POLJES AND CAVES OF NOTRANJSKA

KRAŠKA POLJA IN JAME NOTRANJSKE

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Izvleček UDK 551.435.83(497.4)

France Šušteršič: Kraška polja in jame Notranjske

Kritično je podan pregled poznavanja notranjskih kraški polj in vodoravnih jam v njihovem območju. Avtor ugotavlja, da je proučevanje izhajalo iz predpostavke, da so polja posledica postopnega zakrasevanja predkraških rek. Podobno se tudi študij okoliških jam ni mogel odtrgati od iste predpostavke, kar je vodilo k zaključku, da so polja in jame genetsko neposredno povezane. Raziskovanja zadnjih let, ki izhajajo iz drugačnih pogledov, kažejo, da je povezava polj in jam slučajna. Nekateri danes aktivni jamski sistemi so celo starejši od idrijskega zmika, medtem ko so polja mlajša in posledica dinamike znotraj prelomne cone.

Ključne besede: kraško polje, jamski sistem, speleogeneza, Notranjski kras

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Given is critical survey of the research of the poljes of south-central Slovenia, and the horizontal caves in their neighbourhood. Author is of an opinion that the research has stemmed from a supposition that the poljes are the consequence of gradual karstification of the prekarstic rivers. Similarly, the understanding of the close by caves could not forget this idea, what led to the conclusion that poljes and caves must be genetically interrelated. The very recent research, founded on different paradigms, revealed that the interrelations are merely coincidental. Some cave systems are older than the Idrija strike-slip displacement, while poljes are younger, very probably due to the dynamics within the Idrija fault zone.

Key words: polje, cave system, speleogenesis, karst of Slovenia

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0. FOREWORD

E. Silvestru (1995, p.503) suggested that the phenomenon of the karst polje is a paramount example of how terms/notions were introduced into karst science. *"There is one... extremely important characteristic which makes karstology almost unique: long before being a self-standing science, geography was already coining terms that subsequently became standard karstological terms, without being actually re-defined according to new criteria"*. The situation with poljes is much worse: the popular term was introduced without defining its popular and its scientific meanings. The latter would hardly be possible, because the students of poljes did exactly what G. H. Dury (1967, p.220) described in somewhat different circumstances: *"... Davis's statements to be regarded, not as descriptions of what actually happens, but as expressions of personal views of what may be happening."*

This paper is not meant to suggest a new definition of the polje. It sets out to compare the present level of knowledge about the poljes with the actual understanding of the neighbouring caves, and to consider the poljes together with the caves of the area, in a way that appears to be a stepping stone towards building the poljes into the surrounding karst.

1. INTRODUCTION

The area of the Classical Karst in Slovenia is best considered as a triangle with vertices that just encompass the cities of Ljubljana, Rijeka and Gorica/ Gorizia. One of its gravity lines runs from Ljubljana to Trieste and the present centre for karst studies, Postojna, lies close to the triangle's centre of gravity. Traditionally, the area is sub-divided into the Karst (Slovene: Kras) or the Lower Karst, which lies southwest of the line from Gorica/Gorizia through Postojna to Rijeka, and the High Karst, which covers the rest of the triangle.

The eastern part of the High Karst is known popularly as Notranjska. It approximates to the catchment area of the sinking river Ljubljanica, which is the backbone of the area that drains into the Danube and onward to the Black Sea. The Ljubljanica is widely known as a string of surface and underground stream segments, with the streams emerging onto closed basins that more or less fit the traditional view of poljes.

Fig. 1: The Ljubljanica basin: main dyed connections (simplified), main active caves
a: well determinable border of the karstic Ljubljanica catchment area
b: approximative border of the karstic Ljubljanica catchment area
c: outflow border of the karstic Ljubljanica catchment area
d: main superficial streams
e: dyed connections
f: alluvial bottoms of major poljes and of the Pivka basin
g: international boundary
h: accessible spring cave
I: siphon spring cave
j: unpenetrable karst spring
k: major water caves accessible inside the system
l: accessible ponor cave
m: non accessible ponor
A: Pivka basin
B: Babno polje
C: Loško polje
D: Bloke (Bloško polje)
E: Cerkniško polje
F: Rakovško polje
G: Planinsko polje
H: Logaško polje
J: Ljubljansko Barje (Ljubljana Marsh)

Numeration: numbers[2] of registred caves. See text!

Sl. 1: Porečje Ljubljanice - poglavitne obarvane vodne zveze (poenostavljno), glavne aktivne jame
a: jasno opredeljiva razvodnica
b: približno določena razvodnica na kraških ozemljih
c: odtočni rob kraškega dela porečja Ljubljanice
d: glavni površinski tokovi
e: obarvane vodne zveze
f: aluvialna dna najvažnejših kraških polj in Pivške kotline
g: mednarodna meja
h: dostopna izvirna jama
I: sifonska izvirna jama
j: nedostopen kraški izvir
k: najpomebnejše vodne jame, dostopne iz sredine sistema
l: dostopne ponorne jame
m: nedostopne ponorne jame
A: Pivška kotlina
B: Babno polje
C: Loško polje
D: Bloke (Bloško polje)
E: Cerkniško polje
F: Rakovško polje
G: Planinsko polje
H: Logaško polje
J: Ljubljansko Barje

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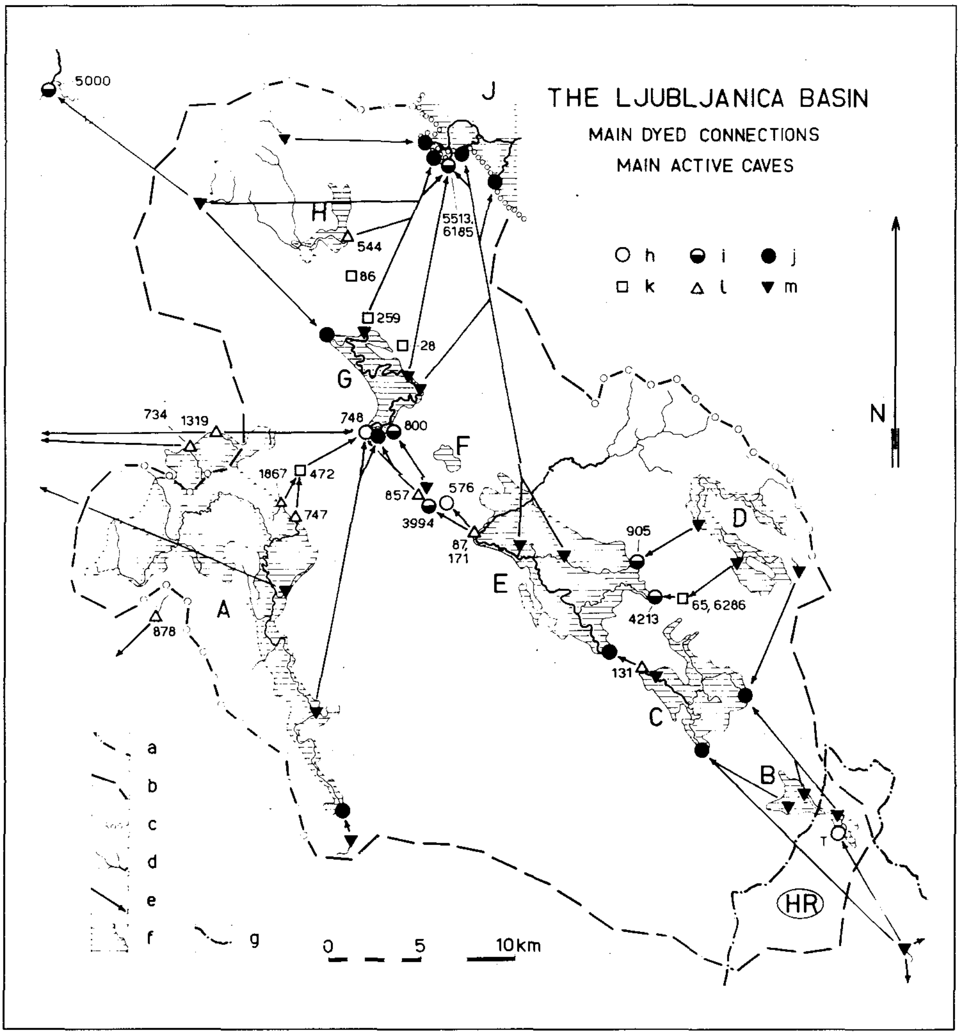
[2] Numeration according to the central register of caves of Slovenia, maintained by the Speleological association of Slovenia and the Karst research institute, ZRC SAZU, Postojna.


