SOME THOUGHTS ON THE PULL-APART ORIGIN OF KARST POLJES ALONG THE IDRIJA STRIKE-SLIP FAULT ZONE IN SLOVENIA

NEKAJ MISLI O RAZPORNEM (PULL-APART) NASTANKU KRAŠKIH POLJ OB IDRIJSKEM ZMIČNEM PRELOMU

MARKO VRABEC

Abstract UDC 551.24 (497.12 Idrija)

Marko Vrabec: Some Thoughts on the Pull-Apart Origin of Karst Poljes along the Idrija Strike-Slip Fault Zone in Slovenia

There is still no satisfactory explanation of mechanisms for karst poljes formation. Some authors have recently assumed them to be pull-apart basins, yet they didn't provide convincing supporting evidence. This article takes into consideration detailed geological field maps, geophysical and borehole data and observations on geometry of poljes and surrounding lineaments. Regarding various published research describing pull-apart basins and their formation, it seems that poljes are not of pull-apart origin. However, depression in the central part of Cerkniško polje could be an early stage in pull-apart basin evolution, which would suggest that poljes are being deformed by current strike-slip activity in Idrija fault zone and are therefore of older origin. Still, more field evidence is required to substantiate this theory.

Key words: karst poljes, pull-apart tectonics, Idrija strike-slip fault

Izvleček UDK 551.24 (497.12 Idrija)

Marko Vrabec: Nekaj misli o razpornem (pull-apart) nastanku kraških polj ob idrijskem zmičnem prelomu

Za nastanek kraških polj še ne poznamo povsem zadovoljive razlage. Nekateri raziskovalci so v zadnjem času domnevali, da so polja ob idrijskem prelomu nastala z mehanizmi razporne (pull-apart) tektonike, vendar ugibanj niso podprli s prepričljivimi argumenti. V tem prispevku so upoštevani rezultati preteklih detajlnih geoloških kartiranj, geofizikalni podatki in podatki plitvega vrtanja ter opazovanje geometrije polj in okoliških lineamentov. Iz primerjave z raziskovalno literaturo, ki obravnava razporne bazene in njihov nastanek, se zdi, da polja niso razpornega nastanka. Špranjasta depresija v centralnem delu Cerkniškega polja bi lahko bila začetna stopnja v razvoju razpornega bazena, kar bi lahko pomenilo, da trenutna zmična aktivnost ob idrijskem prelomu polja deformira in so polja potemtakem starejšega izvora. Tudi ta domneva pa bi zahtevala še dodatnih terenskih dokazov.

Ključne besede: kraška polja, razporna (pull-apart) tektonika, idrijski prelom.

Address-Naslov
Marko Vrabec
Department of Geology, University of Ljubljana
Aškerčeva 12
61000 Ljubljana, Slovenia.

ACKNOWLEDGEMENTS

This article originated as a seminar paper in the course of undergraduate study of geology at the University of Ljubljana. The author would like to thank his advisor J. Čar and F. Šušteršič for their support, discussions, and sharing of field data, and to T. Verbič and J. Vrabec, who commented and thus improved the manuscript.

INTRODUCTION

Neotectonic activity in the Slovenian teritory is generated by collisional/postcollisional processes between the Eurasian and African litospheric plates. Considering the physical nature of plate tectonic processes, we can assume broadly continuous tectonic activity over a large period of time rather than distinct episodes of "orogeny" and calm times. "Tectonic phases" should therefore be regarded as periods of different stress fields and strain rates, which can, as was found recently, change relatively fast over a geologically short period of time.

It is reasonable to expect that surface morphology (relief) of the Slovenian teritory is strongly determined by tectonic activity. However, the interesting question remains, especially in classical karst areas, to what extent this influence is active (relief produced by uplift and subsidence of tectonic blocks) and to what extent only passive (relief shaped by intensified weathering along mechanically weakened fault zones). In either case, in karst areas structurally produced relief forms mostly tend to be unmasked by mass transport processes, as the principal transport direction is downwards (see e.g. Šušteršič 1986).

