GEOLOGIJA 67/2, 249-271, Ljubljana 2024
https://doi.org/10.5474/geologija.2024.012

Geologic structure and origin of the Zadlog karst polje

Geološka zgradba in nastanek kraškega polja Zadlog

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Prejeto / Received 29. 2. 2024; Sprejeto / Accepted 20. 8. 2024; Objavljeno na spletu / Published online 16. 12. 2024

Key words: karst polje, thrust and fault tectonics, dolomite, hydrogeology, Zadlog, Zadloško polje
Ključne besede: kraško polje, narivna in prelomna tektonika, dolomit, hidrogeologija, Zadlog, Zadloško polje

Abstract

In the wider Idrija area in western Slovenia, several large plains formed along the thrusts within the dolomite and at the contact of dolomite and limestone. The purpose of this paper is to present the detailed structural-geological background of one such plain, namely the Zadlog plain, and based on these findings, to provide new starting points for analyzing the genetic conditions of other karst poljes in Notranjska. The Zadloško polje was formed in a wider near-fault crushed zone at the contact of two structural units within the Upper Triassic Norian-Rhaetian dolomite, with the thrust crossing the polje in its central part. The initially lowered area at the thrust represented a morphological basis, and the crushed zones in the dolomite played a hydrological retention role inducing the stagnation of surface water and, as a result, the formation of the karst polje. Younger fault tectonics then established efficient drainage of surface water and the erosion of sediments to the karst underground. Besdies this, slope equilibration leads us to conclude that the karst polje capability of hydrologic retention is recently decreased. The example of Zadloško polje shows that the thrust structures and associated hydrological conditions are the key elements for the formation of karst poljes in the dissected karst surface. Further detailed structural-geological mapping will reveal whether similar structural-geological conditions are the basis for the formation of other karst poljes in the region.

Izvleček

Vzdolž narivov znotraj dolomita in narivov na kontaktu dolomita in apnenca so na Idrijskem v zahodni Sloveniji mestoma nastale večje izravnave. Namen tega prispevka je predstaviti podrobno strukturno-geološko ozadje ene takih izravnav, in sicer Zadloške uravnave in na podlagi teh ugotovitev podati nova izhodišča za prevetritev genetskih razmer tudi drugih kraških polj na Notranjskem. Zadloško polje je tako nastalo v razširjeni obprelomni zdrobljeni coni ob stiku dveh strukturnih enot znotraj zgornjetriasnega norijsko-retijskega dolomita, pri čemer narivnica prečka polje v njegovem osrednjem delu. Začetna obnarivna izravnava je predstavljala morfološko zasnovo, zdrobljeni coni v dolomitu pa sta imeli ključno vodno-zadrževalno vlogo pri zastajanju površinske vode in posledično pri nastanku kraškega polja. Mlajša prelomna tektonika je nato vzpostavila efektivno odvajanje voda in odnašanje sedimentov v kraško podzemlje. Prav tako opazujemo uravnavanje pobočij izravnave, zaradi česar menimo, da je vodno-zadrževalna sposobnost kraškega polja recentno zmanjšana. Primer Zadloškega polja kaže, da so narivna zgradba in z njo povezane hidrološke razmere ključni element za oblikovanje kraškega polja v razčlenjenem kraškem površju. Ali so podobne strukturno-geološke razmere osnova nastanka tudi ostalih kraških polj v regiji, bo razkrilo nadaljnje podrobno strukturno-geološko kartiranje.

Introduction

On the extensive Črni Vrh plateau, northwest of Črni Vrh above Idrija, lies a 2 km long and up to 800 m wide plain, which locals simply call Zadlog but sometimes also Zadloško polje (Fig. 1A, B). On the plain lies the dispersed settlement of Zadlog with many names for the different parts of the polje. The Zadlog plain is surrounded by higher eleva-

Uvod

Na obsežni Črnovrški planoti severozahodno od Črnega Vrha nad Idrijo leži 2 km dolga in do 800 m široka izravnava, ki ji domačini rečejo preprosto Zadlog (v Zadlogu), včasih pa tudi Zadloško polje (sl. 1A, B). Na izravnavi leži raztreseno naselje Zadlog, s številnimi imeni posameznih predelov polja. Zadloška izravnava je z tions on all sides and is therefore often referenced as Zadloška kotlina (Zadlog basin) on geographical maps. Leaving aside different geographical definitions, the term Zadloško polje or just Zadlog will be used hereinafter.

On a printed geological map of Idrija at the scale of 1:25000, the structure of the Zadloško polje area and its surroundings appears to be simple and uncomplicated (Mlakar & Čar 2009, Fig. 1). The conditions are logically and, according to the figures, adequately explained. The geological structure of Zadlog seems very simple for the otherwise complex territory of Idrija. However, a quick geological examination of the central part of Zadloško polje revealed that the geological conditions are quite different. This was indeed reason enough for a renewed, more detailed geological survey of Zadlog and its surrounding area. It revealed that Zadloško polje and its surroundings have a more complex structural-geological composition than previously believed, which is hardly recognizable due to the naturally level terrain, continuous farming and extensive land improvement works. There are few discussions of the Zadlog polje: before the results of detailed fieldwork presented in this research and the identification of complex structural-tectonic conditions, Zadlog was on a geological map represented only in his general features. Although the hydrological conditions were generally known, no one had yet considered them in the wider hydrological context. The findings of the new structural-geological mapping presented here can be used to explain the position of the polje within the broader structural situation of the area, the formation of the karst polje, the position and formation of swallets, and to explain general hydrological and morphological features and how it fits into the broader geological structure of the Črni Vrh plateau and wider Idrija region. The formation of the initial plain of the karst polje is in the existing karst literature often associated with tension conditions (Gams 1978, Vrabec, 1994; Gracia et al., 2003; Doğan et al., 2017), while the formation of the karst polje in the context of thrust tectonics has not yet been discussed.

General features of Zadloško polje

The geographical features of Zadloško polje were discussed in 1968 by Habič in his PhD thesis (Habič, 1968). Only some data from his work that is relevant to this discussion is summarised here.

The extensive plain of Zadlog is located on the western edge of the Črni Vrh plateau at an altitude of between 716 and 720 m. To the north and east towards the Idrijca valley, Idrijski Log and

vseh strani obdana z višjim vzpetinami, zato je na geografskih kartah večkrat označena tudi kot Zadloška kotlina. Ne glede na različne geografske opredelitve bomo v nadaljevanju uporabljali poimenovanje Zadloško polje, ali pa samo Zadlog.

Pogled na natisnjeno idrijsko geološko karto v merilu 1 : 25.000 kaže, da ima območje Zadloškega polja z okolico preprosto in enostavno zgradbo (Mlakar & Čar, 2009, sl. 1). Razmere so logično in, glede na podatke, primerno razložene. Za sicer geološko zapleteno idrijsko ozemlje izgleda geološka zgradba Zadloga zelo enostavna. Vendar je že hiter geološki ogled osrednjega dela Zadloškega polja pokazal, da so geološke razmere očitno drugačne. Seveda je bil to zadosten razlog za ponovno, natančnejše geološko kartiranje Zadloga in okolice. Pokazalo se je, da ima Zadloško polje z okolico bolj zapleteno strukturno-geološko zgradbo od predhodno razumljene, ki je zaradi naravne izravnave terena, stalnega kmetovanja in obsežnih melioracijskih del težje prepoznavna. O Zadloški izravnavi obstaja le malo razprav. Pred, v tej raziskavi predstavljenimi rezultati podrobnega terenskega dela in ugotovitvijo zapletenih strukturno-tektonskih razmer, je bil Zadlog na geoloških kartah izrisan samo v svojih splošnih potezah. Hidrološke razmere so bile sicer v splošnem znane, toda nihče jih še ni obravnaval v širšem hidrološkem kontekstu. Na podlagi ugotovitev tukaj predstavljenih rezultatov strukturno-geološkega kartiranja pa se da dobro razložiti lego polja v širši strukturni zgradbi ozemlja, nastanek kraškega polja, lego in nastanek ponikev in pojasniti splošne hidrološke in morfološke značilnosti ter vpetost v širšo geološko strukturo Črnovrške planote in Idrijskega ozemlja. Nastanek začetne uravnave kraškega polja se v obstoječi krasoslovni literaturi pogosto povezuje z nateznimi razmerami (Gams, 1978; Vrabec, 1994; Gracia et al., 2003; Doğan et al., 2017), medtem ko nastanek kraškega polja v okviru narivne tektonike še ni bil obravnavan.

Splošne značilnosti Zadloškega polja

Geografske značilnosti Zadloškega polja je obravnaval Habič v svojem doktoratu leta 1968 (Habič, 1968). Iz njegovega dela povzemamo le nekaj, za naše razpravljanje pomembnih podatkov.

Obsežna zadloška uravnava na zahodnem obrobju Črnovrške planote leži na višini med 716 in 720 m. Na severu in vzhodu proti dolini Idrijce, Idrijskemu Logu in Koševniku je obrobljena z nižjim grebenom s številnimi manjšimi dolinami, ki se iztekajo na eni strani proti Zadlogu, na

Koševnik, it is lined by a lower ridge with numerous smaller valleys leading towards Zadlog on one side and Idrijski Log on the other (Fig. 1A, B). The ridge, which runs only some 40 m above the present-day base of the plain, is interrupted by a number of indistinct peaks rising up to no more than 100 m above the base of Zadloško polje. The lowest points of the ridge are the distinct pass close to the Podtisov Vrh peak at 724 m, where a forest road from the Belca valley leads to Zadlog, and the pass near Kočar (above Ivanšek) (735 m), where the road from Zadlog leads to Idrijski Log and Idrijska Bela. On the southern edge of Zadlog, there are steep and poorly dissected slopes with ca. 1100 m high peaks. The only notch in the slope is the Bukovska Rovna ledge (782 m) extending into a distinctly dry and heavily karstified lowered area towards Mrzli Log and the pass near Šoštar, where the main road leads to Črni Vrh. Here is also the lowest point of the edge of Zadloško polje at an altitude of 718 m. Given the above-mentioned data, Zadlog could indeed be referred to as a shallow basin.

drugi strani pa proti Idrijskemu Logu (sl. 1A, B). Greben, ki poteka le kakih 40 m nad današnjim dnom izravnave, je prekinjen z nekaj neizrazitimi vrhovi, ki se vzpenjajo največ do 100 m nad dnom Zadloškega polja. Najnižji točki grebena sta izrazita prehod pri Podtisovem Vrhu na višini 724 m, kjer je na Zadlog speljana gozdna cesta iz doline Belce, in prelaz pri Kočarju (nad Ivanškom) (735 m), kjer poteka cesta iz Zadloga proti Idrijskemu Logu in Idrijski Beli. Na južnem obrobju Zadloga ležijo strma in slabo razčlenjena pobočja z vrhovi na višini okrog 1100 m. Zarezo v pobočju predstavlja le polica Bukovska Rovna (782 m), ki se podaljša v izrazito suho in močno zakraselo znižanje proti Mrzlemu Logu, ter prehod pri Šoštarju, kjer poteka glavna cesta proti Črnemu Vrhu. Tu je tudi najnižja točka obrobja Zadloškega polja na višini 718 m. Iz zgornjih podatkov izhaja, da ima Zadlog značilnosti plitve kotline.

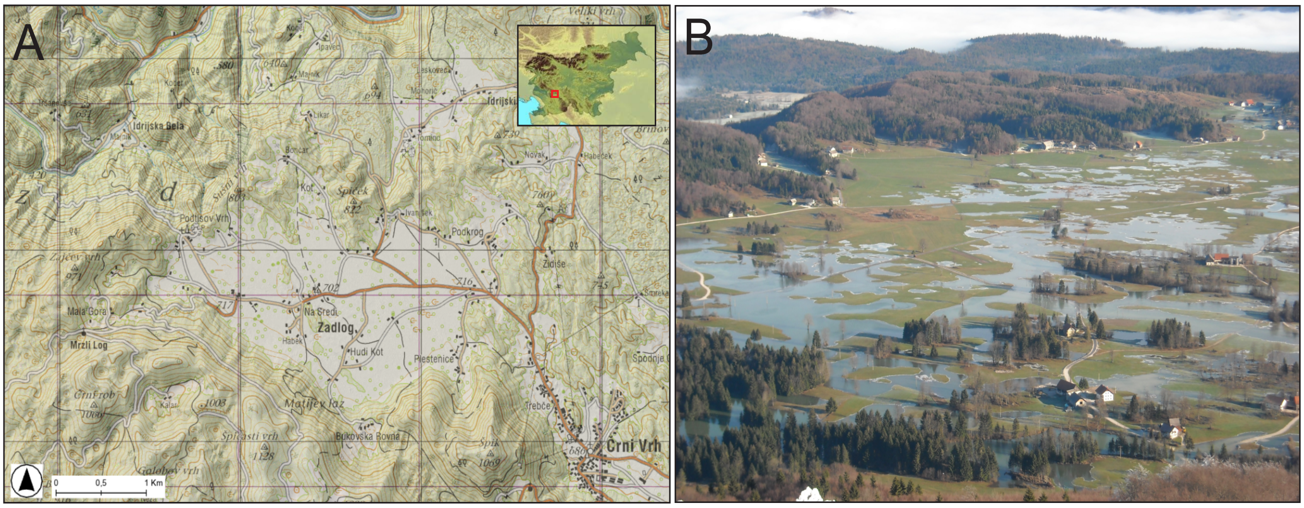

Fig. 1. A – Location and basic topographic features of the Zadloško polje area. B – View on Zadloško polje during floods (18. 12. 2009). Photo: Bojana Zagoda.

Sl. 1. A – Lokacija in osnovne topografske značilnosti območja Zadloškega polja. B – Pogled na Zadloško polje v času poplav (18. 12. 2009). Foto: Bojana Zagoda.