THE LJUBLJANICA BASIN
MAIN DYED CONNECTIONS
MAIN ACTIVE CAVES
h
i
j
k
l
m
N
a
b
c
d
e
f
g
0
5
10km
A
B
C
D
E
F
G
H
J
HR
5000
5513, 6185
544
86
259
28
748
800
734
1319
1867
472
747
857
576
3994
87, 171
905
65, 6286
4213
131
878
T

Though the surface and underground streams form an interconnected network, the river is divided traditionally into two branches. The bulk of the western part encompasses the Pivka basin (A in Fig. 1), which is in fact a relatively large basin, within predominantly flysch (i.e. non-karstic) rocks, that drains underground. I. Gams (1994, p.289) views it as a peripheral polje, but in the further discussions below it is of no direct interest.

On the other hand, the poljes of the eastern branch plus the Planinsko polje (G[1]), which can be considered as the confluence of the two branches (Fig. 1), are formed in karstic rocks. The recognition of the single basins as poljes developed along with the development of the term polje itself. Planinsko, Cerkniško and Loško polje (G, E and C respectively in Fig.1) have been considered poljes from the very beginning (J. Cvijić, 1893). In 1916 F. Kossmat introduced the Logaško (H) and Rakovško (F) poljes and in 1924 N. Krebs added the Babno polje. A composite of F. Kossmat's (1916) and J. Rus' (1925) map (Fig. 2) documents what the pioneers did. Not until the work of A. Šerko (1948) were all the poljes in the area recognized and classified systematically, including the Rakov Škocjan. The latter, however, is not a polje but a (karst) valley, with a surface stream that emerges from a cave and disappears into the karst again.

F. Kossmat (o.c) noted that the previously listed poljes are arranged in a nearly straight line along the Idrija Fault. He also noted that the string of poljes lies within a stripe of relatively low relief that is now called the Notranjsko podolje (Notranjsko lowlands) (Figs. 2, 3). Kossmat recognised similarities between the Notranjsko podolje and the Čepovanski dol, a magnificent dry valley at the foot of the Julian Alps. This led him to explain the formation of poljes as a stage in the karstification of a primarily non-karstic superficial river, and this remained the tenet of further explanations until very recently.

Consequently, the caves in this area have been regarded as being fundamentally more or less epiphreatic in origin, with their development bound intimately to the formation of the poljes and the presumed river terraces at their margins (R. Gospodarič and P. Habič, 1979). On the other hand, extensive speleological work has made this explanation less and less acceptable. Though I. Gams (1963) remarked that this key probably did not fit the lock, it was not until the nineteen-nineties that studies founded upon other paradigms began to appear (M. Brenčič, 1992; S. Šebela, 1994; F. Šušteršič, 1992, 1994; M. Knez, 1996).

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[1] *Labels of poljes according to Figs. 1 and 3.*

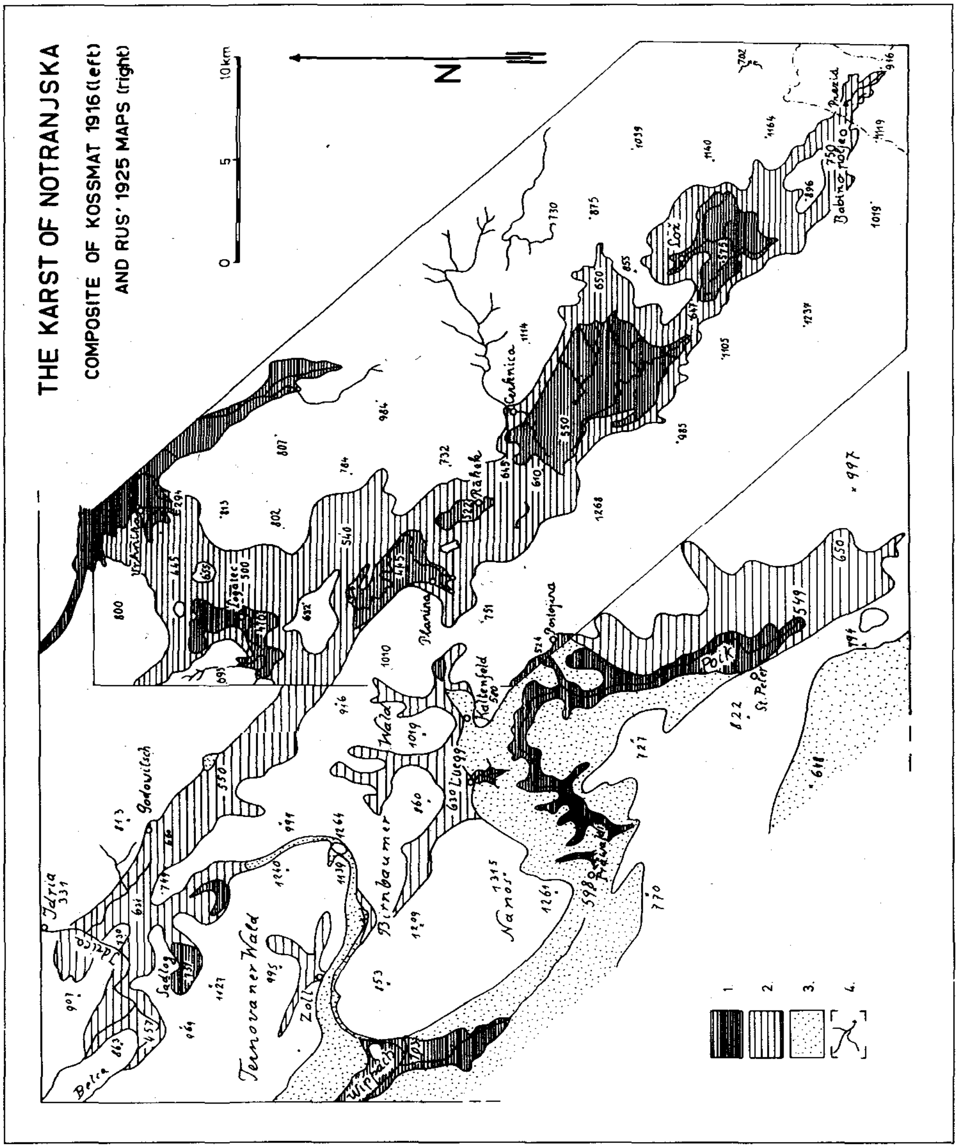
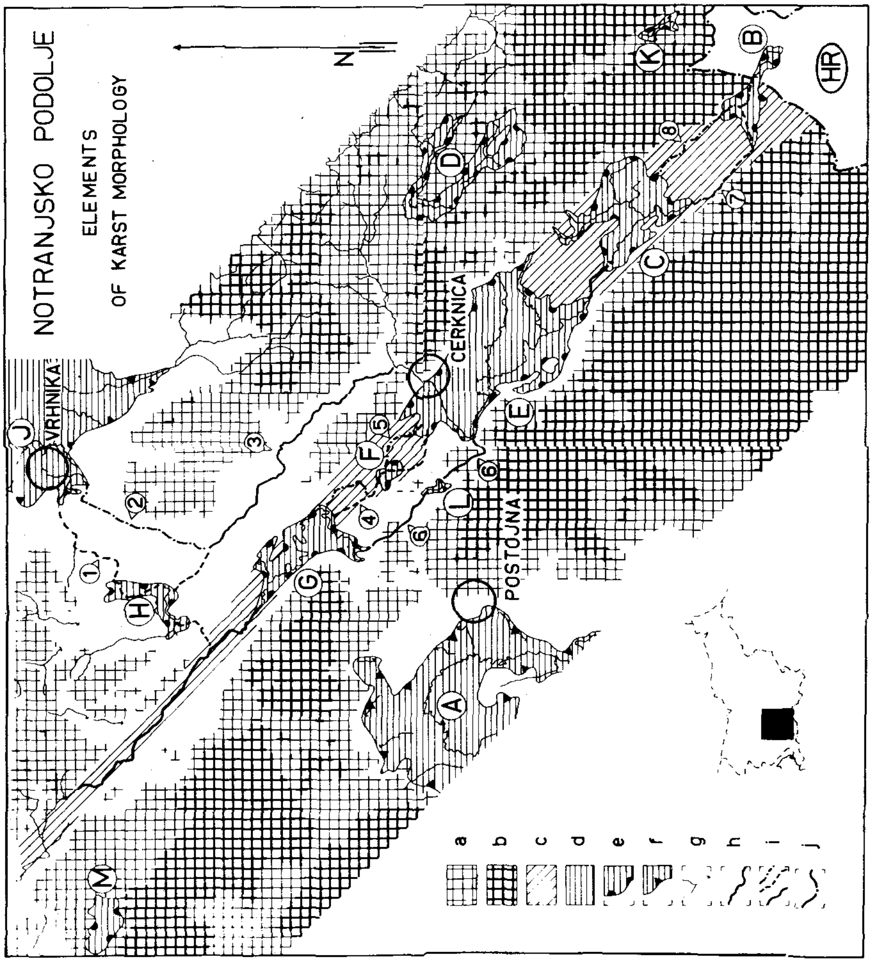