The major Slovenian karst poljes lie along the Idrija strike-slip fault zone, which trends diagonally in the NW-SE direction across southwestern Slovenia. The question of their origin is nearly as old as karstology, the main dispute being over their tectonic vs. erosional/corrosional formation. Although many ideas developed in the last 100 years (see Gospodarič and Habič 1978, for a review) we do not find any of the proposed theories acceptable.

The theory of tectonic origin of poljes seems to be favoured by most geologists. Jevšenak (1986), for example, states that poljes are "neotectonic depressions (seismotectonic grabens)" without giving any further explanation or argumentation. In the search for an explanatory mechanism, some recent papers suggested the pull-apart origin of poljes (Poljak 1986, Verbič et al. 1992); however, they did not provide much supporting evidence.

The purpose of this work was to gather available field data in order to evaluate the feasibility of poljes pull-apart origin theory.

STRIKE-SLIP TECTONICS AND PULL-APART BASIN FORMATION

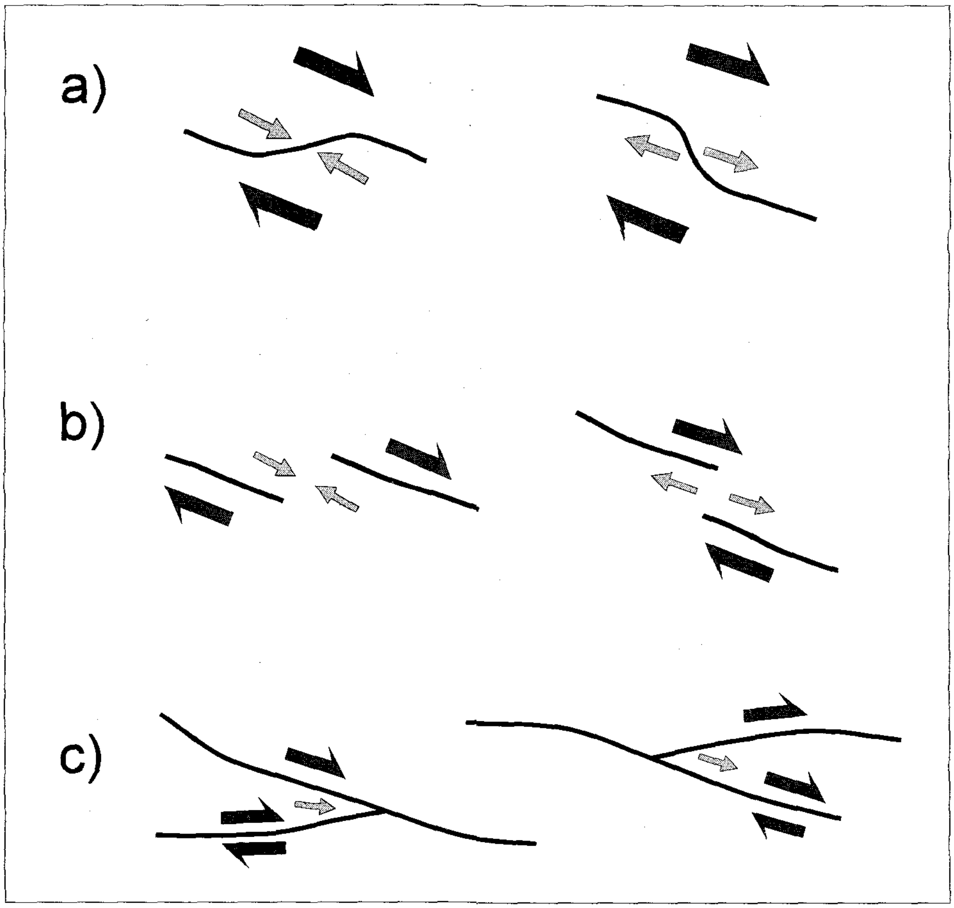

Fig. 1: Restraining (left side) and releasing geometries for right-lateral strike-slip fault. a) Fault bend. b) Overstep between en-echelon faults. c) Fault junction. Large arrows indicate relative movement of blocks, smaller arrows show sense and orientation of stress.
Sl. 1: Kompresijske=stiskajoče (na levi strani) in relaksacijske=sproščujoče geometrije poteka trase desnozmičnega preloma. a) Prevoj trase preloma. b) Prečni preskok med vzporednima (ešaloniranima) prelomoma. c) Stik dveh prelomov. Večje puščice kažejo smer relativnega premikanja blokov, manjše puščice pa smer in orientacijo mehanskih napetosti.

