziljski in terciarni klastiti), manj intenzivno pa je v vrhu klina, kjer prevladujejo mezozojski karbonati. Zožila se je tudi Periadriatska tektonska cona.

E. Za nastanek Posavskih gub je bila poleg formiranja Idrijsko-Srednjemadžarske presečne cone potrebna tudi preusmeritev napetostnih pogojev od desnih strižnih preko transpresivnih k normalnim pravokotno na Periadriatsko tektonsko cono v smeri N-S, ki je verjetno povezana z rotacijo širših razsežnosti. Kot deformacije novega napetostnega stanja obravnavamo poleg gub južno od Savskega preloma in delno znotraj tektonske cone tudi zmične prelome v smeri NW-SE, ki sekajo Periadriatski lineament in Savski prelom in so povzeti po podatkih Mioča & Žnidarčiča (1977), Mioča et al. (1983), Polinskega & Eisbacherja (1992) in Krystyna et al. (1994). Med temi je najpomembnejši Labotski prelom, ki je bil po vsej verjetnosti zasnovan že v začetnem stadiju krčenja Savskega kompresijskega klina, kar je na sl. 6 prikazano z inicialnim prestrigom Periadriatskega lineamenta v prvotni legi. Proces je mogoče razložiti z ločnim efektom, oziroma raztezanjem v smeri Periadriatske tektonske cone in z vplivom Pohorskega masiva kompetentnih kamnin na zmikanje.

Upogib Periadriatske tektonske cone je poleg opisanih moral povzročiti tudi nasledstvene premike ob že obstoječih mehanskih diskontinuitetah tektonskega in sedimentnega izvora, zato bo treba temu dogajanju posvetiti več pozornosti. Ob tej priliki naj opozorimo na prispevek Jelena et al. (1997), kjer ugotavljajo desno progresivno transpresijo ob Savskem prelomu, ki naj bi trajala še danes. Če transpresija obstoja bi lahko imela le sekundarni pomen in krajevni obseg zaradi ločnih učinkov usločenja Periadriatske tektonske cone ne pa regionalnega pomena. Glede na njihovo ugotovitev, da se je zadnje intenzivno strižno premikanje dogajalo pred 6 milijoni leti, torej ob koncu miocena, menimo, da so se pogoji za nastanek Savskega kompresijskega klina ustvarili v pliocenu, sam proces gubanja in stiskanja prostora, pa je, oziraje se na pliokvartarni prod visoko nad sotesko reke Save na Čolnišču in pri Završju, mogel trajati še v kvartarju. Vprašanje ali so recentni premiki nadaljevanje teh procesov bi moralo postati predmet bodočih raziskav.

Predlagana neotektonska geometrijska shema je, kljub nekaterim dovolj trdnim dejstvom, še vedno v fazi intenzivnih raziskav. Zato vse relacije med omenjenimi strukturnimi elementi še niso enoznačno pojasnjene. Zlasti to velja za odnos med južno mejo Periadriatske tektonske cone, oziroma Savskim prelomom in Srednjemadžarsko tektonsko cono, ki ga raziskuje Jelenova skupina v širšem geotektonskem kontekstu, in za vprašanje geneze Idrijsko-Srednjemadžarske presečne cone.

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## References

Aničić, B. & Juriša, M. 1985a: Osnovna geološka karta SFRJ, 1:100.000, List Rogatec (Basic geological map of Yugoslavia, 1:100.000, sheet Rogatec). Zvezni geološki zavod, Beograd.

Aničić, B. & Juriša, M. 1985b: Tolmač lista Rogatec, Osnovna geološka karta SFRJ, 1:100.000 (Guidebook of sheet Rogatec, Basic geological map of Yugoslavia, 1:100.000). Zvezni geološki zavod, Beograd, pp 76.

Bittner, A. 1884: Die Tertiär-Ablagerungen von Trifail und Sagor. - Jb. geol. R.A., *34/3*, 433-596, Wien.

Buser, S. 1969: Osnovna geološka karta SFRJ, 1:100.000, List Ribnica (Basic geological map of Yugoslavia, 1:100.000, sheet Ribnica). Zvezni geološki zavod, Beograd.