THE KARST OF NOTRANJSKA
COMPOSITE OF KOSSMAT 1916 (left)
AND RUS' 1925 MAPS (right)
0 5 10km
N

Fig. 2: The composite of F. Kossmat's (1916, 654) and J. Rus' (1925, 31) maps
1. Alluvial bottoms of poljes and active river valleys
2. Flattened areas in limestone and dolomite
3. Fliysch areas
4. Surficial streams

Sl. 2: Sestavljenka F. Kossmatove (1916, 654) in J. Rusove (1925, 31) karte
1. Aluvialna dnesa kraških polj in aktivnih rečnih dolin
2. Uravnave na apnencu in dolomitu
3. Flišna ozemlja
4. Površinski tokovi

Fig. 3: Notranjsko podolje, elements of karst morphology
a: Elevations 800m a.s.l.
b: Elevations between 610m and 800m a.s.l
c: Zone of the Idrija fault
d: Alluvial bottoms of closed basins
e: Borders of flat bottoms within closed basins
f: Outflow border of the karstic Ljubljanica basin
g: Active surficial streams
h: Main "talwegs" (Fig. 4)
I: Parallel "talwegs"
j: International boundary

Sl. 3: Notranjsko podolje, elementi kraške oblikovanosti
a: Višine nad 800m
b: Višine med 610m in 800m
c: Cona Idrijskega preloma
d: Aluvialna dna večjih zaprtih globeli
e: Robovi ravnega dna večjih zaprtih kraških globeli
f: Odtočni rob kraškega porečja Ljubljanice
g: Activni površinski tokovi
h: Glavne "podolnice" navideznih suhih dolin (Gl. sl. 4)
I: Stranske "podolnice" navideznih suhih dolin
j: Mednarodna meja


NOTRANJSKO PODOLJE
ELEMENTS
OF KARST MORPHOLOGY
N
VRHNIKA
CERKNICA
POSTOJNA
HR
A
B
C
D
E
F
G
H
J
K
L
M
a
b
c
d
e
f
g
h
i
j

2. THE LJUBLJANICA CATCHMENT AREA

The calculated size of the Ljubljanica drainage basin is 1779 km^2, of which about 1100 km^2 are composed of karstic rocks. The location of the water divide is approximate, but bifurcations have been proved at several boundaries by water tracing (Fig. 1). According to studies during the complex water tracing experiments of the nineteen-seventies, the catchment area of the Vrhnika springs, where the main river definitively leaves karst terrain, covers 1108.78 km^2 (K. Žibrik et al, 1976). The mean discharge in the years 1972 to 1975 was 38,60 m^3 sec^{-1}, with a specific run-off of 34.8 l sec^{-1} km^{-2}. I. Gams (1966a) established a mean denudation rate of 65 m^3 km^{-2} a^{-1}.

The karstic rocks are generally micritic, locally oolitic, limestones and dominantly late-diagenetic dolomites, mostly of Mesozoic age. They were formed on the Dinaric platform under conditions of continuous sedimentation. Very uniform shallow sea conditions persisted and were responsible for the extremely high rock purity, generally with less than 5%, but locally as little as 0.1%, insoluble residue. The total thickness of the carbonate sequence is about 6850m (J. Čar, 1996).

Among the non-karstic rocks, only Early Tertiary flysch, deposited directly upon the carbonate sequence, has a significant role. Older Triassic and Permian clastic rocks do not appear to play an important role in karst shaping. Younger sediments are absent, suggesting a final emergence at the end of the Tertiary.

Structurally, the whole of the Ljubljanica basin belongs to the Adriatic sub-plate. The area is composed of several nappes (V. Placer, 1981; U. Premru, 1982) that were overthrust in a NE to SW direction as a result of the collision of the Adriatic sub-plate with the European continent. Gradual change of the movement direction brought about the formation of the Idrija (dextral strike-slip) Fault, which runs through the area in a NW-SE direction. The total displacement on this still-active fault has never been measured systematically, and a widely ranging estimates have been made. However, an apparent displacement of about 12km is evident from the geological map (Fig. 5, inset map).

Examination of satellite imagery gives the impression that the fault is very straight. On the other hand, detailed field observations (J. Čar, 1982; J. Čar and R. Gospodarič, 1984; I. Mlakar, 1969; F. Šušteršič, 1989) revealed that there is not just one fault line. There are at least two main fractures (the Idrija and the Zala faults) and a zone of chaotically displaced blocks between them (Figs. 3, 5), separated by minor faults. Cross correlation of the relief on both sides of the fault zone with that within the central area does not permit the central zone to be attached to any of the blocks on either side. Rather, it displays a unique form and structure, such that the fault zone is best regarded as a separate structural and geomorphic unit in its own right.