Strike-slip faults are defined as the faults along which predominantly horizontal displacement in the direction of the fault strike has taken place. Magnitude and obliquity of the slip can vary significantly along the same fault. Areas of convergent and divergent tectonic regimes also exist inside strike-slip zones and consequently produce associated structural phenomena such as folds, normal and reverse faults, thrusts and basins. Interested reader should turn to other sources for more in-depth treatment and further references (e.g. Sylvester 1984, Allen and Allen 1990, Twiss and Moores 1992).

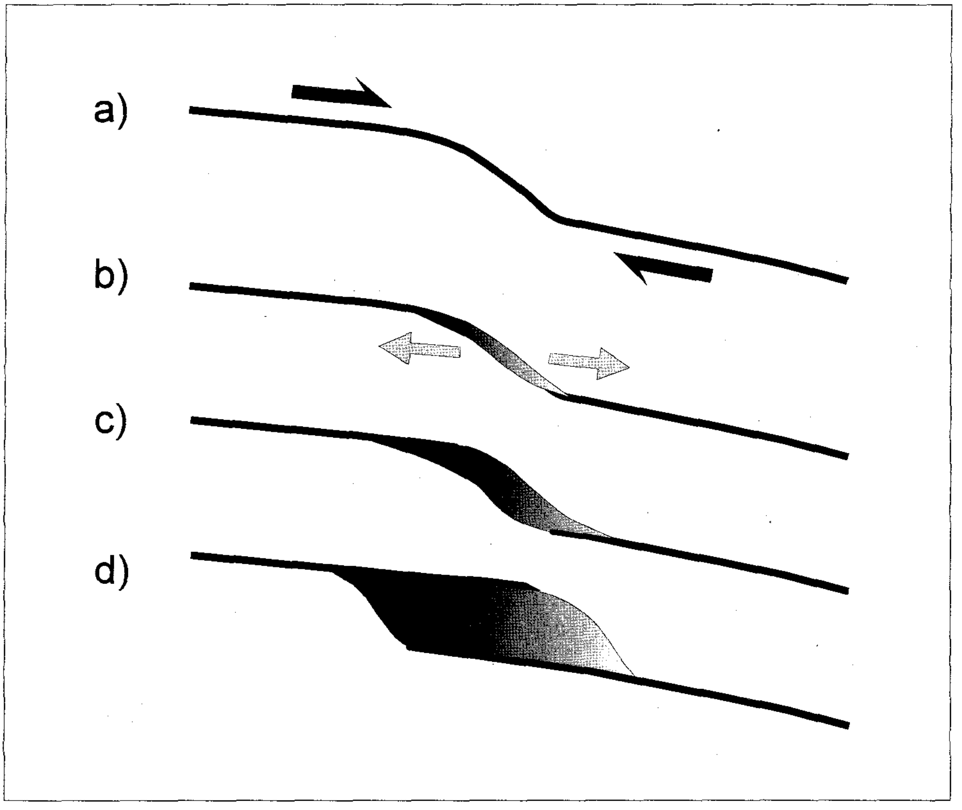

Fig. 2: Continous model of pull-apart basin development (Mann et. al., 1983). a) Right-lateral strike-slip fault with a releasing bend. b) Spindle-shaped basin (pull-apart basin initiation) c) Lazy-Z shaped stage d) Rhomboidal basin.
Faults bounding the basin are termed master faults. Secondary structural pattern inside the basin is not shown. Basin grows with progressing offset along the fault.
Sl. 2: Model zveznega razvoja razpornega bazena (po Mann et. al. 1983). a) Desnozmični prelom z relaksacijskim prevojem trase. b) Špranjasti bazen (začetek rasti razpornega bazena). c) Bazen oblike razpotegnjene črke "Z". d) Bazen romboidalne oblike. Preloma, ki omejujeta bazen, literatura imenuje glavna preloma. Sekundarne strukture znotraj bazena niso prikazane. Bazen raste s povečevanjem zmika ob glavnih prelomih.