Geographers and geologists alike write about how the Idrijca, the Belca and the Kanomljica once probably flowed together across the Zadloško polje, the Črni Vrh plateau and further along the Hotenjsko podolje valley system towards the Ljubljanica (Savnik, 1959; Melik, 1963; Mlakar, 2002). The flow of the watercourses in Idrija towards the Ljubljanica river was discussed in great detail and supported by geomorphological data by Mlakar (2002). Such an assessment is not supported by any material evidence. Habič (1968) had already determined that on the Zadlog-Črni Vrh plateau and the Hotenjsko podolje area between

O tem, da naj bi nekdaj Idrijca, Belca in Kanomljica združeno tekale čez Zadloško polje, Črnovrško planoto in dalje po Hotenjskem podolju proti Ljubljanici, so pisali tako starejši geografi kot tudi geologi (Savnik, 1959; Melik, 1963; Mlakar, 2002). Še posebej podrobno in podprto z geološkimi in morfološkimi podatki je pretok idrijskih vodotokov proti Ljubljanici obravnaval Mlakar (2002). Materialnih dokazov za tako mnenje ne navaja. Že Habič (1968) je ugotovil, da na Zadloško-Črnovrški planoti in Hotenjskem podolju med Godovičem in Hotedršico ni sledov rečne erozije ali prodov, ki bi vsekakor morali biti

Godovič and Hotedršica there are no traces of fluvial erosion or cobble, which should certainly have been preserved, even if only here and there and in marginal amounts. Zadloško polje is covered by an unevenly thick yellowish dolomitic clayey eluvium with rare, small and irregular millimetre-sized chert clasts showing no signs of transport. The clasts were not studied in detail, however, they represent sparingly soluble residue and certainly originate from the parent rock. The thickness of eluvium is locally increased in some lower parts of the terrain. The internal texture shows that it was transported for only a short distance.

The entire Zadloško polje was artificially levelled (ameliorated) to a considerable extent. To get land for farming, the lower dolomite outcrops were mostly levelled out. At the northern and central parts of Zadloško polje, however, there are still dolomite hummocks rising about 1.5 to some metres from the plain that mainly run northwest to southeast and are aligned with strata of dolomite. They are either bare or covered with shallow turf, shrubbery, individual trees or sparse woods. Nowadays it is impossible to deduce how many dolines and other karst formations have been filled. Given the conditions elsewhere on the dolomitic part of the Črni Vrh plateau (Črni Vrh, Predgriže, Koševnik and Idrijski Log), which has comparable structural composition (Zagoda, 2004), it can be concluded that the Upper Triassic dolomite in Zadlog is also relatively poorly karstified, which is as well supported by geological mapping of the same kind of dolomite in a comparable structural position in Idrijski Log and Predgriže. However, there are some morphologically distinctive sinking areas with ponors on Zadloško polje.

The influence of the Pleistocene glaciation on the morphology of Zadlog has not yet been studied and is currently unknown. Undoubtedly, such cold climatic conditions influenced the faster denudation of dolomites in the hinterland and more intense transport of the weathered material to the karst polje.

Geological structure of Zadloško polje

Earlier data

Existing geological maps (Buser et al., 1967; Mlakar, 1969; Pleničar, 1970; Mlakar & Čar, 2009) suggest that the structure of Zadloško polje and its wider surroundings is very simple. The Postojna sheet from the Basic geological map (Osnovna geološka karta, OGK) and the interpreter to this sheet (Pleničar et al., 1970) show that Zadlog and its wider surroundings are made of thinly to moderately stratified Upper Triassic Norian-Rhaetian

ohranjeni, pa čeprav le tu in tam in v neznatnih sledovih. Zadloško polje sicer prekriva neenakomerno debela dolomitna rumenkasta glinasta preperina z redkimi, majhnimi in nepravilnimi klasti roženca milimetrskih dimenzij, ki ne kažejo znakov premeščanja, saj so povsem nepravilnih oblik. Klastov na tem mestu nismo raziskovali, vendar predstavljajo težje topni ostanek in zagotovo izhajajo iz matične kamnine. Preperina je na nekaterih nižje ležečih predelih lokalno debelejša. Notranja tekstura kaže, da je preložena le na kratko razdaljo.

Celotno Zadloško polje je bilo s posegi v dobršni meri umetno izravnano (meliorirano). Za potrebe kmetovanja so bile izravnane predvsem nižje dolomitne golice. V severnem in osrednjem delu Zadloškega polja pa še vedno štrle iz izravnave od 1,5 do nekaj metrov visoke dolomitne grbine, ki potekajo v glavnem v smeri severozahod – jugovzhod, skladno s slemenitvijo dolomitnih plasti. So gole ali pa pokrite s plitvo rušo, grmovjem, posameznimi drevesi ali redkim gozdom. Koliko je v podlagi zasutih vrtač in drugih kraških oblik ni raziskano. Iz razmer drugod na dolomitnem delu Črnovrške planote (Črni Vrh, Predgriže, Koševnik in Idrijski Log), ki ima primerljivo strukturno zgradbo (Zagoda, 2004), lahko sklepamo, da je zgornjetriasni dolomit tudi v Zadlogu razmeroma slabo zakrasel. To podpira tudi geološko kartiranje enakega dolomita v primerljivi strukturni legi v Idrijskem Logu in Predgrižah. Se pa na Zadloškem polju nahaja nekaj morfološko izrazitih ponikalnih območij.

Vpliv pleistocenske poledenitve na morfologijo Zadloga še ni bil preučen in ga ta hip ne poznamo. Nedvomno pa so hladnejše podnebne razmere vplivale na hitrejšo denudacijo dolomitov v zaledju polja in intenzivnejše površinsko premeščanje preperine na izravnavo.

Geološka zgradba Zadloškega polja

Starejši podatki

Pogled na dosedanje geološke karte (Buser et al., 1967; Mlakar, 1969; Pleničar, 1970; Mlakar & Čar, 2009) pokaže, da naj bi bilo Zadloško polje s širšo okolico zelo preprosto zgrajeno. Glede na OGK list Postojna in tolmača k temu listu (Pleničar et al., 1970) vidimo, da Zadlog s širšo okolico gradi tanko do srednje plastnati zgornjetriasni norijsko-retijski (ti. glavni) dolomit. Dno zadloške uravnave v celoti pokrivajo kvartarni sedimenti – nanosi rek in potokov (Pleničar et al., 1970). Od terciarne tektonike je dolomite (so-called main dolomite). The base of the Zadlog plain is entirely covered by quaternary sediments – river and stream deposits (Pleničar et al., 1970). Regarding tertiary tectonics, only the thrust line between the Lower Cretaceous limestone of the first 'slice' (today: Koševnik nappe slice) and the Upper Triassic dolomite of the second 'slice' (today: Čekovnik thrust slice) running north and east of Zadlog along the plain of Idrijski Log and Koševnik is delineated. No other potential tectonic elements have been identified.

Zadloško polje was not remapped during the production of the new 1:25,000 scale geological map (Mlakar & Čar, 2009). The conditions thus remain nearly identical as when delineated and described by Mlakar on his 1969 geological map, while the new map includes corrections of thrust unit designations. According to Placer's (Placer, 1981, 2008) thrust dissection of western Slovenia and his recent oral proposal, the *Hrušica nappe* lies in the deeper bedrock of the territory of Idrija, and over it follow the *Koševnik, Čekovnik and Kanomlje interjacent slice* (*nappe slice* in this paper), covered by the Lower thrust block of Trnovo nappe, which is nowadays divided into four internal overthrust bodies (Mlakar & Čar, 2009; Čar, 2010; Čar et al., 2021). The entire Zadloško polje and its wider surroundings consist of two thrust packages of Upper Triassic Norian-Rhaetian dolomite. The northern border of Zadloško polje and a large portion of the central part belong to the *Čekovik nappe slice*. The Upper Triassic dolomite has a normal stratigraphic position according to recent findings (Čar, 2010). The southern slopes towards Špičasti vrh (822 m), Mrzli Log and Špik also consist of the Norian–Rhaetian dolomite, but it belongs to the Trnovo nappe overthrust unit, i.e. the Tičnica inner thrust sheet (Čar, 2010). The thrust line between the two units should run along the southern edges of Zadlog, the same way as it is delineated on Mlakar's map (1969). Two fault lines are delineated on the map: the first one runs from Mrzli Log across Bukovska Rovna, intersects Zadloško polje and continues across Kotenjski rob (along the location Kot) into the Belca valley, while the second fault intersects the eastern part of Zadloško polje. It enters the polje in Plestenice and continues past Klančar and across Koševnik into the Idrijca valley. This map dating in 1969 also shows that the base of Zadloško polje is covered by alluvial deposits (Mlakar & Čar, 2009).

Previous geological maps (Pleničar, 1970; Mlakar, 1969; Mlakar & Čar, 2009) did not take into account the hydrological conditions in Zadlog and the remarks on the coverage of the polje floor already observed and written down by Habič

izrisana le narivnica med spodnjekrednim apnencem prve luske (danes: Koševniška krovna luska) in zgornjetriasnim dolomitom druge luske (danes: Čekovniška krovna luska), ki poteka severno in vzhodno od Zadloga po uravnavi Idrijskega Loga in Koševnika. Drugi tektonski elementi niso bili ugotovljeni.

Pri izdelavi nove geološke karte v merilu 1: 25 000 (Mlakar & Čar, 2009). Zadloškega polja nismo na novo kartirali. Razmere zato ostajajo skoraj enake, kot jih je izrisal in opisal Mlakar na svoji geološki karti iz leta 1969, vendar s popravki poimenovanja narivnih enot. Soglasno s Placerjevo narivno razčlenitvijo zahodne Slovenije in njegovim novejšim ustnim predlogom (Placer, 1981, 2008) leži v globlji podlagi Idrijskega ozemlja *Hrušiški pokrov,* nad njim si sledijo *Koševniška, Čekovniška in Kanomeljska krovna luska*, pokriva jih spodnji narivni blok Trnovskega pokrova, ki je danes razdeljen na štiri notranje narivne grude (Mlakar & Čar, 2009; Čar, 2010; Čar et al., 2021). Celotno Zadloško polje in njegovo širšo okolico gradita dva narivna paketa zgornjetriasnega norijsko-retijskega dolomita. Severno obrobje Zadloškega polja in velik delež osrednjega dela pripada *Čekovniški krovni luski*. Zgornjetriasni dolomit ima po novejših ugotovitvah normalno stratigrafsko lego (Čar, 2010). Južna pobočja proti Špičastemu vrhu (822 m), Mrzlemu Logu in Špiku gradi prav tako norijsko-retijski dolomit, le da pripada narivni enoti *Trnovskega pokrova* in sicer *Tičenski notranji narivni grudi* (Čar, 2010). Narivnica med obema enotama naj bi potekala po južnem obrobju Zadloga, enako kot je izrisana na Mlakarjevi karti (1969). Na karti sta izrisani dve prelomni liniji: prva poteka iz Mrzlega Loga čez Bukovsko Rovno, seka Zadloško polje in se nadaljuje čez Kotenjski rob (po lokaciji Kot) v dolino Belce, drugi prelom pa seka vzhodni del Zadloškega polja. Na polje prihaja v Plestenicah in se nadaljuje mimo Klančarja in čez Koševnik v dolino Idrijce. Tudi na tej karti iz leta 1969 je izrisano, da prekrivajo dno Zadloškega polja aluvialni nanosi (Mlakar & Čar, 2009).

Pri izdelavi dosedanjih geoloških kart (Pleničar, 1970; Mlakar 1969; Mlakar & Čar, 2009) niso upoštevane hidrološke razmere v Zadlogu in pripombe o pokritosti dna polja, ki jih je ugotovil in zapisal že Habič (1968). To je bil povod za podrobnejše geološko kartiranje Zadloga z obrobjem v merilu 1 : 5000.

(1968). This prompted a more detailed geological mapping of Zadlog and its edges at a scale of 1:5,000.

Fault tectonics

For an easier interpretation and a better understanding of the thrust and thrust–shear deformations on Zadloško polje and its edges, fault tectonics are discussed first. The fault and thrust fracturing nomenclature below and their variability in horizontal and vertical directions is in line with the one published in the discussion by Čar (2018). The data presented are the result of detailed structural-geological mapping, which was carried out for the purposes of the present research.

In the western part of Zadloško polje, from its edges eastwards follow the *Figar, Podtis and Zadlog faults* (Fig. 2). The faults are dextral strike-slips of varying strength and are oriented northwest–southeast. They are grouped together in the *western Zadlog set of faults*. The *Figar fault* is up to 300 m wide, consists of four narrow crushed zones and strong interjacent broken zones, has a general 80° dip to the southwest and runs over the far western edge of Zadloško polje (Fig. 2). The southwestern part of the fault zone transitions over the steep slope on the southern edges of Zadlog into a wide fissure zone, which is typical of the longitudinal changes in fault zones (Čar, 2018). The northeastern part runs along the foot of the Špičasti vrh and later joins the Zadlog fault. The double *Podtis fault* with an approximately 150 m wide fault zone leads from Belca valley across the Podtisov Vrh saddle. The Podtisov Vrh saddle formed in crushed zones with an 80° dip to the southwest (Fig. 3 A). The fault zone runs across the western part of Zadloško polje and joins the strong Zadlog fault, which runs from the Belca valley to the edge of Zadloško polje at Gozdnik and then progresses across the polje all the way to Bukovska Rovna (Fig. 2). The strong fault zone of the Zadlog fault is up to 200 m wide and progresses towards Mrzli Log and Kanji Dol. Within this zone formed a deepened, morphologically dissected, strongly karstified and lowered zone which leads between Bukovska Rovna and Mrzli Log. The degree of rock fracturing varies along the zone from crushed to widely fractured, and fissured zones of varying strength can be observed in the outer fault zones.

The eastern part of Zadloško polje and its edges are also intersected by a series of faults, grouped together in the *eastern Zadlog set of faults*. Running from west to east: *Plestenice, Klančar, Črni Vrh, Abraht (named after a farm)* and stronger *Pred-*

Prelomna tektonika

Za lažjo razlago in boljše razumevanja narivnih in obnarivnih deformacij na Zadloškem polju in njegovem obrobju obravnavamo najprej prelomno tektoniko. Poimenovanje pretrtosti ob prelomih in narivih ter njihovo spreminjanje v horizontalni in vertikalni smeri je soglasno z nomenklaturo v Čarjevi razpravi (2018). Predstavljeni podatki so rezultat podrobnega strukturno-geološkega kartiranja, ki je bilo izvedeno za namene te raziskave.