Except for the fluvio-denudational relief in the flysch area of the Pivka basin, and some areas on the Permian and Early Triassic clastic rocks (together with the Late Triassic dolomite) most of Ljubljanica basin has a typically karstic surface. In earlier times it was believed that different elevations reflect pre-karstic "levels", and that some lower parts are remnants of pre-karstic superficial drainage. Further research has proved that - with only a few exceptions - this is hardly possible, and that the relief is essentially tectonic (P. Habič, 1981, F. Šušteršič, 1979, 1987 a, b). Basically, the area consists of blocks lifted to different levels, marked by isolated hills (hums) at higher elevations and predominantly flat in the lower areas. (See F. Šušteršič, 1996, photos!)

The highest elevations form a string that runs parallel with the Idrija Fault, in direct contact with the southwestern margin of its main zone (Fig. 3). These are Planinska Gora (1019 m), Javorniki (1293 m) and Snežnik (1796 m). The local base level is at Vrhnika, on the border of the Ljubljansko Barje (Ljubljana Marsh, 294m), where the karst waters finally appear at the surface. Locally the lowest relief is in the Notranjsko podolje, which runs parallel to, and northeast of, the range mentioned before (Fig. 3).

3. THE POLJES OF NOTRANJSKO PODOLJE

In longitudinal section (Fig. 4) the Notranjsko podolje appears to be a string of closed basins (poljes), ranged more or less within the Idrija Fault Zone (Figs. 2, 3):

Table 1, poljes within the Idrija fault zone, crossed by the main stream (Figs. 1, 3):

Label	Name:	Elevation:	Classification	
		(general)	Šerko (1948)	Gams (1994)
B	Babno polje	750 m	uvala	border polje
C	Loško polje	575 m	periodicaly flooded polje	overflow polje
E	Cerkniško polje	550 m	priodical lake	border polje
	Rakov Škocjan	500 m	periodicaly flooded uvala	/
G	Planinsko polje	450 m	periodicaly flooded polje	overflow polje

The latter two poljes (Loški potok and Zadlog) are mentioned because, in the literature, they appear to show some connection with those listed in the main part of the table. They are considered no further. The Postojna basin and Bloke are more closely bound to the main poljes and, where necessary,

Table 1, Appendix (neigbouring poljes, Figs. 1, 2):

Label[1]	Name	Elevation (general)	Classification Gams (1994)	Notes
F	Rakovško polje	520 m	border polje	within the zone, main stream passes by
H	Logaško polje	480 m	border polje	out of the zone, main stream passes by
A	Postojna basin		peripheral polje	flysch area, out of the zone
D	Bloke		border polje	out of the zone
K	Loški potok		/	out of the present Ljubljanica basin
M	Zadlog		/	out of the present Ljubljanica basin

will be included in the discussion. The Rakovško polje lies within the Idrija Fault Zone and cannot simply be omitted, though, from the viewpoint of the present hydrological situation, it could be. Its inclusion necessitates inclusion of the Logaško polje, even though it lies outside the zone, but close to the Ljubljanica final resurgence. It must be stressed again that the Rakov Škocjan is not a karst polje, but it cannot be ignored in this discussion because a great deal of water passes through it.

Despite a century of intensive study the actual mechanism of polje genesis remains obscure. R. Gospodarič and P. Habič (1979, p.25) provide an exhaustive survey of the genetic ideas concerning the Cerkniško polje, which may, without any doubt, also be applied to other poljes in the area. The ideas range from pure tectonic lowering, through fluvial erosion, to corrosion. Though their work (o.c.) is the most extensive to date and they present data

Fig 4: Notranjsko podolje - "talweg". Longitudinal projection on the vertical plane, running through regression line of the Idrija Fault.

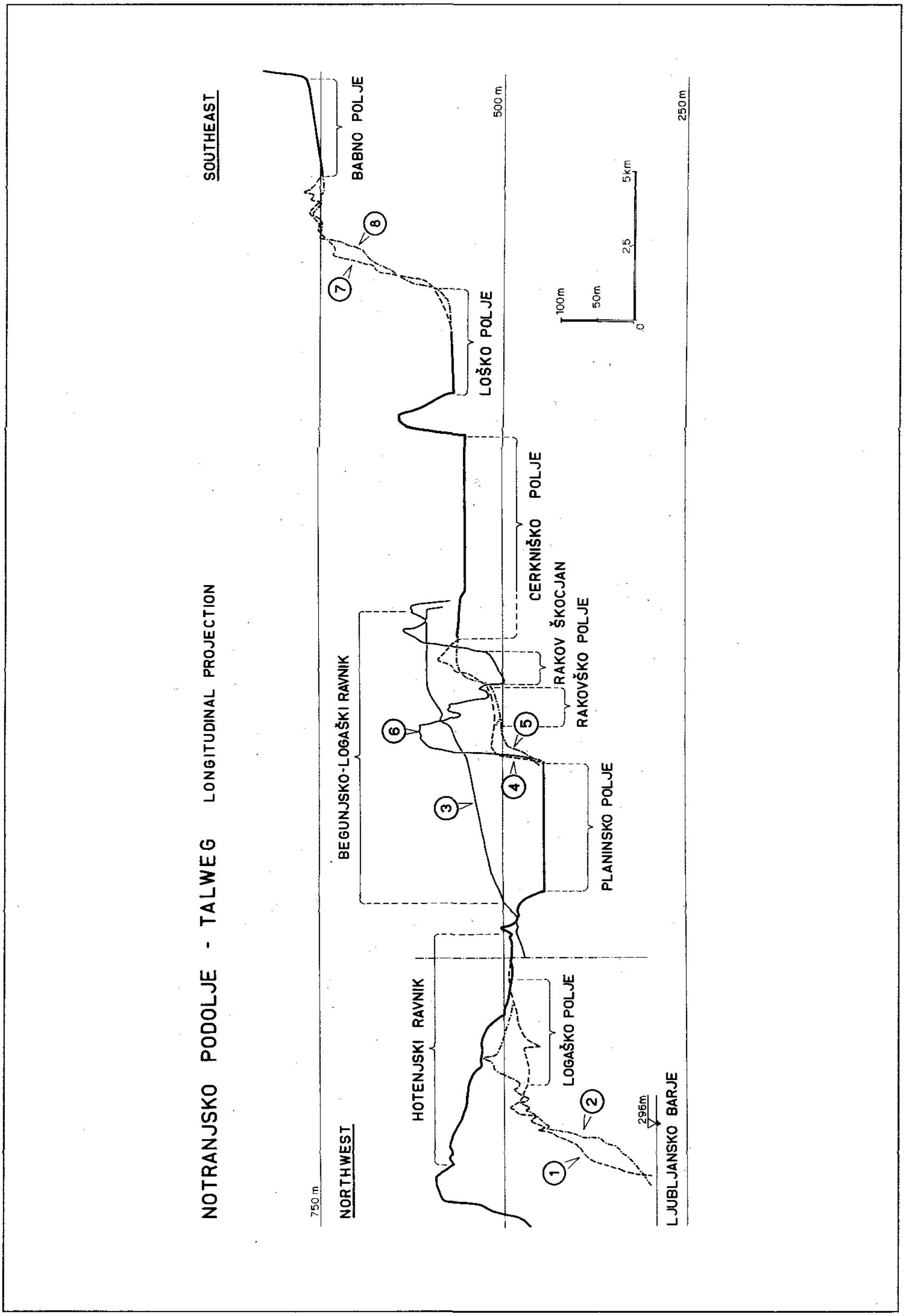
"Talweg" signs identical with Fig. 3.