Buser, S. 1974: Tolmač lista Ribnica, Osnovna geološka karta SFRJ, 1:100.000 (Guidebook of sheet Ribnica, Basic geological map of Yugoslavia, 1:100.000). Zvezni geološki zavod, pp 60.

Buser, S. 1976: Tektonska zgradba južnozahodne Slovenije (Tektonischer Aufbau Südwest - Sloweniens). 8. jugosl. geol. kongres, Bled 1974, *3*, 45-57, Ljubljana.

Buser, S. 1978: Osnovna geološka karta SFRJ, 1:100.000, List Celje (Basic geological map of Yugoslavia, 1:100.000, sheet Celje). Zvezni geološki zavod, Beograd.

Buser, S. 1979: Tolmač lista Celje, Osnovna geološka karta SFRJ, 1:100.000 (Guidebook of sheet Celje, Basic geological map of Yugoslavia, 1:100.000). Zvezni geološki zavod, Beograd, pp. 72.

Carulli, G.B., Nicolich, R., Rebez, A. & Slejko, D. 1990: Seismotectonics of the Northwest External Dinarides. - Tectonophysics, *179*, 11-25.

Csontos, L., Nagymarosy, A., Kovac, M. & Horvath, F. 1992: Tertiary evolution of the Intra-Carpathian area: a model. - Tectonophysics, *208*, 221-241.

Gregorač, V. 1975: Geološke in hidrogeološke razmere na območju jame Hrastnik. Diplomsko delo, manuskript, Arhiv Univerze v Ljubljani.

Jelen, B., Aničić, B., Brezigar, A., Buser, S., Cimerman, F., Drobne, K., Monostori, M., Kedves, M., Pavšič, J. & Skaberne, D. 1992: Model of positional relationships for Upper Paleogene and Miocene strata in Slovenia. I.U.G.S. - S.O.G. Miocene Columbus Project, 71-72, Portonovo (Ancona), Abstracts.

Jelen, B., Márton, E., Fodor, L., Baldi, M., Čar, J., Rifelj, H., Skaberne, D. & Vrabec, M. 1997: Paleomagnetic, Tectonic and Stratigraphic Correlation of Tertiary Formations in Slovenia and Hungary along the Periadriatic and Mid-Hungarian Tectonic Zone (Preliminary Communication). - Geologija, *40*, 325-331, Ljubljana.

Kolar-Jurkovšek, T. & Placer, L. 1987: Ladinijsko-karnijska mikrofavna iz psevdoziljskih plasti Posavskih gub (Microfauna from the Pseudozilian beds /Ladinian-Carnian/ of the Sava folds area /NW Yugoslavia). - Geol. vjestnik, *40*, 53-64, Zagreb.

Kossmat, F. 1913: Die adriatische Umrandung in der alpinen Faltenregion. - Mitt. Geol. Ges., *VI*, 61-165, Wien.

Krystyn, L., Lein, R., Schlaf, J. & Bauer, F.K. 1994: Über ein neues obertriadisch-jurassisches Intraplattformbecken in den Südkarawanken. - Jubiläumsschrift 20 Jahre Geol. Zusammenarbeit Österreich-Ungarn, *2*, 409-416, Wien.

Kuščer, D. 1962: Psevdoziljski skladi v okolici Zagorja (Pseudozilian beds from the Zagorje area). - Geologija, *7*, 67-69, Ljubljana.

Kuščer, D. 1967: Zagorski terciar (Tertiary Formations of Zagorje). - Geologija, *10*, 5-85, Ljubljana.

Kuščer, D. 1975: Ali so Posavske gube zgrajene iz krovnih narivov? (Gibt es in den Sava-Falten Deckenüberschiebungen?). - Geologija, *18*, 215-222, Ljubljana.

Kuščer, D. & Mitrevski, G. 1979: Geologija mejnega območja med jamama Hrastnik in Dol (Geology of the Area between the Coal mines Hrastnik and Dol). - Rudarsko-metalurški zbornik, *26*, 2/3, 167-178, Ljubljana.