V zahodnem delu Zadloškega polja sledijo od njegovega obrobja proti vzhodu *Figarjev, Podtisov in Zadloški prelom* (sl. 2). Prelomi so desno-zmični, različno močni in imajo smer severozahod – jugovzhod. Združujemo jih v *zahodni zadloški prelomni snop*. Na skrajnem zahodnem obrobju Zadloškega polja poteka do 300 m širok, iz štirih ožjih zdrobljenih con in močnih vmesnih porušenih con zgrajen *Figarjev prelom* s splošnim vpadom 80° proti jugozahodu (sl. 2). Jugozahodni del prelomne cone prehaja v strmem pobočju južnega obrobja Zadloga v široko razpoklinsko cono, značilno za vzdolžno spreminjanje prelomnih con (Čar, 2018). Severovzhodni del poteka vzdolž vznožja Špičastega vrha in se v nadaljevanju priključi na *Zadloški prelom*. Čez sedlo Podtisov Vrh poteka iz doline Belce dvojni *Podtisov prelom* z okrog 150 m široko prelomno cono. Sedlo Podtisov Vrh se je oblikovalo v zdrobljenih conah z vpadom 80° proti jugozahodu (sl. 3A). Prelomna cona poteka čez zahodni del Zadloškega polja in se v nadaljevanju priključi na močan Zadloški prelom, ki poteka iz doline Belce do roba Zadloškega polja pri Gozdniku in se nadaljuje čez polje do Bukovske Rovne (sl. 2). Močna prelomna cona Zadloškega preloma je široka do 200 m in se nadaljuje proti Mrzlemu Logu in Kanjemu Dolu. V njej se je oblikovala poglobljena, morfološko razgibana, močno zakrasela in znižana cona, ki poteka med Bukovsko Rovno in Mrzlim Logom. Stopnja pretrtosti kamnin se vzdolž cone spreminja od zdrobljenih do širokih porušenih con, v zunanjih prelomnih conah opazujemo različno močne razpoklinske cone.

Tudi vzhodni del Zadloškega polja in njeno obrobje prav tako seka niz prelomov, združujemo jih v *vzhodni zadloški prelomni snop*. Od zahoda proti vzhodu si sledijo: *Plesteniški, Klančarjev, Črnovrški, Abrahtov* (ime po kmetiji) in močnejši *Predgriški prelom* (sl. 2). Plesteniški prelom je v severnem delu Zadloga usmerjen od severozahoda proti jugovzhodu, v nadaljevanju se približuje močni in široki coni Zadloškega preloma in *griže fault* (Fig. 2). The Plestenice fault runs northwest to southeast in the northern part of Zadlog, and then it approaches the strong and wide Zadlog fault zone and joins it southeast of Mrzli Log outside of this map. Other faults have NNW-SSE direction in the northern part of the geologic map and later turn to NW-SE direction and predominantly appear as relatively wide broken and fissured zones in the dolomite. The fractured zones in both of the examined Zadlog set of faults are densely stacked with only 100 to 300 m distances in-between on average. All faults are dextral strike-slips. The displacements along these faults would need to be determined more precisely, but we estimate that they are relatively small.

se nanjo priključi jugovzhodno od Mrzlega Loga izven okvirja naše karte. Ostali prelomi imajo na severnem delu geološke karte smer SSZ-JJV, nato pa povijejo v smer SZ-JV in se kažejo predvsem kot sorazmerno široke porušene in razpoklinske cone v dolomitu. V obeh obravnavanih prelomnih snopih se pretrte cone nizajo na gosto, med njimi so razdalje v povprečju le od 100 do 300 m. Pri vseh prelomih gre za desne zmike. Kakšni so premiki ob njih, bi bilo potrebno natančnejše ugotoviti, vendar ocenjujemo, da so relativno majhni.

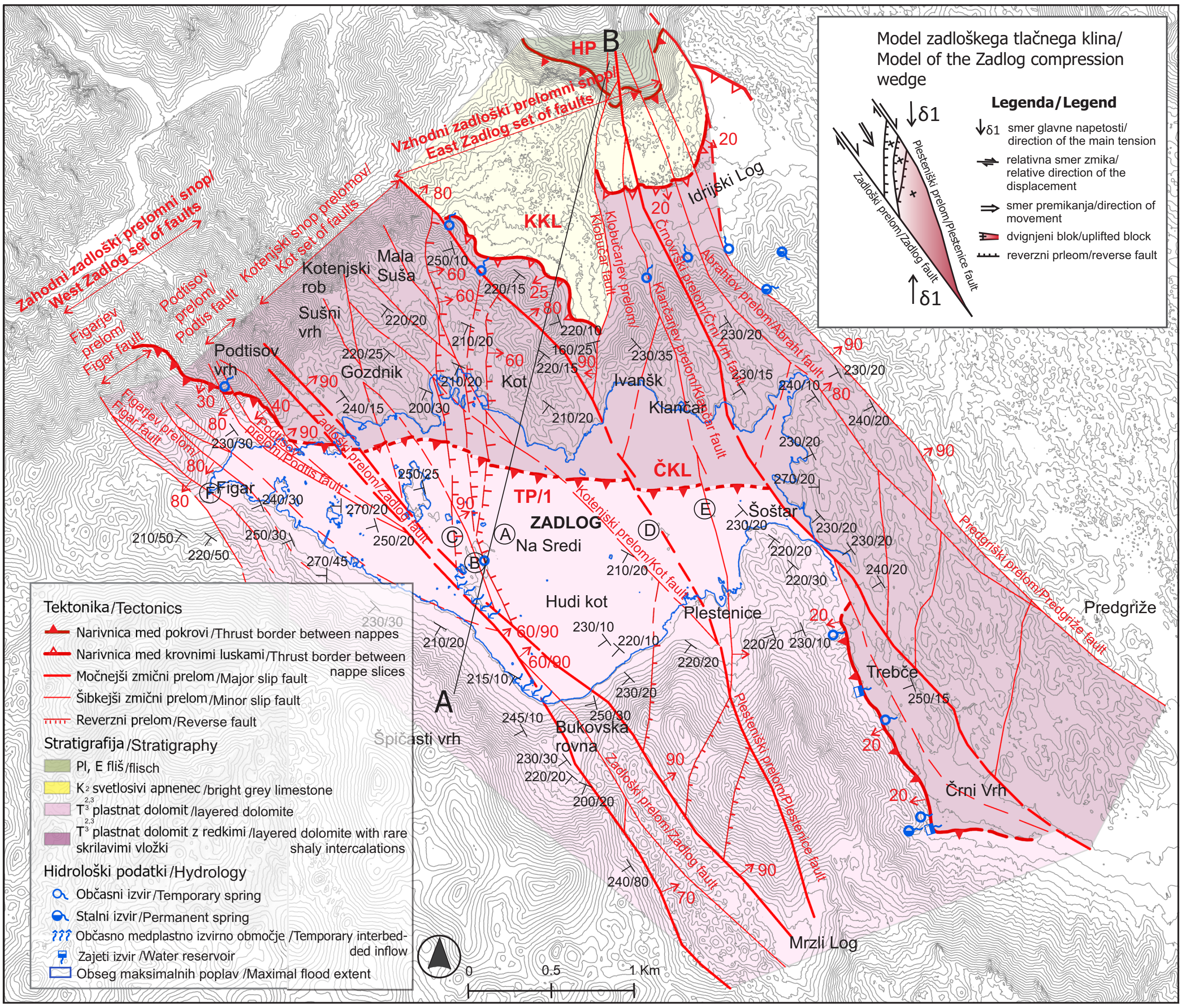

Fig. 2. Structural-geological map of Zadloško polje. The AB profile is shown in Figure 4. HP – Hrušica nappe, TP/1 – Lower thrust block of Trnovo nappe, ČKL – Čekovnik nape slice, KKL – Koševnik nappe slice. Ponor zones: A – Štefkova rupa, B – Ponikva, C – Ponor at Cigale farm, D – Štirnska rupa, E – no name ponor zone, F – Figar ponor zone.

Sl. 2. Strukturno-geološka karta Zadloškega polja. Profil AB je prikazan na sliki 4. HP – Hrušiški pokrov, TP/1 – Spodnji narivni blok Trnovskega pokrova, ČKL – Čekovniška krovna luska, KKL – Koševniška krovna luska. Ponikalna območja: A – Štefkova rupa, B – Ponikva, C – Ponikva pri kmetiji Cigale, D – Štirnska rupa, E – ponikalno območje brez imena, F – Figarjevo ponikalno območje.

The central part of Zadlog, which is loctated between the Zadlog and Plestenice faults, is about 1300 m wide at the northwestern edge of the polje and gradually becomes narrower towards the southeast (Fig. 2). It encompasses Hudi Kot on the southern edges of the polje, the central part of the polje Na Sredi and the levelled extensions between numerous dolomite outcrops towards Sušni vrh, Mala Suša and Kot in the northwest. The faults intersecting the central part of Zadloško polje are genetically distinct. The eastern faults branch off the Plestenice fault in the area of Kot and Mala Suša, and lean on the approximately 300 m long area of the Zadlog fault at the Na Sredi site. This is the 'Kotenjski niz' (after the hamlet of Kot) set of three morphologically less distinct, reverse faults in the north–south direction. According to the geological data, they are the result of secondary pressure conditions between the Plestenice fault on the one hand and the Zadlog fault on the other. Both dextral strike-slip faults are relatively strong and, as already mentioned, converge and merge towards the southeast. A pressure wedge has formed between them where weak and branched reverse faults formed due to intense dextral strike-slips (Zadlog compression wedge model, Fig. 2). They dip about 60° to the east, which is in line with their origin. Along these there are slightly uplifted eastern blocks. The western set consists of several weaker branched out strike-slip faults of Kot with narrow fault zones. On the northwestern edges of Zadloško polje they run in the NW–SE direction, then gently bend in the SSW–SSE direction, intertwine with eastern set of reverse faults zones at location Na Sredi and lean on the Zadlog fault at the same section as the reverse faults. The entwinement at Na Sredi shows that reverse faults are slightly older as they are intersected by strike-slip faults (Fig. 2). Intersections of reverse and strike-slip fault zones are connected to the sinking zones at Na Sredi (Fig. 2).

Thrust tectonics

Reflecting on the hitherto inconsistent designation of the different types of thrust units, as well as the differing graphic tracing of thrust contacts between them on geological maps, a table with the subdivision and designation of individual thrust elements was presented in 2021 (Čar et al., 2021).

The deeper bedrock of the Idrija territory contains Upper Cretaceous limestones and through erosion overlying Palaeocene-Eocene flysch rocks of the Hrušica nappe (HP) (Fig. 4), which are visible at the southern margin of the Strug tectonic window. According to older literature, the above-mentioned thrust unit is believed to be native bedrock of the Idrija territory (Mlakar, 1969, Fig. 5; Placer, 1973, 1981).

Osrednji del Zadloga med Zadloškim in Plesteniškim prelomom je na severozahodnem robu polja širok okrog 1300 m, proti jugovzhodu pa se postopno oži (sl. 2). Zaobjema Hudi Kot na južnem obrobju polja, osrednji del polja Na Sredi in izravnane podaljške med številnimi dolomitnimi izdanki proti Sušnemu vrhu, Mali Suši in Kotu na severozahodu. Prelomi, ki sekajo osrednji del Zadloškega polja, so genetsko različni. Vzhodni se odcepijo od Plesteniškega preloma na območju Kota in Male Suše, in se naslanjajo v okrog 300 m dolgem območju na Zadloški prelom na lokaciji Na Sredi. Gre za *Kotenjski* (po zaselku Kot) *niz* treh morfološko manj izrazitih, reverznih prelomov v smeri sever-jug. Glede na geološke podatke ugotavljamo, da so rezultat sekundarnih tlačnih razmer med Plesteniškim prelomom na eni in Zadloškim na drugi strani. Oba desno zmična preloma sta razmeroma močna in se proti jugovzhodu, kot smo že omenili, približujeta in združita. Med njima je nastal tlačni klin, v katerem so ob intenzivnih desnih zmikih nastali šibki reverzni prelomi (Model zadloškega tlačnega klina, sl. 2). Vpadajo okrog 60° proti vzhodu, kar je v soglasju z njihovim nastankom. Ob njih so vzhodni bloki nekoliko dvignjeni. Zahodnejši snop sestavlja več šibkejših in razvejanih Kotenjskih zmičnih prelomov z ozkimi prelomnimi conami. Na severozahodnem obrobju Zadloškega polja potekajo v smeri SZ-JV, nato povijejo rahlo v smer SSZ-JJV. Na lokaciji Na Sredi se prepletejo s conami vzhodnega reverznega prelomnega snopa in naslanjajo na Zadloški prelom na istem odseku kot reverzni prelomi. Pri prepletanju Na Sredi vidimo, da so reverzni prelomi nekoliko starejši, saj jih zmični prelomi sekajo (sl. 2). Na sekanje omenjenih reverznih in zmičnih prelomnih con so vezana ponikalna območja Na Sredi (sl. 2).

Narivna tektonika

Ob premisleku o doslej neenotnem poimenovanju različnih tipov narivnih enot, kot tudi zaradi različnih grafičnih izrisov narivnih stikov med njimi na geoloških kartah smo leta 2021 podali preglednico razčlenitve in poimenovanje posameznih narivnih elementov (Čar et al., 2021).