It is known that structural patterns in strike-slip zones tend to be similar regardless of scale (Aydin and Nur 1982). On a local scale (several km to several 10km), extension and/ or compression is mainly due to curvature of the fault trace, stepovers between en-echelon faults or due to stress at fault junctions (Fig. 1). Note that the fault geometry and the sense of slip determine the stress regime.

Pull-apart basins form in the zones of extension within the strike-slip zones. They are predominantly elongated and usually of rhomboidal shape. Their further characteristics include high subsidence rates, large total subsidence and therefore rapid sedimentation with thick sediment accumulations (Ballance and Reading 1980, Sylvester 1984, Christie-Blick and Biddle 1985, Allen and Allen 1990).

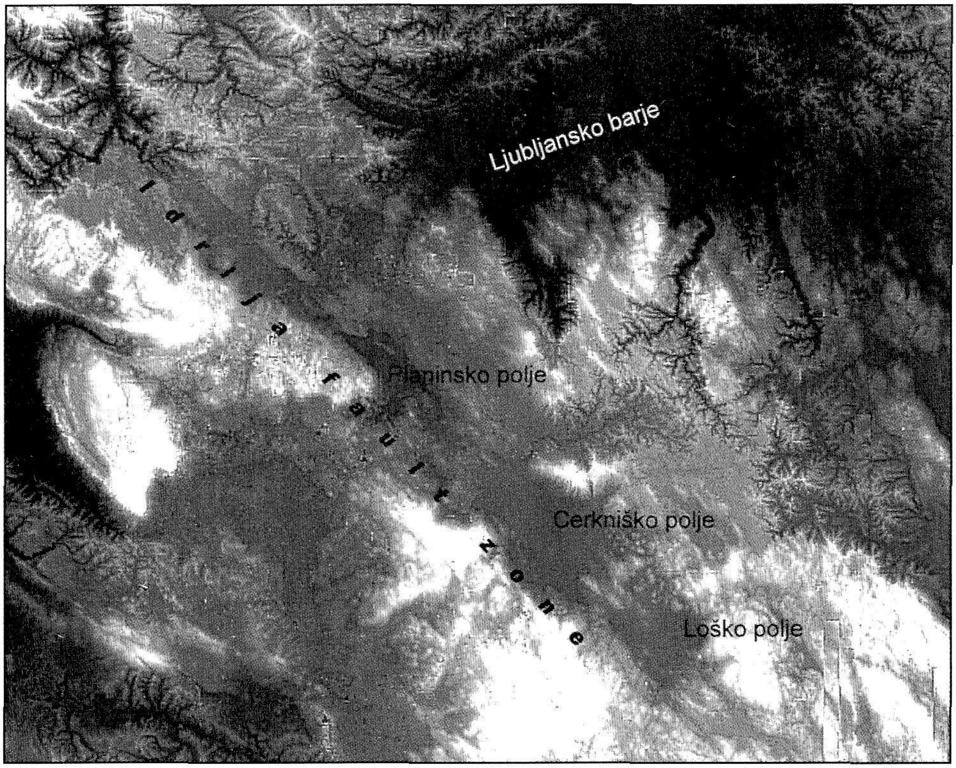

Fig. 3: View of the SW Slovenia showing the Idrija fault zone and major karst poljes. The Ljubljansko barje basin is a quaternary graben structure (Mencej, 1989). Image produced by edge enhacement (Laplacian method) of Digital Elevation Model data. Width of area shown is 60 km.

Sl. 3: Slika jugozahodne Slovenije prikazuje cono idrijskega preloma in večja kraška polja. Bazen Ljubljanskega barja je kvartarna tektonska udorina (Mencej 1989). Slika je izdelana z računalniško obdelavo (ojačanje robov po Laplacéovi metodi) digitalnega modela reliefa. Širina območja na sliki je 60 km.

Several models of pull-aparts evolution were proposed, based on field observations as well as numerical modelling and theoretical considerations (see Mann et al. 1983, for review). Of those, the continuous model of Mann et al. (1983) is most widely accepted (Fig. 2). This, however, is not the only known basin-forming mechanism in strike-slip settings (see e.g. fault-wedge basins in Crowell 1974).