(Numeration not needed in this context)

Sl. 4: Notranjsko podolje - "podolnica". Vzdolžna projekcija na navpično ravnino, položeno skozi regresijsko premico idrijskega preloma.

Oznake "podolnic " so iste kot na sliki 3.

(Oštevilčenje v tem kontekstu ni potrebno)


NOTRANJSKO PODOLJE - TALWEG LONGITUDINAL PROJECTION
SOUTHEAST
NORTHWEST
750 m
500 m
250 m
BABNO POLJE
LOŠKO POLJE
CERKNIŠKO POLJE
RAKOV ŠKOCJAN
RAKOVŠKO POLJE
BEGUNJSKO-LOGAŠKI RAVNIK
PLANINSKO POLJE
HOTENJSKI RAVNIK
LOGAŠKO POLJE
LJUBLJANSKO BARJE
296m
100m
50m
0
2,5
5km
1
2
3
4
5
6
7
8

partially supporting each of the previous ideas, they appear to remain undecided, and a true synthesis is lacking. Recently M. Vrabec (1994) offered a radically new tectonic explanation, viewing the Cerkniško polje as a rudimentary pull-apart basin.

This is an important indication either that something is fundamentally wrong, or that, in spite of the impressive amount of data collected, the proper conclusions have not yet been drawn. However, some possible mistakes may be indicated:

3.1. Since the very earliest scientific explanations, karst, together with poljes, has been regarded as something transient, and the main relief features were obviously taken as being inherited from some pre-karstic, fluvial phase. Kossmat's (o.c.) analogy between two sectors of the Notranjsko podolje - the Begunjsko-logaški ravnik and Hotenjski ravnik (Figs. 2, 4) - and the evidently trans-environmental dry valley, Čepovanski dol, appeared to support this idea. His followers did not test the idea against the fundamental logic of fluvial systems (longitudinal profiles, sediments etc). Instead they continued hunting for dry valleys, recognising them in any topographic feature that appeared linear in plan (N. Krebs, 1924; J. Rus, 1925; A. Melik, 1928; R. Gospodarič and Habič, 1979).

Poljes have always been viewed as a karst stream piracy phenomenon. The decline of Davisianism and the ascent of climatic geomorphology only changed the postulated mechanisms, without affecting the foundations. F. Šušteršič (1986 a) offered a completely different view of poljes in general, but did not apply it directly to the poljes in this consideration.

3.2. It has always been taken as self-evident that presently visible caves and poljes are intimately related genetically. The idea that their present configuration in a string might be only coincidental has never appeared. This is simpler to understand by considering that, in connection with polje formation, underground transmission systems have always been viewed as tube patterns, basically formed and functioning in epiphreatic (i.e. fluvial-like) conditions. In contrast, water tracing results, not to mention other hydrogeological research, indicated just the opposite. I. Gams (1963) noted that direct relations between the cave "levels" and surface "terraces" simply do not exist. Nevertheless, the necessary conclusions were not drawn, and he appears partly to have turned back to the general opinion (I. Gams, 1973 b).

3.3. Another "axiom" is that processes shaping the slopes around polje basins are fundamentally the same as those forming the closed basins themselves. Consequently, the apparent study of polje genesis turned into a study of their Quaternary transformations (A. Melik, 1955; I. Gams, 1965; R. Gospodarič and P. Habič, 1979). Two facts, self-evident from the viewpoint of the Pure Karst Model (F. Šušteršič, 1986 a, 1996), were neglected (F. Šušteršič, 1986 b): a) the share of slopes that might be specific to poljes is nearly negligible compared to those that appear generally in the neighbourhood (F. Šušteršič, 1987), and they always appear locally, and b) depression positions within the karst are not something exceptional, and depressions generated by any endo-dynamic process (being subsequently filled up within other geomorphic systems) might survive unmodified within the karst. In that case, only the questions of how and why the bottoms became, or possibly remained, flat is relevant.

3.4. Early theories invoking a tectonic origin for poljes failed due to field evidence (R. Gospodarič and P. Habič, 1979, p.25) that did not support contemporary explanations. Further detailed geological mapping (cited above) revealed a different tectonic pattern within the main Idrija Fault Zone. Students were still being influenced by the (otherwise refuted) contractional theory of Earth development, and continued to search for the impossible answer within the context of radial tectonics. They neglected the last decades' comprehension that the dynamics of the continental crust are basically tangential, and offer a number of potential mechanisms for the formation of closed depressions (M. Vrabec, 1994).

3.5. Too much interest has been directed towards the study of a few "important" caves, which are, at first sight, directly connected to the present watering and drainage of the poljes. Far more less spectacular, inactive, caves in the close neighbourhood (i.e. fragments of the same systems) were generally neglected, or at least, misinterpreted. Significant clustering of similar segments at some locations, far from the poljes, was simply overlooked. Consequently, nobody appreciated that the cave systems might have developed according to their own logic, totally unrelated to the poljes, and the present situation might be only coincidental. However, it appears that D. Kuščer (1963) realised that direct interpretation of the active caves together with polje formation might not be reasonable.

3.6. J. Rus (1925) noted that all of the poljes previously listed lie at the contact between limestone and dolomite. He offered an explanation of their genesis, arguing that the actual contact is crucial to polje formation. Today, the processes he listed seem rather naive, but his ideas appeared to receive support from H. Lehmann (1959). I. Gams (1973 b) combined Lehmann's classification with his own findings and the combined view become very popular, but despite being founded partly on field observations and partly upon theoretical calculations, it has never been elaborated into a consistent, convincing system. Nevertheless, the "contact" explanation inhibited further research, and many attempts to understand polje formation were suspended by the belief that *"poljes develop on contacts"*. The field evidence cannot be denied, but this is not the point. In the territory between the poljes, within the zone of the Idrija Fault, geologically completely equivalent contacts exist that display no tendency to evolve into polje-like depressions. As might be expected, many contacts outside the zone did not evolve into poljes either. Even more significantly, the Bloke polje (D) lies completely within dolomite.

4. OVERVIEW OF THE "HORIZONTAL" CAVES

Though the underground karst has been explored intensively for at least 200 years, blank areas still exist. Most of the efforts were directed towards finding presumed underground cave connections between the main poljes, yet no through connection has been explored. It has become clear that the accessible dry caves are just fragments of complex, collapsed and in-filled systems, and the active stream caves - which are relatively unfrequented - are just subaerial sections of basically drowned conduits.

The difference between the caves that have formed as system drains and the vadose caves is very clear. In this paper only the former group is discussed. These caves are referred to as "horizontal caves", though they are generally not horizontal in the true sense of the word. The structure of the 1534 known caves within the Slovenian part of the Ljubljanica catchment area is as follows:

Table 2:

V	Formed exclusively in the unsaturaded (vadose) zone	39.59 %
H	Formed at least partly in the saturated (phreatic or epiphreatic) zone	35.04 %
U	Unsufficient data to recognize the circumstances of formation	6.23 %
C	Transformed to undeterminable shape by collapsing	2.27 %
A	Artificially adapted to indeterminable shape	0.08 %
M	Missing data	16.79 %

Generally, it is believed that the ratio between the bulk frequencies of groups V and H is 2:1, but this figure is based mainly upon cavers' technical experience. Field inspection of many "vertical shafts" reveals that, although steep or really vertical, some of them are phreatic loop channels, and it is possible that if all the caves were re-examined the ratio might change in favour of group H. This paper is intentionally concerned with sub-set H and, unless stated otherwise, all the following considerations deal exclusively with this group.