V globlji podlagi idrijskega območja ležijo zgornjekredni apnenci in erozijsko na njih paleocensko-eocenske flišne kamnine Hrušiškega pokrova (HP) (sl. 4), ki se na obravnavanem območju pojavijo v južnem obrobju Tektonskega okna Strug. Po starejši literaturi naj bi bila omenjena narivna enota avtohtona podlaga idrijskega območja (Mlakar, 1969, sl. 5; Placer, 1973, In the Idrija area, Lower and Upper Cretaceous limestone of the Koševnik nappe slice (KKL) is thrust onto the rocks of the Hrušica nappe in a normal position and measures 100 to 500 m in thickness (Fig. 4). In view of the geological conditions in the Strug tectonic window and Idrijska Bela, the Koševnik nappe slice underneath Zadloško polje mainly consists of Upper Cretaceous limestone, but may deeper down already continuously transition into Lower Cretaceous limestones with rare intercalations of early diagenetic dolomite. Along the thrust line, soft flysch rocks are often pushed out in such a way that Upper Cretaceous limestones of the Hrušica nappe are directly overlain by Lower or Upper Cretaceous limestones of the Koševnik nappe slice (Fig. 4). The Koševnik nappe slice is covered by Norian-Rhaetian dolomite of the Čekovnik nappe slice (ČKL) in its normal position. The morphologically very distinctive thrust line between the two nappe units runs along the northern preiphery of Idrijski Log (Zagoda, 2004) (Fig. 2) and then crosses Predgriško polje east of Črni Vrh (Mlakar & Čar, 2009). The northern edges and northern part of Zadloško polje consist of Upper Triassic dolomite of the Čekovnik nappe slice. The remaining part of Zadlog as well as its southern and western edges consist of the Trnovo nappe Norian-Rhaetian dolomite (TP/1 – the Trnovo nappe underthrust block). High below the northern edge of Trnovski gozd (not shown in Fig. 2), the Norian-Rhaetian dolomite of the Trnovo nappe is sliced by another thrust plane (Čar, 2010). Over it lies the Norian-Rhaetian dolomite with continuous transitions to Jurassic limestones of the next thrust unit (TP/2 – Trnovo nappe overthrust block, outside Fig. 2).

The Norian-Rhaetian dolomite has a normal position and practically identical dip and strike in the Čekovnik nappe slice as well as in the lower part of the Trnovo nappe (TP/1). The strata dip from 10 to 30° to the southwest. The dolomite is generally medium to thick-bedded (10 to 30 cm), with thinner (10 cm) or thicker strata (up to one metre) only as an exception. The dolomite is light to dark grey, here and there nearly white, and most often laminated or stromatolitic. In some places, thinly coated flat pebble conglomerate can be observed on the top surface. In the Norian-Rhaetian dolomite sequence of the Čekovnik nappe slice, interbedded claystone intercalations and rare strata with fine oncoids occur in the lower part of the sequence in the Belca valley. Thin interbedded intercalations of shaly claystone and dolomitic marlstone occur only above Carnian clastic rocks in the Norian-Rhaetian dolomite in the Idrija area. This indicates that the dolomite of the Čekovnik nappe slice is part of the lower Norian-Rhaetian dolomite sequence. Within the Trnovo nappe, there are no shaly

1981). Na Idrijskem je na kamnine Hrušiškega pokrova narinjen spodnje in zgornjekredni apnenec Koševniške krovne luske (KKL) v normalni legi in debelini od 100 do 500 m (sl. 4). Glede na geološke razmere v Tektonskem oknu Strug in Idrijski Beli gradi Koševniško krovno lusko pod Zadloškim poljem predvsem zgornjekredni apnenec, v globljih delih pa že lahko zvezno prehaja v spodnjekredne apnence z redkimi vložki zgodnjediagenetskega dolomita. Ob narivnici so mehke flišne kamnine pogosto iztisnjene tako, da na zgornjekrednih apnencih Hrušiškega pokrova ležijo neposredno spodnje ali zgornjekredni apnenci Koševniške krovne luske (sl. 4). Koševniško krovno lusko prekriva norijsko-retijski dolomit Čekovniške krovne luske (ČKL) v normalni legi. Morfološko zelo izrazita narivnica med krovnima enotama poteka po severnem obrobju Idrijskega Loga (Zagoda, 2004) (sl. 2), nato pa poteka čez Predgriško polje vzhodno od Črnega Vrha (Mlakar & Čar, 2009). Zgornjetriasni dolomit Čekovniške krovne luske gradi severno obrobje in severni del Zadloškega polja. Preostali del Zadloga in njegovo južno in zahodno obrobje je iz norijsko-retijskega dolomita Trnovskega pokrova (TP/1- spodnji narivni blok Trnovskega pokrova). Visoko pod severnim robom Trnovskega gozda (ni prikazano na karti sl. 2) reže norijsko-retijski dolomit Trnovskega pokrova še ena narivna ploskev (Čar, 2010). Nad njo leži norijsko-retijski dolomit z zveznimi prehodi v jurske apnence naslednje narivne enote (TP/2 - zgornji narivni blok Trnovskega pokrova, izven okvirja sl. 2).

Norijsko-retijski dolomit ima v Čekovniški krovni luski, kot tudi v spodnjem delu Trnovskega pokrova (TP/1) normalno lego in praktično enak vpad. Plasti vpadajo od 10 do 30° proti jugozahodu. Dolomit je v splošnem srednje do debelo (od 10 do 30 cm) plastnat, le izjemoma opazujemo tanjše plasti (10 cm) ali debele do enega metra. Dolomit je svetlo do temno siv, tu in tam skoraj bel, največkrat laminiran ali stromatoliten. Ponekod opazujemo na zgornji površini plasti tanke prevleke nadplimskega konglomerata. V zaporedju norijsko-retijskega dolomita Čekovniške krovne luske se v spodnjem delu plasti v dolini Belce pojavljajo medplastni vložki glinavca in redke plasti z drobnimi onkoidi. Tanki medplastni vložki skrilavega glinavca in dolomitnega laporovca se v norijsko-retijskem dolomitu na Idrijskem pojavljajo le nad karnijskimi klastiti. To kaže, da je dolomit Čekovniške krovne luske del spodnjega zaporedja norijsko-retijskega dolomita. V okviru Trnovskega pokrova v norijsko-retijskem marlstone intercalations in the Norian-Rhaetian dolomite. The same dip of strata and strong lithological similarity between the dolomites of both thrust units were an important reason why the thrust line between the Čekovnik nappe slice and the Trnovo nappe was previously delineated along the southern edges of Zadloško polje (Mlakar & Čar, 2009).

The thrust–shear deformations in the dolomites of both thrust units can be directly observed along the forest road Ipavšk–Podtisov Vrh on the slope of the Belca valley. The intensity and extent of the thrust–shear crushed zone varies, it is at least 10 to 15 m thick and gradually transitions to a several metres thick zone of less tectonically deformed dolomite. Within the crushed zone, the main thrust plane with a dip of 40 to 20° runs southwards. At Podtisov vrh (724 m), the thrust line veers to the western edges of Zadloško polje. An approximately 200 m wide zone of completely crushed dolomite has formed here as a result of a strong thrust–shear crushed zone intersecting the Podtis fault zone (Fig. 3A). A thrust-fault crushed zone with a tectonic (cataclastic) structure of 'meal, grit and detritus' is exposed in the larger sand quarry, where an intricate interplay of thrust and fault zones can be observed. Due to fault-induced deformations, sections of the thrust plane dip 60° to the southwest (230/60°). The thrust zone continues beneath the anthropogenically levelled and ameliorated bedrock of Zadloško polje and cannot be observed directly. Indirectly, the thrust line can be traced based on a distinctively levelled surface with no bedrock outcrops. Thrust line crosses the complex zone of the Zadlog fault, intersects the less disturbed part of the polje between the Zadlog and the Plestenice fault, and continues to the Črni Vrh fault on the western edge of Zadlog. Its course

dolomitu skrilavih laporastih vložkov ni. Prav enak vpad plasti in velika litološka podobnost med dolomitoma obeh narivnih enot je bil pomemben razlog, da je bila narivnica med Čekovniško krovno lusko in Trnovskim pokrovom doslej izrisana po južnem obrobju Zadloškega polja (Mlakar & Čar, 2009).

Obnarivne deformacije v dolomitih obeh narivnih enot lahko neposredno opazujemo ob gozdni cesti Ipavšk – Podtisov Vrh na pobočju doline Belce. Intenzivnost in obseg obnarivne zdrobljene cone se spreminja; debela je vsaj 10 do 15 m in postopno prehaja v več metrov debelo cono manj pretrtega dolomita. Znotraj zdrobljene cone poteka glavna narivna ploskev z vpadom 40 do 20° proti jugu. Pri Podtisovem Vrhu (724 m) se narivnica previje na zahodno obrobje Zadloškega polja. Tu je nastalo okrog 200 m široko območje povsem zdrobljenega dolomita, ki je rezultat močne obnarivne zdrobljene cone, ki jo seka cona Podtisovega preloma (sl. 3A). Narivno-prelomna zdrobljena cona s tektonsko (kataklastično) strukturo 'moka, zdrob in drobir' je odprta v večjem peskokopu, kjer lahko opazujemo zapleteno prepletanje narivnih in prelomnih con. Zaradi obprelomnih deformacij vpadajo odseki narivne ploskve za 60° proti jugozahodu (230/60°). Narivna cona se nadaljuje pod antropogeno izravnanim in melioriranim dnom Zadloškega polja in jo neposredno ne moremo opazovati. Posredno lahko narivnici sledimo na podlagi izrazito uravnanega terena brez izdankov matične kamnine. Narivnica prečka zapleteno cono Zadloškega preloma, seka manj pretrti del polja med Zadloškim in Plesteniškim prelomom in se nadaljuje do Črnovrškega preloma na zahodnem obrobju Zadloga. Njen potek

Fig. 3. A – thrust-fault crushed zone in a quarry at Podtisov Vrh on the western perimeter of Zadloško polje. B – A thrust crushed zone in a sand quarry at Trebče near Črni Vrh, southeast of Zadloško polje. Photo: Jože Čar.

Sl. 3. A – Narivno-prelomna zdrobljena cona v peskokopu pri Podtisovem Vrhu na zahodnem obodu Zadloškega polja. B – Narivna zdrobljena cona v peskokopu v Trebčah pri Črnem vrhu, jugovzhodno od Zadloškega polja. Foto: Jože Čar.

is also confirmed by the finding of pieces of cataclastic rocks in the field west of the Črni Vrh fault. The thrust line reappears about a kilometre further south in the sand quarry near the hamlet of Trebče at Črni Vrh, on the western side of the Črni Vrh fault, i.e. in the same structural block as in Zadloško polje. Further towards Črni Vrh, the thrust zone runs parallel to the fault zone of the Črni Vrh fault. In the Trebče sand quarry, the thrust line dips 20° to the southwest (Fig. 3B) and has the same dip all the way to Črni Vrh (Fig. 2).

Structural and hydrological conditions

The structural conditions and associated hydrological features of Zadloško polje are evident from the attached cross-section (Fig. 4). In addition to the geological data directly from the line of the cross-section, the geological structure of the wider area of the Črni Vrh plateau has also been taken into account. The profile is a geologically typical cross-section of the Idrija overthrust structure.

The cross-section starts at the Strug tectonic window in the Idrijca valley, where the Idrijca riverbed already cuts into Upper Cretaceous limestone and the overlying Palaeocene-Eocene flysch rocks of the Hrušica nappe. The cross-section then crosses the thrust contact between flysch rocks and Cretaceous limestones of the Koševnik nappe slice. The thrust contact dips approx. 25° to the south and southwest. The Cretaceous limestone underneath Zadloško polje is, based on geological mapping at the Strug tectonic window in Idrijski Log and Predgriže, presumed to be slightly folded into synclinals and anticlinals (Fig. 4). It is overthrust by Norian-Rhaetian dolomite of the Čekovnik nappe slice (Mlakar, 1969; Zagoda, 2004; Mlakar & Čar, 2009; Čar, 2010) (Figs. 1 and 4) with the thrust plane dipping 10 to 15° to the southwest or south. The dolomite constitutes the higher northern edge of Zadlog and the northern part of the Zadloško polje plain, and then the section intersects the thrust line between the Čekovnik nappe slice and the Norian-Rhaetian dolomite of the Trnovo nappe underthrust block. The thrust contact between the two dolomites dips approx. 7° to 10° in general southwards. Southward of here, the geological cross-section continues in the slope of Špičasti vrh (1127 m) (Fig. 2).

The cross-section shows that three strong hydrological retention-deflection structures follow each other vertically below Zadloško polje (Čar, 2018), i.e. flysch rocks, a lithological hydrological retention-deflection zone (marked **a** in the profile), and two thrust–shear hydrological retention-deflection zones with several-metre-thick impermeable cataclastic dolomite rocks (marked **b** & **c** in the profile) (Fig. 4).

potrjuje tudi najdba kosov kataklastičnih kamnin na njivi zahodno od Črnovrškega preloma. Narivnica se ponovno pokaže kak kilometer južneje v peskokopu pri zaselku Trebče pri Črnem Vrhu, na zahodni strani Črnovrškega preloma, torej v istem strukturnem bloku kot na Zadloškem polju. V nadaljevanju proti Črnemu Vrhu poteka narivna cona vzporedno s prelomno cono Črnovrškega preloma. V peskokopu v Trebčah vpada narivnica za 20° proti jugozahodu (sl. 3B) in ima enak vpad vse do Črnega Vrha (sl. 2).

Strukturno-hidrološke razmere

Strukturne razmere in nanje vezane hidrološke značilnosti Zadloškega polja so vidne iz priloženega prereza (sl. 4). Poleg geoloških podatkov neposredno v liniji prereza je pri izrisu upoštevana tudi geološka zgradba širšega območja Črnovrške planote. Profil je v geološkem pogledu značilen presek idrijske narivne zgradbe.

Presek poteka iz Tektonskega okna Strug v dolini Idrijce, kjer je korito reke Idrijce že vrezano v zgornjekrednem apnencu in na njem ležečih paleocensko-eocenskih flišnih kamninah Hrušiškega pokrova. Prerez nato prečka narivni kontakt med flišnimi kamninami in krednimi apnenci Koševniške krovne luske. Narivni stik vpada za okrog 25° proti jugu in jugozahodu. Iz razmer, s kartiranjem ugotovljenih v Tektonskem oknu Strug v Idrijskem Logu in Predgrižah sklepamo, da so kredni apnenci pod Zadloškim poljem rahlo sinklinalno in nato antiklinalno upognjeni (sl. 4). Nanj je narinjen norijsko-retijski dolomit Čekovniške krovne luske (Mlakar, 1969; Zagoda, 2004; Mlakar & Čar, 2009; Čar, 2010) (sl. 1 in 4) z vpadom narivne ploskve od 10 do 15° proti jugozahodu ali jugu. Dolomit gradi višje severno obrobje Zadloga in severni del izravnave Zadloškega polja. V nadaljevanju prerez seka narivnico med Čekovniško krovno lusko in norijsko-retijskim dolomitom spodnjega narivnega bloka Trnovskega pokrova. Narivni kontakt med dolomitoma vpada okrog 7 do 10° v splošnem proti jugu. Južno od tod se geološki prerez nadaljuje v pobočju Špičastega vrha (1127 m) (sl. 2).