IDRIJA STRIKE-SLIP FAULT ZONE

The Idrija fault is a right-lateral strike-slip fault extending diagonally in the NW-SE direction accross southwestern Slovenia (Fig. 3). Its trace can be well seen on satelite images and is therefore regarded as a structure of regional importance, although this aspect, to our knowledge, hasn't been fully studied yet. The fault was most thoroughly studied in the Idrija mercury mine area where plenty of surface and subsurface data was available (Placer 1982). The maximum horizontal slip has been determined to amount about 2500m (Placer 1982). The fault is highly active as recent movements of 1cm/year have been postulated from changed position of trigonometric points since the beginning of the century (after unpublished work of Vodušek, in Čar and Pišljar 1993).

Field data show that the Idrija fault is a zone of several parallel faults rather than a single fault. Detailed field maps are scarce, however, and cover only a minor portion of the entire zone (Placer 1982, Čar 1981, Čar and Gospodarič 1983, Šušteršič 1989). Lineaments observed on the computer image (Fig. 3) correspond well with larger faults that were determined (Fig. 4). Therefore it seems justified to use this image in the evaluation of the major structural patterns in the area.

Čar and Gospodarič (1983) have determined four generations of faults during their painstaking study of the area between Planinsko and Cerkniško polje. According to their observations the Idrija structures are the youngest as they cut and displace the older ones. The magnitude of the displacements seems to be quite small, which was also supposed by Placer (personal communication), who predicted the slip to be nearly vertical at Planinsko polje.

POLJES INSIDE THE IDRIJA FAULT ZONE

Within the Idrija strike-slip fault zone lie three large karst poljes: Planinsko, Cerkniško and Loško (Fig. 3). Their geometry seems to be strongly influenced by geological structures. Poljes are covered with thin (several m) sediment cover, ranging from clay to sand (Gospodarič and Habič 1978). Their limestone/dolomitic basement is more or less uniformly flat with many small scale irregularities due to various karstic forms, mostly dolines and shafts (Ravnik 1976, Gospodarič and Habič 1978).

If poljes are indeed of predominantly tectonic origin as many workers claim (see the Introduction), the model of their formation should be argumented as well. One of the possible explanations could be pull-apart processes. A definite answer cannot be given until a detailed geological mapping of the broader area including further geophysical investigations is carried out. Yet, the data gathered so far allow at least a feasibility evaluation of this theory.

Although at a first glance poljes, notably Planinsko, are geometricaly similar to pull-apart basins described elsewhere (see references in the Section 2 of this text), many inconsistencies with the classical pull-apart models exist.

1. The lenghth of poljes is greater than the total slip assumed at the Idrija fault zone, which contradicts observations of Mann et al. (1983), according to which pull-apart basins are generally much shorter.