Detailed study of these caves according to their (penetrable) dimensions revealed that four main classes exist. The least important is the group consisting of caves shorter and shallower than 10m. Because they were registered only exceptionally, their number is highly underestimated, and therefore they are omitted from further consideration.

Among the rest, the greatest frequency is provided by a group that appears to consist predominantly of fragments of longer caves or systems within several tiers. If this is so, an asymptotic approach to the maximum depth of about 300m, as predicted by S.R.H. Worthington (1991), could be expected. However, many such caves are accessible only through vertical vadose shafts, and this dimension becomes blurred, even if the expected dimension is correct.

Another group evidently encompasses "horizontal" caves that are accessible by mere chance, through relatively deep shafts.

In general, caves in the latter two groups are dry. Their walls have been heavily remodelled by collapse or the less extensive spalling of rock slabs, but in many cases it is clear that they were formed under D.C. Ford and R.O. Ewers' (1978) state 2 or 3 conditions. Preserved channels in the bedrock are never horizontal in the proper sense of the word. Phreatic development of the primary passages followed a relatively small number of bedding planes and joints. Most passage cross-sectional areas range between $10m^2$ and $100m^2$. Scallops are generally not preserved or, if preserved, they are barely distinguishable.

Most of these objects are relatively short, one corridor caves and, as a rule, their ends are choked by boulders, loam or, more rarely, by flowstone. Based on the data obtained in extensive excavations during the construction of the motorway between Ljubljana and Postojna, F. Šušteršič (1978 a) calculated that about 95% of the voids in the bedrock had been filled with red soil. More recent detailed mapping of the karst surface confirms this estimate. Thus, the present lengths of these caves are controlled to a great extent by the dynamics of collapse and in-filling/washing of bedrock openings.

The fourth group contains exclusively horizontal active caves, watering or draining some of the poljes. Their present condition matches the Ford and Ewers' (o.c.) states 3 or 4, but it must be stressed that none has really achieved the latter. The general pattern of these caves is a vertical zigzag of phreatic channels, partly incised by canyon-like sections. At some locations, especially in Planinska jama (**748**[2], Fig. 1), the mechanical stability of cave roofs has been surpassed and extensive collapse has occurred to re-establish equilibrium, forming huge, tunnel-like passages. Though some extensions are ended by frontal collapse, the general rule is that even passages some kilometres long end in deep and long "sumps". In the Rak (east) branch of Planinska jama, it is evident that the whole channel is submerged, as branching was discovered several hundred metres from the entrance of the "sump". Shorter caves belonging to the former two groups are common in the close neighbourhood of these caves, indicating that all of them belong to a single tier.

Given the maximum annual discharge and average cross-sectional area of main channels in these caves, and employing S.R.H. Worthington's equation for calculation of the dynamic equilibrium channel dimensions (1991, p.73, Eq. 5.9), it is possible to compute whether the general balance in these systems has been achieved or not. It emerges that "main" channels in the caves of the fourth group, even those that are exceptionally large among the others in the set, have not yet achieved dynamic equilibrium dimensions. On the other hand, if the cross-sectional areas of all the caves in a cluster (tier) are added together, their total area is many times greater than the maximum needed to transmit present drainage. It can be concluded that all these systems were formed in conditions that might differ completely from present ones.

5. SPATIAL DISTRIBUTION OF CAVES

It has already been mentioned that horizontal caves appear in clusters, implying an idea that such concentrations might reflect the positions of abandoned/active flow corridors. In the Ljubljanica catchment area the approximate area of influence of a cave was calculated as 1.38 caves per km^2. However, neglecting caves in the close neighbourhood would introduce great bias due to border effects, and also exclude the possibility of gaining insight into circumstances in areas on the outer side of the watershed. To diminish these effects, a wider area of south-central Slovenia, totalling 5997.27km^2, was taken into consideration, where 2489 caves have been explored and mapped on 4231.39km^2 of karstic rocks. Consideration of this area yields a value of 0.8 caves per km^2 of karstic rocks, and the statistical influence area of a cave becomes 1.25km^2. The absolute values have changed, but the proportions, which are the main interest, remain the same.

Simplified spatial statistics are presented on Fig. 5, which is an adapted cave density map of the Ljubljanica catchment area. Four regions are extracted:

a and b: areas where more than 4 caves of class H and of class V, respectively, appear per influence area (see Table 2), so that relatively stable proportions can be calculated.

a: count "H" per influence area / count "V" per influence area > 1;
b: count "H" per influence area / count "V" per influence area ≤ 1;

c: count "H" per influence area < 4, not regarding the number of caves "V".

d: no caves of group "H".

Several groupings are evident. In order to facilitate discussion, only those of special interest are numbered, and only the ones ranging along the Notranjsko podolje are discussed. The "H" enriched stripes along the polje borders are considered self-evident, and of no special interest.

No. 1: The "H" enriched zone contains relatively small (less than 20m^2 in cross-section) abandoned phreatic tubes about 300m above the present water-table. F. Šušteršič (1994) interpreted them as the highest tier within the lower Ljubljanica system, between the Planinsko polje and the Ljubljana Marsh, whose upper parts have been removed by denudation.

No. 2: The "H" enriched zone encompasses somewhat larger, highly collapsed dry passages, partly in dolomite, developed within a vertical range of more than 300m.

No. 3 and No. 4: The "H" enriched zones evidently fit together and they are separated only by a "V" enriched stripe. They encompass some of the longest river caves in the area, i.e. Postojnska jama (**747**), Planinska jama (**748**), Tkalca jama (**857**) and Zelške jame (**576**) (Figs. 1, 5). Only a narrow stripe of the "V" enriched zone separates it from the NW corner of the Cerkniško polje, the site of the continuation of the Zelške jame, i.e. Karlovice (**87**, **171**). R. Gospodarič (1976) and F. Šušteršič (1978 b) argued that the present flow direction in part of the system has been reversed with respect to the previous one.

No. 5: The "H" enriched zone is in all aspects similar to No. 2.

No. 10: The "H" enriched zone, containing Križna jama. Though smaller, it is similar to zones Nos. 3 and 4.

No. 11. The "H" enriched zone on the northern slopes of the Snežnik massif. Present conditions give rise exclusively to vadose karstification, if considering accessible caves. Relatively small, predominantly highly reworked passages, are found within a vertical range of nearly 1000m. As neotectonic activity is lifting the core of the Snežnik massif quite rapidly, all the caves might belong to a single tier, subsequently displaced vertically.

The evident similarity of some zones, as well as the sudden end of zone No. 11 just in touch with the Idrija Fault Zone, prompts closer inspection of their relationships. Comparable zones (i.e. Nos. 2 and 5, Nos. 4 and 10) are separated by the Idrija Fault Zone, and the displacements match the dextral strike-slip along the fault. Approximate displacements even match the apparent horizontal displacement along the Idrija Fault. Perhaps this holds true for zone No. 11, too, the counterpart of which might have been moved outside the Ljubljanica catchment area, and even out of Slovenia.

If returned to their, presumably, original positions, the paired zones fuse into single ones, if the narrow stripe of the Idrija Fault Zone is ignored.