Iz preseka vidimo, da si pod Zadloškim poljem v vertikali sledijo tri močne hidrološke zadrževalno-zaporne strukture (Čar, 2018) in sicer flišne kamnine kot litološka hidrološka zadrževalno-zaporna cona (na profilu oznaka **a**) ter dve obnarivno hidrološki zadrževalno-zaporni coni z več-metrskimi neprepustnimi kataklastičnimi dolomitnimi kamninami (na profilu oznaki **b** in **c**) (sl. 4). Flišne kamnine so ob narivnem stiku večkrat iztisnjene tako, da sta na več območjih

Several flysch rocks are pushed out along the thrust contact in such a way that Upper Cretaceous limestone of the Hrušica nappe and Cretaceous limestone of the Koševnik nappe slice are in direct contact with each other. In such cases, water flows almost unimpeded from one thrust unit to the other. Such conditions can be observed in several places in the Strug tectonic window and are most likely also present beneath the Črni Vrh plateau. A smoothed out thrust plane in the limestone in several places and an up to 20 m thick thrust–shear zone of completely crushed dolomite can be observed at the thrust contact between the limestone of the Koševnik nappe slice and the Norian-Rhaetian dolomite of the Čekovnik nappe slice in Strug and Bevk tectonic windows (Fig. 4, mark **b**, Fig. 3B). The thrust–shear cataclastic rocks at the thrust contact of the two dolomites between the Čekovnik nappe slice and Trnovo nappe (Fig. 4, mark **c**) are from some metres up to 15 m thick, in some areas even thicker. Thrust–shear crushed zones may vary in thickness, but do not pinch out in the lateral direction.

There is no direct data available on how deep underneath Zadloško polje the thrust contacts between flysch and limestone, as well as between the dolomite of the Čekovnik nappe slice and the lower thrust block of Trnovo nappe, are located. The dip of the thrust plane between flysch and Upper Cretaceous limestone of Čekovnik nappe slice, and its location underneath Zadloško polje may be inferred from the conditions observed in the Strug tectonic window and from the findings of mapped flysch outcrops in Dolenje Lome east of Črni Vrh (Mlakar & Čar, 2009; Čar, 2010). In the tectonic window, the thrust plane dips 15 to 25° roughly to the south, and then the contact gradually rises and surfaces in expansive outcrops in Dolenje Lome.

The course and nature of the thrust line between Cretaceous limestones of the Koševnik nappe slice and Norian-Rhaetian dolomite of the Čekovnik nappe slice were observed on the plain of Idrijski Log and 1.5 to 2 km east of Zadlog between Idrijski Log and Predgriže (Zagoda, 2004; Čar & Zagoda, 2005) (Fig. 2). The thrust line runs NW–SE and only drops by about 20 m over a distance of 3.5 km. The structural conditions beneath Zadloško polje are presumed to be similar. Taking into account the structural-geological data from the wider surroundings, the thrust contact between limestone and dolomite is only about 100–150 m below the surface of the polje. Based on the conditions in the vicinity of Črni Vrh and Predgriže, the thrust line gently descends towards the Na Sredi site (sinking zones A, B & C) (Fig. 2), and lifts up at reverse faults.

neposredno v stiku zgornjekredni apnenec Hrušiškega pokrova in kredni apnenec Koševniške krovne luske. Voda se v takih primerih skoraj nemoteno pretaka iz ene narivne enote v drugo. Take razmere lahko opazujemo na več mestih v Tektonskem oknu Strug in jih najverjetneje imamo tudi pod Črnovrško planoto. Na narivnem stiku med apnencem Koševniške krovne luske in norijsko-retijskim dolomitom Čekovniške krovne luske (sl. 4, oznaka **b**) opazujemo v tektonskih oknih Strug in Bevk zglajeno narivno ploskev v apnencu in do 20 m debelo obnarivno cono povsem zdrobljenega dolomita. Obnarivne kataklastične kamnine na narivnem stiku dveh dolomitov med Čekovniško krovno lusko in Trnovskim pokrovom (sl. 4, oznaka **c**, sl. 3B) so debele od nekaj metrov do 15 m, ponekod lahko tudi več. Po debelini se obnarivno zdrobljene cone lahko spreminjajo, v horizontalni smeri pa se ne izklinjajo.

Neposrednih podatkov, kako globoko pod Zadloškim poljem se nahajajo narivni stiki med flišem in apnencem, dolomitom Čekovniške krovne luske in spodnjega narivnega bloka Trnovskega pokrova ter apnencem Koševniške in dolomitom Čekovniške krovne luske, nimamo. Na vpad narivne ploskve med flišem in zgornjekrednim apnencem Koševniške krovne luske in njeno lego pod Zadloškim poljem lahko sklepamo na podlagi opazovanih razmer v Tektonskem oknu Strug in ugotovitvah kartiranih izdankov fliša v Dolenjih Lomeh vzhodno od Črnega Vrha (Mlakar & Čar, 2009; Čar, 2010). V tektonskem oknu vpada narivna ploskev od 15 do 25° približno proti jugu, nato se stik postopno dviga in izdanja v obsežnih golicah v Dolenjih Lomeh.

Potek in značaj narivnice med krednimi apnenci Koševniške krovne luske in norijsko-retijskim dolomitom Čekovniške krovne luske opazujemo na izravnavi Idrijskega Loga ter od 1,5 do 2 km vzhodno od Zadloga med Idrijskim Logom in Predgrižami (Zagoda, 2004; Čar & Zagoda, 2005) (sl. 2). Narivnica poteka v smeri SZ-JV in se na dolžini 3,5 km spusti le za okrog 20 m. Predpostavljamo, da imamo podobne strukturne razmere tudi pod Zadloškim poljem. Ob upoštevanju geološko-strukturnih podatkov iz širše okolice se nahaja narivni stik med apnenci in dolomitom le kakih 100 do 150 m pod površjem polja. Sodeč po razmerah v okolici Črnega Vrha in Predgriž se narivnica proti lokaciji Na Sredi rahlo spušča (ponikalna območja A, B, in C) (sl. 2), ob reverznih prelomih pa je dvignjena.

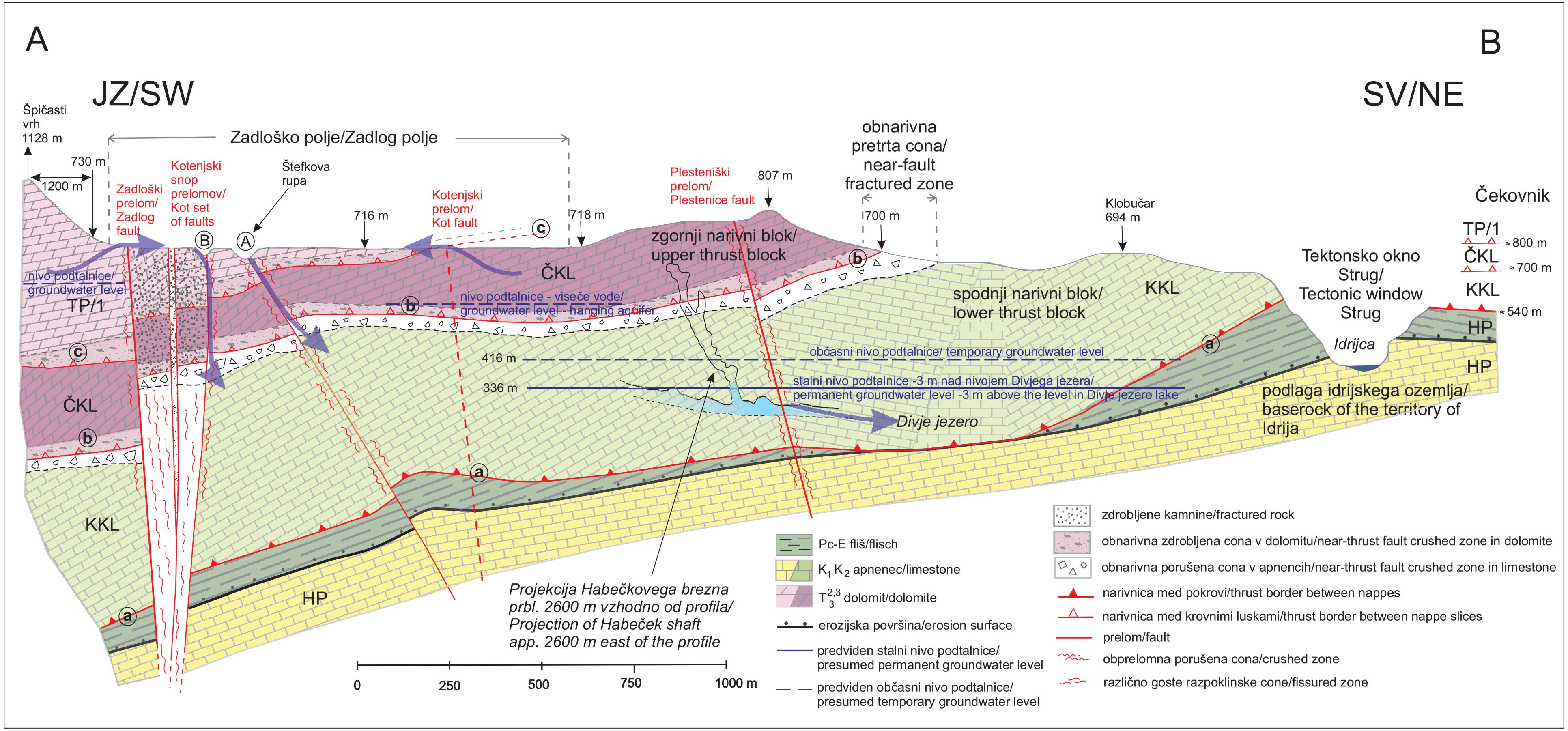

Fig. 4. Hydrogeological cross-section of Zadloško polje. HP – Hrušica nappe, TP/1 – Lower thrust block of Trnovo nappe, ČKL – Čekovnik nappe slice, KKL – Koševnik nappe slice. Ponor zones: A – Štefkova rupa, B – Ponikva. Hydrological retention-deflection structures: a - lithological hydrological retention-deflection zone in flysch, b, c - thrust–shear hydrological retention-deflection zones.

Sl. 4. Strukturno-geološki presek Zadloškega polja s hidrogeološkimi značilnostmi. HP – Hrušiški pokrov, TP/1 – Spodnji narivni blok Trnovskega pokrova, ČKL – Čekovniška krovna luska, KKL – Koševniška krovna luska. Ponikalna območja: A – Štefkova rupa, B – Ponikva. Hidrološke zadrževalno-zaporne strukture: a - litološka hidrološka zadrževalno-zaporna cona v flišu, b, c - obnarivni hidrološki zadrževalno-zaporni coni.

More information is available on the thrust contact between the Norian-Rhaetian dolomites of the Čekovnik nappe slice and the lower part of the Trnovo nappe (TP/1). The thrust zone is visible in the slope above the Belca valley, in the sand quarry at Podtisov vrh and in the Trebče sand quarry (Fig. 3 B), and further towards Črni Vrh. From north to south the thrust line descends at a slight angle of 5 to 7° southward, then almost levels off or even rises slightly. The Norian-Rhaetian dolomite of the Trnovo nappe north of Štefkova rupa is estimated to be only 20 to 30 m thick, depending on the dip of the thrust plane. Its thickness increases on the southwest side of the Zadlog fault.

Hydrological and geomorphological conditions

Weak and temporary springs with a small hydrological catchment area can be found on the southern slopes of Idrijski Log (Fig. 2) while Zadloško polje has no permanent running water.

Morphological analysis of the surface of Zadloško polje showed that its bottom is relatively well levelled out, and lies between 714 and 716 m above sea level. The entire bottom is covered by dolomite eluvium. The perimeter of the basin is covered by colluvium, indicating that the recent maximal flood range is smaller than in the past. The influence of sediment transport from the dolomitic catchment area is most clearly visible in the form of the colluvial fan at Plestenice on the southeastern edge of the basin (Fig. 8). A network of wide and shallow channels formed in the otherwise flat bottom of Zadloško polje. Up to several metres deep erosion ditches formed in fractured zones along the faults (Zadlog, Kot, Plestenice, Klančar faults), while more shallow ones evenly drain the relatively flat bottom. The whole western part that formed in the wider Zadlog fault zone from Podtisov Vrh to the southern edge of the polje, the entire western part (to Plestenice fault towards the east) and the southern and southeastern part of the polje drain towards the ponor zones on the location Na Sredi, which confirms the absence of similar drainage structures in the western and eastern parts of the polje. The NW–SE oriented strike-slip faults and the N–S oriented reverse faults in the central part of the polje that cross the outer fault (crushed and fractured) zone of the Zadlog fault appear to be the key structures allowing water to drain from the major part of the polje to the underground.

During heavy rainfall, the lower parts of the northern structural block of Zadlog quickly become partially flooded from the northern edge of the polje to the thrust line between the Čekovnik nappe slice and the lower thrust block of Trnovsko

O narivnem stiku med norijsko-retijskima dolomitoma Čekovniške krovne luske in spodnjim delom Trnovskega pokrova (TP/1) imamo več podatkov. Narivna cona je vidna v pobočju nad dolino Belce, peskokopu v Podtisovem Vrhu in peskokopu Trebče (sl. 3B) ter dalje proti Črnemu Vrhu. Od severa proti jugu se narivnica spušča pod blagim kotom od 5 do 7° proti jugu, nato skoraj izravna ali celo rahlo dviga. Debelina norijsko-retijskega dolomita Trnovskega pokrova je severno od Štefkove rupe, glede na vpad narivne ploskve, po oceni le 20 do 30 m. Na jugozahodni strani Zadloškega preloma se poveča.