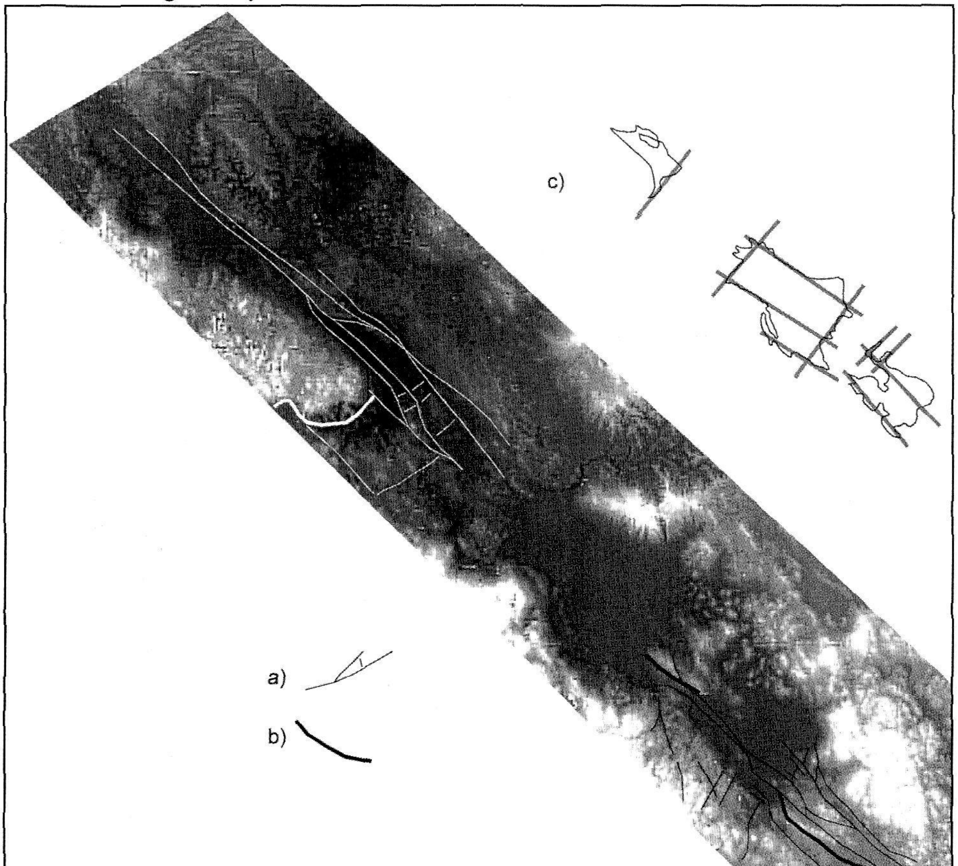

Fig.4: Larger faults as mapped by detailed field work. a) Faults. b) Thrust front (direction of thrusting towards the S). c) Outline of major lineaments (see text for discussion). Structures in white after Čar (1981), Čar and Gospodarič (1983); black after Šušteršič (1989).
Sl. 4: Potek pomembnejših prelomov, povzeto po rezultatih podrobnega geološkega kartiranja. a) Prelom. b) Narivno čelo (smer narivanja je proti jugu). c) Potek glavnih lineamentov (razlaga v besedilu). Strukture, izrisane v beli barvi po Čarju (1981), Čarju in Gospodariču (1983); strukture v črni barvi po Šušteršiču (1989).

2. Known field data and observation of lineaments on Figs. 3 and 4 indicate mostly parallel faults without significant releasing bends or en-echelon arrangement of fault segments, which usually generate pull-apart basins.
3. The rhomboidal shape of Planinsko polje is oriented opposite to the geometry necessary to produce divergence in the right-lateral slip environment. Therefore, if the northern edge of Planinsko polje was a fault bend or an overstep connecting parallel faults, right-lateral movement would cause a compression and not an extension (see Fig. 1).
4. If poljes are (or have been) active tectonic basins, we expect their basement would be segmented by secondary faults and differentialy subsided, which is not the case with poljes (see Mencej 1989, for comparsion, or Allen and Allen 1990, their Fig. 7.54, for examples from pull-apart environment). Borehole and geophysical data (Ravnik 1976, Gospodarič and Habič 1978) show flat and uniform basement, as already mentioned above.
5. Rapid subsidence, as generally observed in pull-apart basins, would undoubtedly produce more significant sediment accumulations than seen today in poljes, at least in the