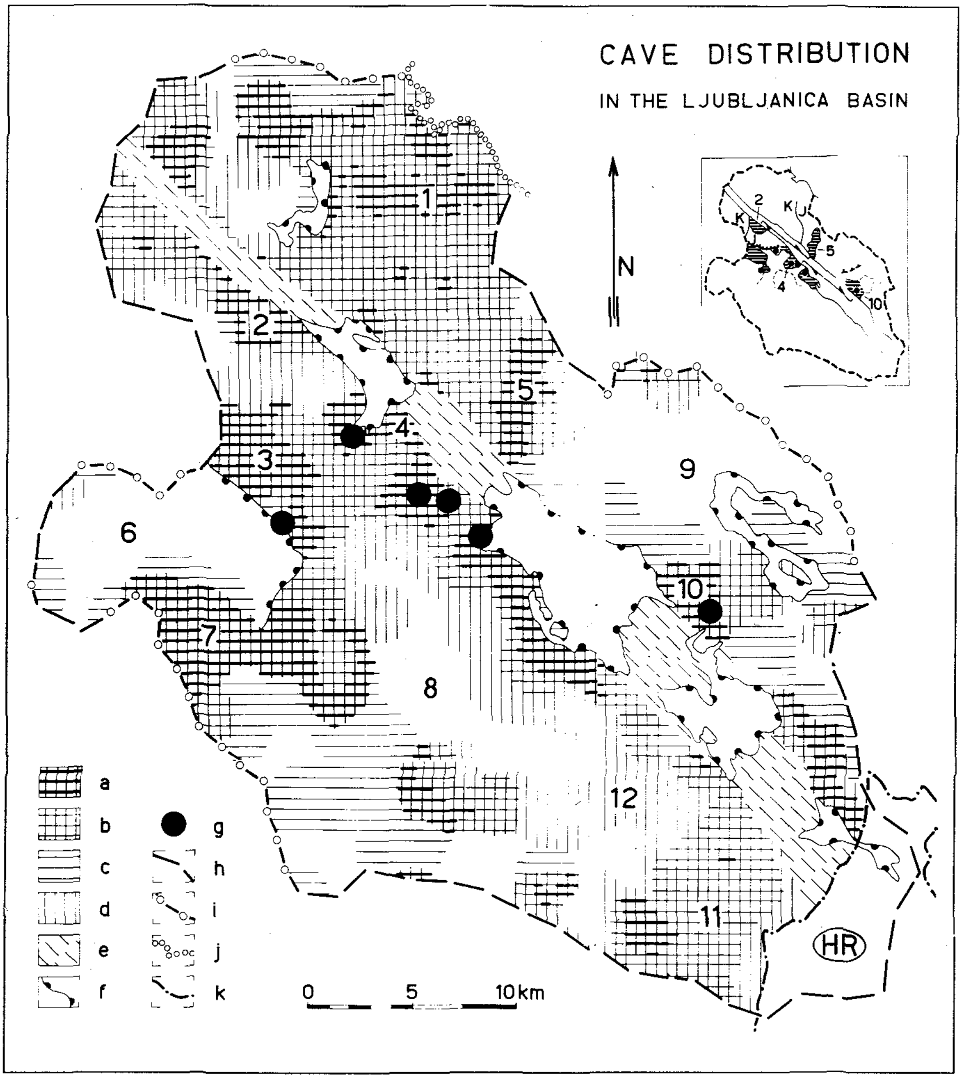

CAVE DISTRIBUTION
IN THE LJUBLJANICA BASIN
N
1
2
3
4
5
6
7
8
9
10
11
12
HR
a
b
c
d
e
f
g
h
i
j
k
0 5 10km

Fig. 5: Cave distribution in the Ljubljanica basin
a: count H ≥ 4 & count V ≥ 4 : count H / count V > 1
b: count H ≥ 4 & count V ≥ 4 : count H / count V ≤ 1
c: 1 ≤ count H < 4
d: no horizontal caves
e: zone of the Idrija fault
f: borders of the alluvial bottoms of major poljes and lower part of the Pivka basin
g: major river caves
h: approximative border of the karstic Ljubljanica catchment area
I: well determinable border of the karstic Ljubljanica catchment area
j: outflow border of the karstic Ljubljanica catchment area
k: international boundary
Numeration: See text!

Sl. 5: Razporeditev jam v porečju kraške Ljubljanice
a: Število H ≥ 4 & število V ≥ 4 : število H / število V > 1
b: Število H ≥ 4 & število V ≥ 4 : število H / število V ≤ 1
c: 1 ≤ število H < 4
d: Ni vodoravnih (H) jam
e: Cona Idrijskega preloma
f: Robovi večjih kraških polj in Pivške kotline
g: Glavne vodne jame
h: Približno določena razvodnica na kraških ozemljih
I: Jasno opredeljiva razvodnica
j: Odtočni rob kraškega dela porečja Ljubljanice
k: Mednarodna meja
Oštevilčenje: Glej besedilo!

Thus, all the major river caves, i.e. Postojnska (**747**, **472**, Figs. 1, 5), Planinska (**748**), Tkalca (**857**), Zelške (**576**), Karlovice (**87,171**) and Križna (**65**, **6286**) form one single string. This "mega" zone is, at the same time, also the richest in shorter, dry caves, i.e. fragments of conduits. The combination of zones Nos. 2 and 5 does not reveal so convincing a result, but the logic is the same. Both reconstructed "corridors" are orientated more or less west-east (however, this was not necessarily the flow direction), as are zones Nos. 1 and 7. Perhaps this indicates that all of them were formed in the same hydrogeological situation, which evidently differed from the present one.

Active stream caves within the string formed by zones 3, 4 and 10 are the largest within the karstic Ljubljanica basin (the caves on the outlet side of the Planinsko polje - Nos. **28**, **259**, **86** - are modest compared to the former ones). They are not situated in the region of the highest discharge between the Planinsko polje and the final Vrhnika springs. Rather, they are located approximately in the middle of the system, and they are arranged approximately at right-angles to the general flow direction. If connections confirmed by dye-test are considered, it becomes clear that, despite many bifurcations, non-accessible connections follow quite direct lines between the inlets and outlets. On the other hand, parts of the main caves string, notably between Cerkniško in Planinsko polje, are situated in quite illogical positions, especially if the geological situation at the inflow part of the Planinsko polje is taken into consideration (F. Šušteršič, 1978 b).

The conclusion that at least part of the transmission system formed under different hydrogeological conditions to those of today becomes the most readily acceptable. What these conditions were remains within the realm of speculation.

Detailed study was done on two locations north and east from the Planinsko polje (F. Šušteršič, 1994, 1996). In the former case a number of horizontal caves are known in the area, and even at first sight they appear to be ranged along the lower and upper contacts of dolomite packages. In Najdena jama (**259**), it is evident that about 3km of its main passages developed along the upper and lower contacts of the stratigraphically higher dolomite package, and along a third bedding plane within the lower Cretaceous limestones, parallel with and about 5m beneath the lower dolomite contact.

The primary tubes are lenticular to ellipsoid but their cross-sections have been altered locally by entrenchment (canyonisation). Apparently the passages are orientated either down/up dip or along the strike, but detailed inspection reveals that this is only an approximation. Passages formed along joints are greatly subordinate and generally they developed at the locations of break-through that provided links from one major bedding plane to another. Phreatic jumps, some more than 50m (downstream) up-wards, are not uncommon. Though some canyonisation has occurred, due to local sources of bedload, most of the system is typically phreatic, with no features suggestive of water-table formation. Later blockfall modification in some passages is evidently related to tectonic injuries of the parent rock.