Hidrološke in geomorfološke razmere

Na južnih pobočjih Idrijskega Loga se ob prelomnih conah pojavljajo večinoma občasni in šibki izviri z majhnim hidrološkim zaledjem (sl. 2). Zadloško polje pa nima stalne tekoče vode.

Morfološka analiza površja Zadloškega polja pokaže, da je njegovo dno relativno dobro uravnano, in sicer na višini med 714 in 716 m nad morjem. Dno je med številnimi izdanki dolomita prekrito z dolomitno preperino, ki je nastajala v času ojezeritve. Obod kotline je prekrit s koluvijem, kar kaže na recentno manjši obseg poplav kot v preteklosti. Najbolj jasno se vpliv premeščanja sedimentov z dolomitnih pobočij kaže v obliki vršaja v Plestenicah na jugovzhodnem robu kotline (sl. 8). V sicer ravnem dnu Zadloškega polja se je oblikovala mreža širokih in plitvih kanalov. Do nekaj metrov globoki jarki so nastali v pretrtih conah vzdolž prelomov (Zadloški, Kotenjski, Plesteniški, Klančarjev prelom), plitvejši enakomerno drenirajo relativno ravno površino dna. Zahodni del polja, ki je oblikovan v širši coni Zadloškega preloma od Podtisovega Vrha do južnega obrobja polja, ves osrednji del polja (do Plesteniškega preloma proti vzhodu) ter južni in jugovzhodni del polja drenirajo proti ponikvam na lokaciji Na Sredi, kar potrjuje odsotnost podobnih odvodnih struktur v zahodnem in vzhodnem delu polja. Kaže, da so zmični prelomi z orientacijo SZ-JV in reverzni prelomi v smeri S-J osrednjega dela polja, ki sekajo zunanjo prelomno cono (porušena in razpoklinska cona) Zadloškega preloma ključne strukture, ki omogočajo podzemno odtekanje vode z velikega dela polja.

Ob večjem deževju so nižji deli od severnega roba polja do narivnice med Čekovniško krovno lusko in spodnjim narivnim blokom Trnovskega pokrova razmeroma hitro delno poplavljeni. Glede na geološke podatke (sl. 2 in 4) imamo v tem delu Zadloškega polja nad hidrološko pregrado nappe. According to the geological data (Figs. 2 and 4), there is permanently hanging aquifer in this part of Zadloško polje above the hydrological barrier **b**. Based on the observations, its level rapidly rises to the surface of the polje and floods the lower parts and hollows on the polje (Fig. 1B). The conditions described also show that the dolomite of the Čekovnik nappe slice over the limestone of the Koševnik nappe slice is relatively thin, while the thrust–shear hydrological barrier **b** is largely impermeable and leaks only at the faults intersecting it.

The hydrological conditions south of the thrust zone between the Čekovnik nappe slice and the Trnovo nappe (TP/1), are similar to the conditions to the north of it. We presume that the groundwater here also needs to stay quite high above the hydrological retention-deflection thrust zone **c** at all times, as it starts to relatively rapidly overflow to the surface when it rains. Large amounts of groundwater flow onto Zadloško polje from the south during heavy rainfall (mostly along the layers) due to the extensive and rugged catchment area of Mrzli log with its highest peak Špičasti vrh (1127 m).

Several morphologically distinct, intermittent sinking zones are observed in Zadlog, which are shown in capital letters A to F on the Fig. 2. The largest one – *Štefkova rupa* (mark A, Fig. 6A, B) – is up to 13 m deep, at the Na Sredi site in the central part of Zadlog. From the large sinkhole Štefkova rupa (mark A), a narrow, some 200 m long valley or rather an erosion ditch in the fault zone runs southsoutheastward along the strike-slip fault. A relatively strong temporary spring flows to the surface at its southern part. The water flows northnortheastward down the erosion ditch to the central sinking area Štefkova rupa. At low inflows, the water gradually sinks already in the strike-slip fault zone and does not flow to the central large sinkhole. An extensive larger sinkhole formed at the junction of one of the reverse faults of Kot with the connecting strike-slip fault, which intersect the area between the Zadlog and Plestenice faults. Štefkova rupa does not have an open swallow hole (Fig. 6A, B), but has slightly deepened, bare surface in its NE part where substantial volumes of water sink through. The geological conditions suggest that, due to the uplift along the reverse fault, there are karstified and therefore highly permeable Upper Cretaceous limestones of the Koševnik nappe slice close to the surface. At high groundwater level, the water outflows even sideway from the sinkhole in the crushed zone of Zadlog fault and Kot set of faults.

b stalno ujeto ali visečo podtalnico. Na podlagi opazovanj se njen nivo hitro dvigne in zalije nižje dele in kotanje na polju (sl. 1 B). Opisane razmere tudi kažejo, da je dolomit Čekovniške krovne luske nad apnencem Koševniške krovne luske sorazmerno tanek, obnarivna hidrološka pregrada **b** pa je v večini neprepustna in pušča le ob prelomih, ki jo sekajo.

Južno od poteka narivne cone med Čekovniško krovno lusko in Trnovskim pokrovom (TP/1) imamo podobne hidrogeološke razmere kot severno od nje. Domnevamo, da je podtalnica nad hidrološko zadrževalno zaporno narivno cono **c** stalno dokaj visoko, saj ob deževju začne razmeroma hitro iztekati na površje. Zaradi obsežnega in razgibanega zaledja Mrzlega loga z najvišjim Špičastim vrhom (1127 m) se ob izdatnejšem deževju z južne strani v glavnem medplastno stekajo na Zadloško polje velike količine podtalnice.

V Zadlogu opazujemo več morfološko izstopajočih, občasnih ponikalnih območij, ki so na sliki 2 označeni z velikimi črkami od A do F. Največje je do 13 m globoka *Štefkova rupa* (oznaka A, sl. 6A in B) na lokaciji Na Sredi v osrednjem delu Zadloškega polja. Iz ponikalne globeli Štefkove rupa (oznaka A) poteka ob zmičnem prelomu proti JJV okrog 200 m dolga ozka dolina, ali bolje, razširjen erozijski žleb v prelomni coni. Na njegovem južnem delu je relativno močan občasni izvir. Voda odteka po jarku proti SSZ k osrednjemu ponikalnemu območju Štefkove rupe. Ob nizkih pretokih voda postopno ponikne že v coni zmičnega preloma in ne priteče do osrednje ponikalne globeli. Obsežna ponikalna globel je nastala na stičišču enega izmed Kotenjskih reverznih prelomov z veznim zmičnim prelomom, ki seka območje med Zadloškim in Plesteniškim prelomom. V Štefkovi rupi ni odprtega požiralnika (sl. 6A in B), vendar je v njenem SV delu nekoliko poglobljeno golo območje, skozi katerega poniknejo izredno velike količine vode. Glede na geološke razmere sklepamo, da se zaradi dviga ob reverznem prelomu zakraseli in zato dobro prepustni zgornjekredni apnenci Koševniške krovne luske nahajajo blizu površja. Ob višjih vodah se voda izteka iz globeli tudi bočno v pretrti coni Zadloškega preloma in Kotovega prelomnega snopa.

V podobnih geoloških razmerah sta nastali tudi ponikalni območji *Ponikva* (oznaka B in sl. 5B) in *ponikalno območje pri kmetiji Cigale* (oznaka C) severozahodno od Štefkove rupe v osrednjem delu polja. Ponikalno območje Ponikva je proti vzhodu povezano z erozijskim

The *Ponikva* sinking area (mark B and Fig. 5B) and the *sinking area at the Cigale farm* (mark C) northwest of Štefkova rupa in the central part of the polje formed under similar geological conditions. The Ponikva sinking area is connected to the erosion ditch of Štefkova rupa to the east and on the other side to the inflow area below Tomažon (Fig. 5B), and at high waters it connects to the springing/sinking puddle *Gregorcova lokev*. This is an approx. 400 m long water channel which runs in the NW–SE direction and formed in the Zadlog fault zone. It ends in a large sinkhole where water also flows into from the southeast from the Podgora farm. The extensive sinkhole (mark C) below the Cigale farm extends northward along the reverse fault and drains waters from the wide area under Podtisov Vrh north from the road Na Sredi – Figar and from the northern portion of the central part of the polje. Next is an approx. 15 m deep intermittent swallow hole (mark D) called *Štirnska rupa*. It lies between the two roads leading from the central part of Zadlog towards Šoštar at the crossing towards Črni Vrh (Fig. 2). It formed in the Plestenice fault zone and extends along the Plestenice fault in the NW–SE direction of the fault. Štirnska rupa is approximately 200 m long and has a morphologically distinct swallow hole in its central part. Eastward lies an up to 6 m deep less pronounced sinking zone in the Klančar fault zone (mark E) with numerous sinkholes that are interconnected with shallow lowered passes. The extensive and morphologically less visibly lowered sinking area in the wide broken zone of the Figar fault on the far western edge of Zadloško polje is also worth mentioning (mark F).

During heavy rainfall or rise of the groundwater level, Štefkova rupa fills up and water spills out into its wider surroundings. Gregorcova lokev fills up and water starts to flow along the distinctive and wide erosion ditch towards Ponikva, marked B. Strong temporary springs and water from several scattered interbedded inflows from the wider area below Tomažon join together before the sinking area. Water flows from the northwestern part of Zadloško polje into the wider fault zone of Zadlog and drains at Rovtar into the extensive sinkhole below Cigale. Excess water flows on the southern side of the sinkhole further towards Štefkova rupa. The sinking areas D and E also fill up (Fig. 2). As the groundwater rises in the central and southern parts of the Zadloško polje, even weaker inflows spring up along the permeable fault zones and along the stratification. In the poorly permeable lower parts of dolomite in the Čekovnik nappe slice and the Trnovo nappe water starts to stagnate and the impoundments on Zadloško polje grow and merge. The entire Zadloško

jarkom Štefkovih rup, na drugi strani pa z dotočnim območjem pod Tomažonom (sl. 5B) in ob višjih vodah z izvirno-ponikalno Gregorcovo lokvijo. To je okrog 400 m dolg jarek, ki poteka v smeri SZ-JV in je nastal v coni Zadloškega preloma. Zaključuje se z večjo globeljo, v katero priteka voda tudi od jugovzhoda od kmetije Podgora. V obsežno ponikalno globel pod kmetijo pri Cigaletu (oznaka C), ki je razpotegnjena proti severu ob reverznem prelomu, se stekajo vode z obsežnega območja izpod Podtisovega Vrha severno od ceste Na Sredi – Figar in s severa osrednjega dela polja. Naslednji je okrog 15 m globok občasni požiralnik imenovan *Štirnska rupa* (oznaka D). Leži med obema cestama, ki vodita iz osrednjega dela Zadloga proti Šoštarju na prehodu proti Črnemu vrhu (sl. 2). Nastal je v prelomni coni Plesteniškega preloma in je ob njem podaljšan v prelomni smeri SZ-JV. Štirnska rupa je dolga okrog 200 m z morfološko izrazitim požiralnikom v osrednjem delu. Vzhodno od tod leži v prelomni coni Klančarjevega preloma manj izrazito, do 6 m globoko ponikalno območje (oznaka E) s številnimi globelmi, ki so povezane s plitvimi znižanimi prehodi. Omenimo še obsežno in morfološko manj izrazito znižano ponikalno območje v široki porušeni coni Figarjevega preloma na skrajnem zahodnem obrobju Zadloga (oznaka F).

Ob močnejših nalivih in dvigu podtalnice se Štefkova rupa napolni in voda se razlije v širšo okolico. Napolni se Gregorcova lokev in voda začne po izrazitem in širokem jarku odtekati proti Ponikvi z oznako B. Pred ponikalnim območjem se iz širšega območja pod Tomažonom priključijo močnejši občasni izviri in voda iz številnih razpršenih medplastnih dotokov. Iz severozahodnega dela Zadloškega polja se voda pretaka po širši coni Zadloškega preloma in se pri Rovtarju izteka v ponikalno globel pod Cigaletom. Višek vode odteka na južni strani ponikalne globeli naprej proti Štefkovi rupi. Napolnita se tudi ponikalni območji D in E (sl. 2). Z dviganjem podtalnice se v osrednjem in južnem delu Zadloškega polja aktivirajo še šibkejši dotoki ob prepustnih prelomnih conah in tudi vzdolž plastnatosti. V slabo prepustnih znižanjih na dolomitu Čekovniške krovne luske in Trnovskega pokrova začne voda zastajati, zajezitve na Zadloškem polju se večajo in združujejo. Postopno lahko poplavi celotno Zadloško polje tako, da nastane začasna ojezeritev (sl. 5A) ali, kot pravijo domačini, nastane 'zadloško morje' (Bajec, 2007). Ob izjemnih hidroloških razmerah začne voda odtekati čez nizek prehod polje can gradually become flooded, forming a temporary impoundment (Fig. 5A) or the ‘sea of Zadlog’, as the locals call it (Bajec, 2007). Under exceptional hydrologic conditions, the water starts to flow over a low pass at Šoštar in the eastern part of Zadlog in the Črni Vrh fault zone towards Trebče at Črni Vrh. A particularly high lake impoundment formed in 1923, when the water flowed for three hours over the pass at Šoštar towards Trebče (Bajec, 2007).

pri Šoštarju na vzhodnem delu Zadloškega polja v coni Črnovrškega preloma proti Trebčam pri Črnem Vrhu. Posebno visoka ojezeritev je bila leta 1923, ko je voda kar tri ure tekla čez prelaz pri Šoštarju proti Trebčam (Bajec, 2007).