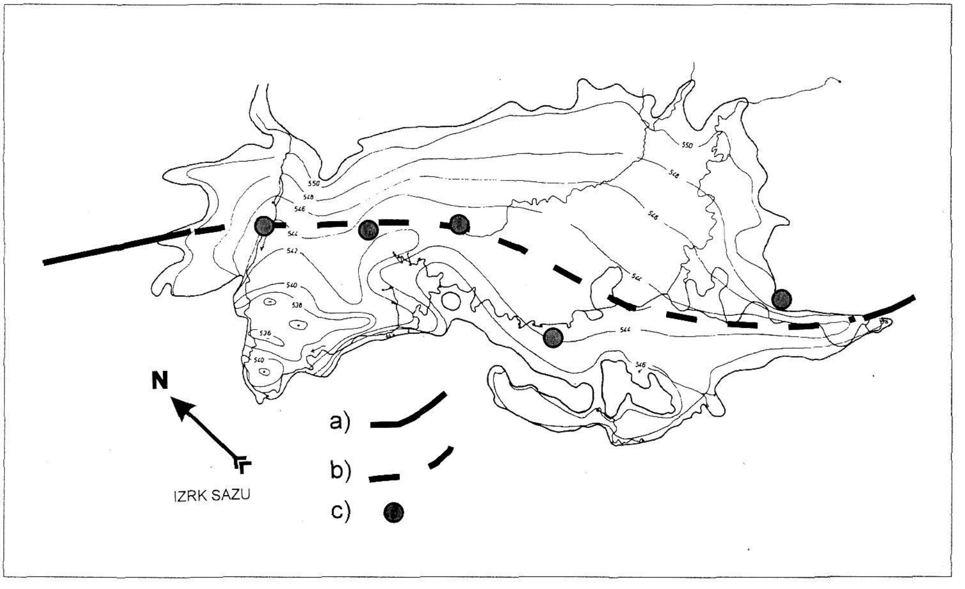

Fig. 5: Basement contours of Cerkniško polje (map after Gospodarič and Habič 1978), showing hypotetical spindle-shaped pull-apart basin. Contours at every 2m. a) Trace of major mapped fault. b) Hypotetical fault trace c) Earthquake epicenters after Jevšenak (1986).

Sl. 5: Oblika kameninske podlage Cerkniškega polja (karta po Gospodariču in Habiču 1978) s prikazanim hipotetičnim špranjastim razpornim bazenom. Izohipse na vsaka 2 metra. a) Potek pomembnejših prelomov (po objavljenih geoloških kartah). b) Hipotetični potek preloma. c) Epicentri potresov po Jevšenakovi (1986).

form of marginal talus and debris fans (the opposite view might be that the solutional lowering of poljes surroundings is rapid enough to compete with their subsidence).

6. The shape of Loško polje is highly irregular with height to width ratio well above the 3:1 average for pull-apart basins (Aydin and Nur 1982)

If the shape of Cerkniško polje is approximated by a pair of parallelograms, their longer axis is inclined for about 20 degrees to the Idrija fault zone (Fig. 4). The shorter sides of those parallelograms as well as some other lineaments from the area have approximately the same orientation as the first generation of faults mapped by ar and Gospodarič (1983). Those faults are reported to be very prominent with wide crumbled zones and are presumably significantly older than the fourth generation (Idrija) faults. Such correlation made on the base of lineaments seen on images is doubtful, however, until proven in the field.

A large number of boreholes was made on Cerkniško polje in order to determine thickness of Quaternary sediments. A basement map (Gospodarič and Habič 1978) shows a prominent elongated depression lying accross the polje (Fig. 5). Its ends trend towards two larger faults of the Idrija fault zone. The faults are most probably linked together, in which case there is a releasing bend or an overstep in between. According to Jevšenak (1986), several earthquake epicenters have been located along this inferred line. The depression could therefore be an initial stage of pull-apart basin development of Mann et al. (1983, see Fig. 2).

CONCLUSION

It seems that strike-slip faults of the Idrija fault zone cross and deform poljes, which, if tectonic origin is still assumed, are therefore of older origin. As already mentioned, extensive field work will be needed to substantiate this theory and borehole data from Cerkniško polje must be statictically re-evaluated to prove that the observed basement depth differences are significant.

REFERENCES

Allen, P.A., Allen, C.R., 1990: Basin analysis. Blackwell Scientific Publications, Oxford.

Aydin, A., Nur, A., 1982: Evolution of pull-apart basins and their scale independence. Tectonics 1, 91-105.

Ballance, P.F., Reading, H.G. (eds.), 1980: Sedimentation in oblique-slip mobile zones. Spec. Publ. Int. Assoc. Sedim. 4, Oxford.

Christie-Blick, N., Biddle, K.T. (eds.), 1985: Strike-slip deformation, basin formation and sedimentation. Spec. Publ. Soc. econ. Paleont. Mineral. 37, Tulsa.

Crowell, J.C., 1974: Sedimentation along the San Andreas Fault, California. In: Tectonics and sedimentation (Ed. by W.R. Dickinson), Spec. Publ. Soc. econ. Paleont. Mineral. 19, 292-303.