Mioč, P. 1976: Prilog poznavanju tektonskih odnosa granične cone istočnih Posavskih bora i dinarskog šelfa (Contribution to the knowledge of the tectonic relations of the boundary zone of the eastern Sava folds and Dinaric shelf). Sekc. za prim. geol. geof. i geok. JAZU, II, Znanst. skup 1975, Ser. A, *5*, 223-228, Zagreb.

Mioč, P. 1981: Tektonski odnosi savske navlake prema susjednim jedinicama u Sloveniji te njena veza sa širim jugoslavenskim područjem. - Nafta, *32*, 543-547, Zagreb.

Mioč, P. & Žnidarčič, M. 1977: Osnovna geološka karta SFRJ, 1:100.000, List Slovenj Gradec (Basic geological map of Yugoslavia, 1:100.000, sheet Slovenj Gradec). Zvezni geološki zavod, Beograd.

Mioč, P. & Žnidarčič, M. 1983: Osnovna geološka karta SFRJ, 1:100.000, List Ravne na Koroškem (Basic geological map of Yugoslavia, 1:100.000, sheet Ravne na Koroškem). Zvezni geološki zavod, Beograd.

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

Placer, L. & Kolar-Jurkovšek, T. 1990: O starosti psevdoziljskih skladov v vzhodnih Posavskih gubah (The age of the Pseudozilian beds in the east part of the Savafolds). - Rudarsko-metalurški zbornik, *4*, 529-534, Ljubljana.

Placer, L. 1996: O premiku ob Savskem prelomu (Displacement along the Sava fault). - Geologija, *39*, 283-287, Ljubljana.

Placer, L. 1998: Contribution to the macrotectonic subdivision of the border region betwe-

en Southern Alps and External Dinarides. - Geologija, *41*, Ljubljana.
P o l i n s k i, R. & E i s b a c h e r, G.H. 1992: Deformation partitioning during polyphase oblique convergence in the Karawanken Mountains, southeastern Alps. - Jour. Struc. Geol., *14/10*, 1203-1213.
P r e l o g o v i ć, E. & C v i j a n o v i ć, D. 1976: Kvartarne tektonske deformacije i seizmogene zone Hrvatske (Quartärtektonische Deformationen und seismogene Zonen Kroatiens). 8. jugosl. geol. kongres, Bled 1974, *3*, 175-190, Ljubljana.
P r e m r u, U. 1974: Triadni skladi v zgradbi osrednjega dela Posavskih gub (Trias im geologischen Bau der mittleren Sava-falten). - Geologija, *17*, 261-297, Ljubljana.
P r e m r u, U. 1975: Posavske gube so zgrajene iz narivov (Die Sava-Falten sind aus Überschiebungen gebildet). - Geologija, *18*, 223-229, Ljubljana.
P r e m r u, U. 1980: Geološka zgradba osrednje Slovenije (Geologic structure of Central Slovenia). - Geologija, *23/2*, 226-278, Ljubljana.
P r e m r u, U. 1983a: Osnovna geološka karta SFRJ, 1:100.000, List Ljubljana (Basic geological map of Yugoslavia, 1:100.000, sheet Ljubljana). Zvezni geološki zavod, Beograd.
P r e m r u, U. 1983b: Tolmač lista Ljubljana, Osnovna geološka karta SFRJ, 1:100.000 (Guidebook of sheet Ljubljana, Basic geological map of Yugoslavia). Zvezni geološki zavod, Beograd, pp 75.
T e l l e r, F. 1889: Daonella Lommeli in den Pseudo-Gailthalerschiefern von Cilli. -Verh. geol. R.A., *1*, 210-211, Wien.
T e l l e r, F. 1907: Geologische Karte der österr.-ung. Monarchie, 1:75.000, Gruppe 93, Cilli-Ratschach, Wien.
W i n k l e r, A. 1923: Ueber den Bau der östlichen Südalpen. - Mitt. Geol. Ges., *XVI*, 1-272, Wien.