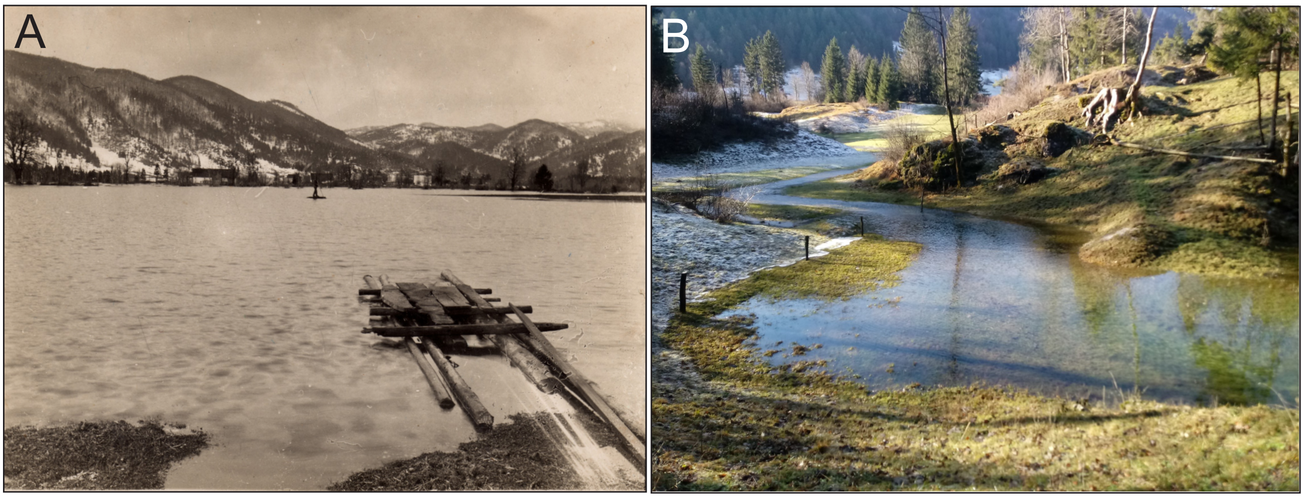

Fig. 5. A – Zadloško polje during temporary lake-formation (‚Zadlog sea‘), view to the west (Figar). Photo: Francka Zagoda B – Inflow into the sinking zone B (Fig. 2). Photo: Jože Čar.

Sl. 5. A – Zadloško polje v času začasne ojezeritve (‚zadloško morje‘), pogled proti zahodu (Figar). Foto: Francka Zagoda B – Dotok v ponikalno območje B (sl. 2). Foto: Jože Čar.

All sinking areas are formed in the dolomite of the Trnovo nappe, where the impermeable thrust–shear deflector zone (thrust–shear and hydrological collector & deflecting structure **c**) between the Čekovnik nappe slice and the Trnovo nappe is intersected by faults. The favourable conditions are apparently the result of relatively weak reverse faults pulling fractured and highly soluble Lower Cretaceous limestones of the Koševnik nappe slice closer to the surface. These are the positions of the sinking zones A, B & C. The prerequisite for the formation of swallets at the Plestenice and Klančar faults are wide fault zones with sufficiently extensive broken and fissure zones.

Water flows from Zadloško polje underground towards the Divje jezero lake and Podroteja in the Idrijca valley through Cretaceous limestones in which extensive cave systems have already formed, as confirmed by cave diving surveys (Vrhovec, 1997).

The permanent groundwater level below Zadloško polje is now 336 m (Habe et al., 1955; Vrhovec, 1997), which is only 3 m above the standing water level at Divje jezero. In flood conditions, the groundwater level in the catchment area of Divje jezero rises by 80 m, which was proven by the traces of stagnating water at the mentioned level in

Vsa ponikalna območja so oblikovana v dolomitu Trnovskega pokrova in sicer na mestih, kjer neprepustno obnarivno zaporno cono (obnarivno-hidrološka zadrževalno-zaporna struktura **c**) med Čekovniško krovno lusko in Trnovskim pokrovom sekajo prelomi. Očitno so ugodni pogoji nastali ob sicer sorazmerno šibkih reverznih prelomih, ki so potegnili pretrte in dobro topne spodnje kredne apnence Koševniške krovne luske bliže površini. Tako lego imajo ponikalna območja A, B, in C. Pogoj za nastanek ponikev ob Plesteniškem in Klančarjevem prelomu sta široki prelomni coni z dovolj obsežnima porušenima in razpoklinskima conama.

Iz Zadloškega polja voda odteka podzemno proti Divjemu jezeru in Podroteji v dolini Idrijce po krednih apnencih, v katerih so že oblikovani obsežni jamski rovi, kar so potrdile potapljaške raziskave (Vrhovec, 1997).

Stalna gladina podzemne vode pod Zadloškim poljem se danes nahaja na koti 336 m (Habe et al., 1955; Vrhovec, 1997), kar je le 3 m nad nivojem stoječe vode v Divjem jezeru. V poplavnih razmerah se podtalnica v zaledju Divjega jezera dvigne za 80 m, kar je bilo dokazano z znaki stagnacije vode na omenjeni višini

Fig. 6. A – The main larger sinkhole of Štefkova rupa. B – The inflow channel to Štefkova rupa formed along the connecting faults in the northeastern outer fault zone of Zadlog. Photo: Jože Čar.

Sl. 6. A – Glavna ponikalna globel Štefkove rupe. B – Dotočni kanal v Štefkovo rupo, nastal ob veznih prelomih v severovzhodni zunanji coni Zadloškega preloma. Foto: Jože Čar.

the Habečkovo brezno shaft (personal communication). Nowadays, the hanging groundwater in ČKL occasionally floods Zadloško polje to the north of the thrust line while the groundwater within the Trnovo nappe (TP/1) floods the polje to the south of the thrust line only during heavy rainfall. Numerous dolomite outcrops that emerge from the sediment-covered bedrock have an average dip of 230/20–30°, which is consistent with the stratification of the underlying dolomites in the wider surrounding. The equilibration of slopes at the thrust front and the emergence of parent rock outcrops in the sinking areas are indicative of the recent decreased capability of hydrologic retention of karst polje and intensive washing out of eluvium. The present hydrological conditions are therefore largely the result of leaching fault zones and clayey eluvium from the polje floor, and the resulting increased drainage capacities. Instead of the accumulation and displacement of material, which took place during the formation of Zadloško polje sediment plain, we now observe a gradual leaching into the subsurface as a result of the new hydrogeological conditions, as well as of the increased karsification and associated flow capacity of the karst subsurface.

Conditions for the formation of Zadloško polje

The detailed structural-geological mapping of Zadloško polje and the analysis of its morphological and hydrological conditions have provided some new insights and interesting benchmarks for further reflection on the origins of karst poljes in the Dinaric Karst. The authors define the karst polje as a large-scale depression of tectonic origin, formed by the selective karstification of regional tectonic structures at the groundwater level, where the

v Habečkovem breznu (ustni vir). Danes viseča podtalnica v ČKL občasno poplavlja Zadloško polje severno od narivnice, južno pa podtalnica v okviru Trnovskega pokrova (TP/1) tako, da poplavi polje le ob močnejšem deževju. Številni dolomitni izdanki, ki izdanjajo iz s sedimenti pokritega dna, imajo vpad plasti povprečno 230/20-30°, kar je skladno s plastovitostjo dolomitov v širši okolici. Pojav uravnovešanja pobočij polja in pojav izdankov matične kamnine na ponikalnih območjih nakazujeta na recentno zmanjšano vodno zadrževalno sposobnost izravnave in intenzivno izpiranje preperine. Današnje hidrološke razmere so torej predvsem posledica izpiranja prelomnih con in glinene preperine iz dna polja in zaradi tega povečanih odtočnih kapacitet. Namesto kopičenja in premeščanja materiala, ki sta potekala v času nastajanja sedimentne uravnave Zadloškega polja, zdaj opazujemo postopno izpiranje v podzemlje, ki je posledica novih hidrogeoloških razmer, pa tudi povečane zakraselosti in s tem povezane pretočnosti kraškega podzemlja.

Razmere za nastanek Zadloškega polja

Podrobno strukturno-geološko kartiranje Zadloškega polja in analiza njegovih morfoloških in hidroloških razmer so podali nekaj novih vpogledov in zanimivih izhodišč za nadaljnje razmišljanje o nastanku kraških polj Dinarskega krasa. Avtorja opredeljujeva kraško polje kot depresijo večjih dimenzij tektonskega nastanka, nastalo s selektivnim zakrasevanjem regionalnih tektonskih struktur na gladini podtalnice, pri čemer se stopnja njene nadaljnje ojezeritve prilagaja danim razmeram v degree of its further capacity for surface water retention is adapted to the given conditions in the dynamic karst hydrological system (Šegina, 2021, 92), which also provides the basis for the formation of Zadloško polje and its evolution presented below.

In accordance with the structural-geological conditions presented in the previous chapters, two types of thrusting were observed in the wider area of Zadloško polje, i.e. thrusts between different lithological units (thrusts of dolomite of the Čekovnik nappe slice onto the limestone of the Koševnik nappe slice) and thrusts within the same lithological unit (thrusts of dolomite of the Trnovo nappe (TP/1) onto the dolomite of the Čekovnik nappe) (Fig. 2). All three thrust packages present a specific, intrinsically characteristicsurface morphology. The Koševnik nappe slice isdensely interspersed with small dolines with an average diameter of 30 m, the surface of the Čekovnik nappe slice is mostly the reflection of denuded and with occasional surface runoff deepened tectonic structures, while the surface of the Trnovo nappe is more strongly dissected, interspersed with few large dolines with an average diameter of 60 m and intermediate conical peaks (Fig. 8).

In the case of both the thrust within the dolomite (TP/1–ČKL) and dolomite thrust over limestone (ČKL–KKL) somewhat similar relief phenomena were observed. Both shall be considered for a better understanding of the impact of thrust structures on the formation of the karst polje, albeit the interest of this research predominantly lies in the thrust within the dolomite in the area of Zadlog.

At the thrust of the lower thrust block of the Trnovo nappe dolomite package onto the Čekovnik nappe slice, a thrust line formed with the corresponding thrust–shear crushed zone in the dolomite. Underneath the thrust front a thrust plain formed in the less permeable, thrust–shear crushed zone in the dolomite as a morphological basis for karst polje (Fig. 7A). This is where groundwater from the nappe block of the Trnovo nappe (TP/1) flowed and stagnated on the surface due to the poor permeability of the crushed thrust–shear zone in the dolomite. During the lake-formation the bottom of the karst polje was covered by the sediment (Fig. 7B). The karts polje expanded laterally along the fractured crushed zone. The main direction of expansion was towards the thrust front, where the dolomite slopes adapted to slope erosion. The perimeter of the hollow gradually cut into the dolomite of the Trnovo nappe southwest of the thrust zone and the Čekovnik nappe slice northeast of it (Fig. 7C). During the formation of fault structures in the NW-SE direction, underground drainage formed in the Trnovo nappe dolomite and the Čekovnik

dinamičnem kraškem hidrološkem sistemu (Šegina, 2021, 92), na čemer tudi temelji v nadaljevanju predstavljen nastanek in razvoj Zadloškega polja.

Soglasno s predstavljenimi strukturno-geološkimi razmerami v predhodnih poglavjih na širšem območju Zadloškega polja opazujemo dve vrsti narivov, in sicer nariv med različnima litološkima enotama (nariv dolomita Čekovniške krovne luske na apnenec Koševniške krovne luske) in nariv znotraj iste litološke enote (nariv dolomita Trnovskega pokrova (TP/1) na dolomit Čekovniške krovne luske) (sl. 2). Vsi trije narivni paketi kažejo specifično, zase značilno morfologijo površja. Na Koševniški krovni luski so gosto posejane manjše vrtače premera povprečno 30 m, površje Čekovniške krovne luske je predvsem odraz denudiranih in z občasnim površinskim odtokom poglobljenih tektonskih struktur, medtem ko je površje na Trnovskem pokrovu močneje razčlenjeno, posejano z redkimi večjimi vrtačami povprečnega premera 60 m in vmesnimi kopastimi vrhovi (sl. 8).

Pri narivu tako znotraj dolomita (TP/1-ČKL), kakor tudi pri narivu dolomita na apnenec (ČKL-KKL) opazujemo do neke mere podobne reliefne pojave. Za boljše razumevanje vpliva narivnih struktur na oblikovanje kraškega polja bomo obravnavali oba, čeravno je v ospredju te raziskave nariv znotraj dolomita na območju Zadloga.

Ob narivu spodnjega narivnega bloka dolomitnega Trnovskega pokrova na dolomit Čekovniške krovne luske se je oblikovala narivnica s pripadajočo obnarivno zdrobljeno cono v dolomitu. V narivni coni se je v slabo prepustni, obnarivni zdrobljeni coni v dolomitu oblikovala narivna izravnava kot morfološka zasnova za kotanjo (sl. 7A). Tja je zatekala podzemna voda iz krovninskega bloka Trnovskega pokrova (TP/1), kjer je zaradi slabe propustnosti zdrobljene obnarivne cone v dolomitu površinsko zastajala. V času ojezeritve je nastalo skoraj povsem uravnano sedimentno dno (sl. 7B). Kotanja se je bočno širila po pretrti zdrobljeni coni. Glavna smer širjenja je bila proti čelu nariva, kjer so se dolomitna pobočja prilagajala spodjedanju pobočij. Postopno je obod kotanje zarezal v dolomit Trnovskega pokrova jugozahodno od narivne cone in Čekovniške krovne luske severovzhodno od nje (sl. 7C). Ob nastanku prelomnih struktur v smeri SZ-JV se je na mestih prelomov v dolomitu Trnovskega pokrova in Čekovniške krovne luske vzpostavil podzemni odtok, nastali so ponori. Skozi oba paketa nappe slice at the faults, and ponors emerged. Surface water drainage and sediment transport to the underground developed through both rock packages, which are now part of the basin floor. This is why parent rock outcrops through the sediments covering the bottom of the karst polje. Similar conditions to those in Zadlog are present in the wider surroundings of Črni Vrh.

kamnine, ki zdaj gradita dno kotline, se je vzpostavilo odtekanje površinskih voda in odnašanje sedimentov v podzemlje, zaradi česar so skozi sediment, ki prekriva kraško polje, pogledali izdanki matične kamnine. Podobne razmere kot v Zadlogu so tudi v širši okolici Črnega Vrha.