Čar, J., 1981: Geološka zgradba požiralnega obrobja Planinskega polja (English summary: Geologic setting of the Planina polje ponor area). Acta Carsologica 10, 78-105.

Čar, J., Gospodarič, R., 1983: O geologiji krasa med Postojno, Planino in Cerknico (English summary: About geology of karst among Postojna, Planina and Cerknica). Acta Carsologica 12, 93-106.

Čar, J., Pišljar, M., 1993: Presek Idrijskega preloma in potek doline Učje glede na prelomne strukture (English summary: Cross section of the Idrija fault and the course of the Učja valley regarding the fault structures). Rudarsko-metalurški zbornik 40, 79-91.

Gospodarič, R., Habič, P., 1978: Kraški pojavi Cerkniškega polja (English summary: Karst features of Cerknica polje). Acta Carsologica 8, 11-162.

Jevšenak, B., 1986: Strižne razpoke in recentno napetostno polje na področju Cerkniškega jezera (English summary: Shear joints and recent strain field in the Cerknica lake area). XI. kong. geol. Jugosl., knjiga 3, 369-393.

Mann, P., Hempton, M.R., Bradley, D.C., Burke, K., 1983: Development of pull-apart basins. Journal of Geology 91, 529-554.

Mencej, Z., 1989: Prodni zasipi pod jezerskimi sedimenti Ljubljanskega barja (English summary: The gravel fill beneath the lacustrine sediments of the Ljubljansko barje). Geologija 31-32, 517-553.

Placer, L., 1982: Tektonski razvoj Idrijskega rudišča (English summary: Structural history of the Idrija mercury deposit). Geologija 25, 7-94.

Poljak, M., 1986: Strukturna evolucija Slovenskih Vanjskih Dinarida u terciaru i kvartaru (English summary: The structural evolution of the Slovene Outer Dinarides in Tertiary and Quaternary). XI. kong. geol. Jugosl., knjiga 3, 299-322.

Ravnik, D., 1976: Kameninska podlaga Planinskega polja (English summary: Bedrock of the Planina polje). Geologija 19, 292-315.

Sylvester, A.G. (comp.), 1984: Wrench fault tectonics. Amer. Assoc. Petrol. Geol. Reprint Series 28, Tulsa.

Šušteršič, F., 1989: Informacija o kartiranju dolomitnega pasu Loškega in Babnega polja (English summary: An information about the geological mapping of the Loško and Babno polje dolomitic stripe). Rudarsko-metalurški zbornik 36, 289-296.

Šušteršič, F., 1986: Model čistega krasa in nasledki v interpretaciji površja (English summary: The "pure karst model" and its consequences in the karst relief interpretation). Acta Carsologica 14-15, 59-70.

Twiss, R.J., Moores, E.M., 1992: Structural geology. W.H. Freeman & Company, New York.

Verbič, T., Vrabec, M., Poljak, M., 1992: Structural evolution of the large scale relief in Slovenia. Terra Nova 4 abstract supplement 2, 68-69.

NEKAJ MISLI O RAZPORNEM (PULL-APART) NASTANKU KRAŠKIH POLJ OB IDRIJSKEM ZMIČNEM PRELOMU

Povzetek

Za nastanek kraških polj še ne poznamo povsem zadovoljive razlage. Nekateri raziskovalci so v zadnjem času domnevali, da so polja ob idrijskem prelomu nastala z mehanizmi razporne (pull-apart) tektonike, vendar ugibanj niso podprli s prepričljivimi argumenti. V tem prispevku so upoštevani rezultati preteklih detajlnih geoloških kartiranj, geofizikalni podatki in podatki plitvega vrtanja ter opazovanje geometrije polj in okoliških lineamentov. Iz primerjave z raziskovalno literaturo, ki obravnava razporne bazene in njihov nastanek, se zdi, da polja niso razpornega nastanka. Špranjasta depresija v centralnem delu Cerkniškega polja bi lahko bila začetna stopnja v razvoju razpornega bazena, kar bi lahko pomenilo, da trenutna zmična aktivnost ob idrijskem prelomu polja deformira in so polja potemtakem starejšega izvora. Tudi ta domneva pa bi zahtevala še dodatnih terenskih dokazov.