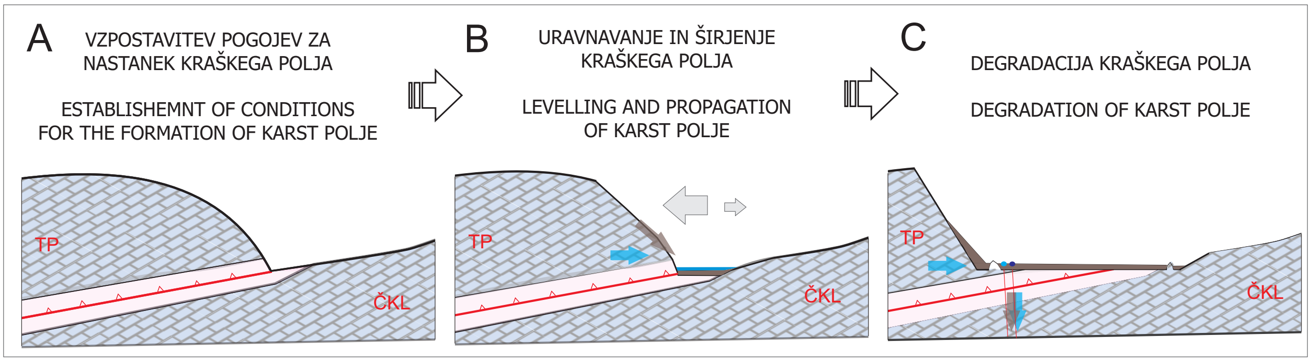

Fig. 7. Formation of a karst polje along a dolomite thrust. A – Thrust tectonics. B – Peneplanation and lake-formation on the poorly permeable fault-induced crushed zones in the dolomite, and lateral expansion of the plain. C – Expansion of the plain into the dolomite, younger fault tectonics and the formation of subsurface drainage of surface water and sediments.

Sl. 7. Razvoj kraškega polja ob narivu v dolomitu. A – Narivna tektonika. B – Uravnavanje in ojezeritev slabo prepustne obprelomne zdrobljene cone v dolomitu in bočno širjenje uravnave. C – Razširitev uravnave v dolomit, mlajša prelomna tektonika in vzpostavitev podzemnega odtoka površinske vode in sedimentov.

The conditions were somewhat different when the dolomite package of the Čekovnik nappe slice was thrust over the limestone of the Koševnik nappe slice. Underneath the thrust front, there was a slopeward displacement of dolomite eluvium from the thrust front and eluvium of the thrust–shear crushed zone, with no water retention on the surface due to limestone contact. Water flowed superficially over poorly permeable eluvium and percolated into well-karstified limestone. Due to erosion of the thrust–shear crushed zone, the slope of the thrust front gradually retreated and the slightly sloped surface covered with sediments spread towards the thrust front. Younger fault tectonics established subsurface drainage and small areas of ponors. The weak springs in the thrust front (rather than in the floor of the plain) suggest that the entire sedimentary plain did not expand beyond the thrust–shear zone, as its potential for lateral expansion is limited only to the levelling of the dolomite slope at the thrust front. Such conditions are present in the area of Idrijski Log and Predgriže. The karst which formed along the thrust belt of dolomite over limestone has its own features. This phenomenon has its specific characteristics which has not yet been explored systematicall so far (Čar, 2001; Čar & Šebela, 2001; Zagoda, 2004; Čar & Zagoda, 2005).

Ob narivu dolomitnega paketa Čekovniške krovne luske na apnenec Koševniške krovne luske so bile razmere nekoliko drugačne. Pod čelom nariva je potekalo pobočno premeščanje dolomitne preperine s čela nariva in preperine obnarivne zdrobljene cone, pri čemer zaradi kontakta z apnencem ni prišlo do površinskega zadrževanja vode. Voda se je po slabo propustni preperini pretakala površinsko in ponikala v dobro zakraselem apnencu. Zaradi erozije obnarivne zdrobljene cone se je pobočje čela nariva postopoma umikalo in blago nagnjeno površje pokrito s sedimenti se je širilo v smeri proti čelu nariva. Mlajša prelomna tektonika je vzpostavila podzemni odtok in nastanek manjših ponornih območij. Šibki izviri v čelu nariva (in ne v dnu uravnave) kažejo na to, da se celotna sedimentna uravnava ni razširila izven obnarivne cone, saj je njen potencial za bočno širjenje povezan zgolj z uravnavanjem dolomitnega pobočja v čelu nariva. Takšne razmere so na območju Idrijskega Loga in Predgriž. Kras, ki je nastal ob narivnem pasu dolomita na apnenec, ima svoje značilnosti, ki pa zaenkrat še niso bile sistematično raziskane (Čar, 2001; Čar & Šebela, 2001; Zagoda, 2004; Čar & Zagoda, 2005).

The Figure (Fig. 8) shows a typical profile of the dolomite-dolomite thrust and dolomite-limestone thrust, illustrating the characteristic and unique features of surface evolution along thrust structures (Fig. 8). Under the given conditions, steep slopes with an inclination of more than 30° formed at the thrust front between dolomite packages (Fig. 8, mark **a**). High inclinations facilitated occasional surface runoff along the fault structures where the removal of fractured dolomite on steep slopes led to the formation of mostly simple, rectilinear gullies. These have contributed additional deposits of dolomitic eluvium to the area of the thrust line. Slightly sloped sedimentary plains at the foot of the thrust block are nowadays made of dolomite eluvium from the thrust front that partially filled in the flattened sedimentary bed along the edges (Fig. 8, mark **b**). In the expanded thrust–shear zone (Fig. 4),

Na sliki 8 je prikazan značilen profil čez nariv dolomita na dolomit in dolomita na apnenec, ki ponazarja značilne in svojstvene značilnosti razvoja površja vzdolž narivnih struktur (sl. 8). V danih razmerah so se na čelu nariva med dolomitnima paketoma oblikovala strma pobočja z naklonom nad 30° (sl. 8, oznaka **a**). Zaradi visokih naklonov se je na njih občasno vzpostavil površinski odtok vzdolž prelomnih struktur, kjer so se zaradi odnašanja pretrtega dolomita po strmih pobočjih oblikovale večinoma enostavne, premočrtne grape. Te so na območje narivnice prispevale dodaten vnos dolomitne preperine. Dolomitna preperina s čela nariva danes gradi rahlo nagnjene obode sedimentnih uravnav ob vznožju narivnega bloka, ki ob robovih deloma prekrivajo uravnano sedimentno dno (sl. 8, oznaka **b**). V razširjeni obnarivni coni

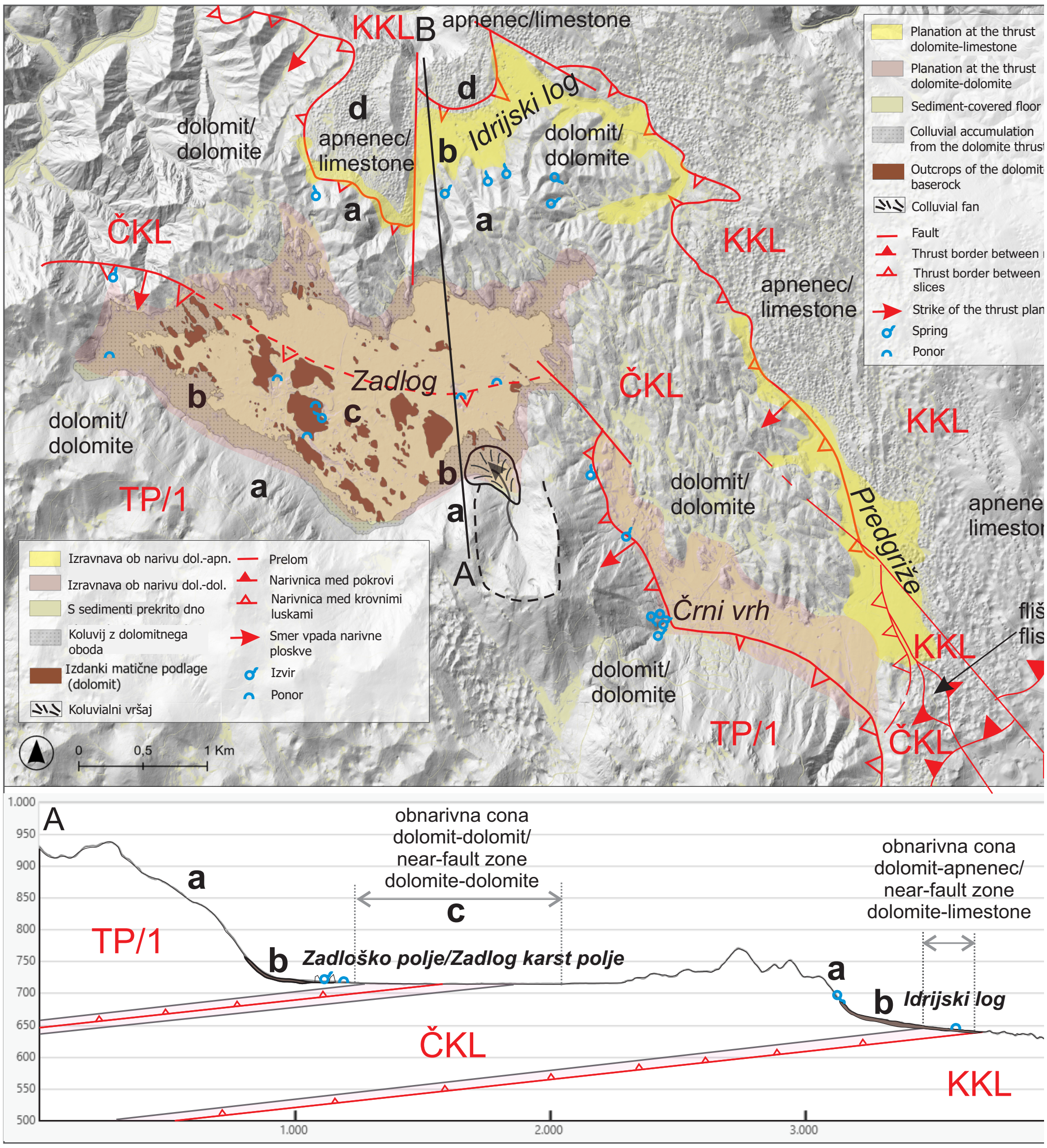

Fig. 8. Thrust–shear surface morphology.
Sl. 8. Obnarivna morfologija površja.

a sediment-covered levelled surface can be observed today (Fig. 8, mark **c**). The absence of outcrops towards the northern part of the polje marks the area of the thrust–shear zone and crushed rocks. There are springs and ponors along the younger faults in the extended bed of the karst polje, which extends beyond the thrust–shear zone.

A steep slope in the dolomite also formed at the thrust front between the dolomite and limestone packages (Fig. 8, mark **a**), where the dolomite eluvium originates from, overlying the expanded area of the thrust–shear zone at a slight inclination (up to 7°) (Fig. 8, mark **b**). It transitions into a classically dissected, morphologically distinct karstified karst surface of the Koševnik nappe slice (Fig. 8, mark **d**). Temporary springs are located in the slope of the thrust front over the dolomite crushed zone. Ponors and dolines formed along the younger faults.

Conclusion

With detailed geological mapping on a scale of 1:5000, we found significantly different geological conditions in Zadlog and the surrounding area than those previously drawn on geological maps. Three hydrological retention-deflection levels and numerous, different fault zones intersecting these levels have been identified. The established lithological-structural elements determine the inflow and outflow conditions in Zadloško polje and provide the basis for the formation of karst polje, while present geomorphological and hydrological characteristics indicate recently reduced hydrologic-retention capability of the karst polje and intensive washing out of the eluvium. Denudation, karstification and sediment transport to the underground are the principal processes that, at present, shape the Zadlog karst polje.

Similar thrust and tectonic structures probably occur also in large karst poljes in the Notranjska region. What is the role of thrust tectonics in the formation of these karst poljes and what is the impact on their recent morphological and hydrogeological characteristics will have to be verified with the detailed geological mapping in the future.

Acknowledgement

The research was funded by the Slovenian Research Agency through grants P1-0419 and project Mladi forum which is co-funded by the Slovenian Research and Innovation Agency within the framework of DFP (Developmental funding pillar).

(sl. 4) danes opazujemo s sedimentom prekrito, uravnano površje (sl. 8, oznaka **c**). Odsotnost izdankov proti severnemu delu polja nakazuje na območje obnarivne cone in zdrobjenih kamnin. Ob mlajših prelomih v razširjenem dnu kraškega polja, ki sega izven obnarivne cone, so izviri in ponori.

Na čelu nariva med paketom dolomita in apnenca se je prav tako oblikovalo strmo pobočje v dolomitu (sl. 8, oznaka **a**), od koder izvira dolomitna preperina, ki v blagem naklonu (do 7°) prekriva razširjeno območje obnarivne cone (sl. 8, oznaka **b**). Ta prehaja v klasično razčlenjeno, morfološko izraziteje zakraselo kraško površje Koševniške krovne luske (sl. 8, oznaka **d**). Občasni izviri se nahajajo v pobočju čela nariva nad dolomitno zdrobljeno cono. Ob mlajših prelomih so nastali ponori in vrtače.

Zaključek

S podrobnim geološkim kartiranjem v merilu 1: 5000 smo v Zadlogu in širši okolici ugotovili bistveno drugačne geološke razmere, kot so bile na geoloških kartah izrisane doslej. Ugotovljeni so bili trije zaporno-zadrževalni nivoji in številne, različne prelomne cone, ki te nivoje sekajo. Ugotovljeni litološko-strukturni elementi določajo dotočne in odtočne razmere na Zadloškem polju ter dajejo osnove za oblikovanje kraškega polja, zatečene geomorfološke in hidrološke značilnosti pa kažejo recentno zmanjšano vodno zadrževalno sposobnost kraškega polja in intenzivno izpiranje preperine. Denudacija, zakrasevanje in odnašanje sedimenta v podzemlje so poglavitni procesi, ki trenutno delujejo na območju Zadloškega kraškega polja.

Podobne narivne in tektonske strukture se verjetno pojavljajo tudi na velikih kraških poljih na Notranjskem. Kakšna je njihova vloga pri nastanku, morfološkem oblikovanju in hidrogeoloških značilnostih bo potrebno preveriti z natančnejšim geološkim kartiranjem.

Zahvale

Članek je bil sofinanciran s strani programske skupine P1-0419 in projekta Mladi forum, ki ga financira Javna agencija za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije v okviru razvojnega stebra (RSF).

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