Among other abandoned dry fragments, Kloka Cave (**3113**, F. Šušteršič, 1994) was studied in detail. Closer inspection of the development revealed three stages of relationship to geological structures:

- initiation along bedding planes;
- penetration into joints;
- expansion by collapsing of crushed zones of faults.

In the location known as Javorjev Grič, an area of about 1km^2 was mapped geologically and geomorphologically at 1:5000 scale. Special care was taken to observe and record all detectable originally underground karst phenomena that now appear at the surface due to denudation. Among the superficial karst phenomena, four types of underground ones were recorded: a/ openings of small phreatic tubes; b/ small collapsed features (<3m) evidently continuing to a choked tube; c/ segments of (sub-)vertical tubes, formed under phreatic conditions; d/ denuded cave passages filled with loam and other sediments. Accessible cave corridors were not found at this location, and true vertical (vadose) shafts were omitted from the previous list.

It appears that around Javorjev Grič an earlier sector of an abandoned tier is exposed. Despite the area being strongly re-worked by denudation, it was possible to observe that most traces of phreatic tubes lie close to either the upper or lower limestone/dolomite contact, which was, again, the most prone to channel formation. The relationship between joints and the channels is less well expressed, however, and more difficult to detect.

6. POLJES AND CAVES

Figs. 4 and 6 show longitudinal sections of the Notranjsko podolje, including the poljes, the caves and the intermediate relief, i.e. the "talwegs" of the previously supposed dry valleys. It becomes clear that the depressions, except for the Planinsko polje and the Loško polje, are relatively shallow. Only those two poljes are without any surficial inflow and it may be that the input of dolomitic gravel must have braked the corrosional (in this case) lowering of the rocky bottoms. The same principle might also be applied to the Babno polje, which has a karstic inflow, but extensive penetration of Pleistocene colluvial material is evident.

On the other hand, caves on the polje borders follow different patterns. Considering the accessibility, and probably origin, too, six basic types may be defined. Interestingly enough, they fit the inflow and outflow caves quite equally, though fundamental differences might have been expected.

CA: Completely inaccessible caves: vertical springs between boulders at the bottoms of funnel-like depressions, springs choked by boulders, "vertical" ponors in the bottoms of poljes. Massive digging has never revealed important cave continuations.

SF: Ascending or descending phreatic, siphon caves, with or without air bubbles.

DS: Short caves, direct extensions from the polje. In the case of springs it appears that they grew backwards, organising inaccessible voids into one main drain. On the outflow side, they appear to disintegrate into smaller tubes, according to Ewers (cf. Ford and Williams, 1989, p.251, Fig. 7.5), and dying out according to Atkinson's (1968) calculations.

PS: Parts of larger systems, open directly to the polje but displaying no direct relation to the polje.

EC: Epiphreatic, tunnel-like, river caves. Their present outlook is due to extensive (especially in the cold periods of the Pleistocene) input of fluvial bed load. Canyonisation is common, though the entrenchment scale is modest

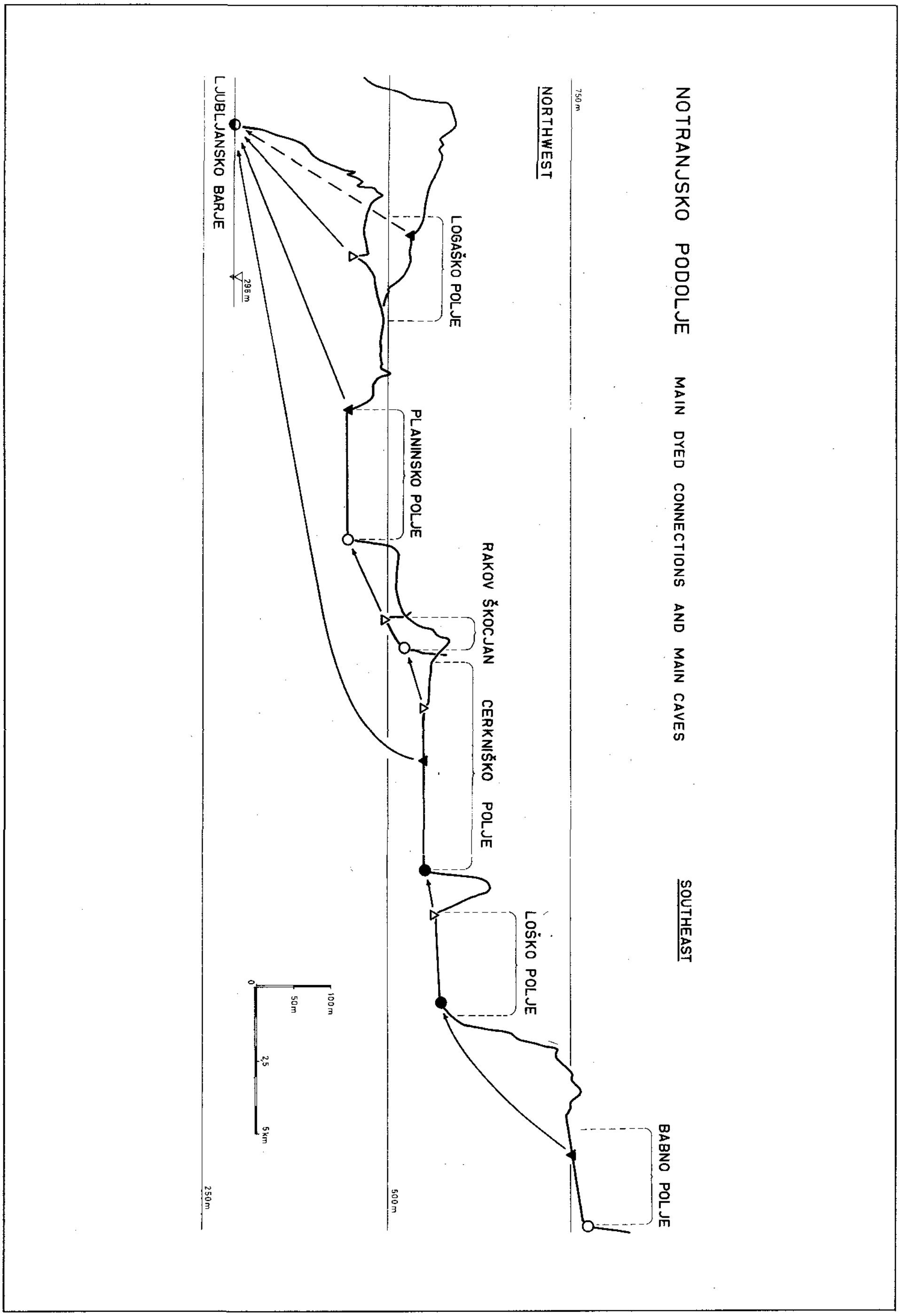

NOTRANJSKO PODOLJE
MAIN DYED CONNECTIONS AND MAIN CAVES
NORTHWEST
SOUTHEAST
750 m
500 m
250 m
LOGAŠKO POLJE
PLANINSKO POLJE
RAKOV ŠKOCJAN
CERKNIŠKO POLJE
LOŠKO POLJE
BABNO POLJE
LJUBLJANSKO BARJE
298 m
0
50m
100m
2,5
5km

Fig. 6. Main dyed connections
Signs identical with Figs. 1 and 4

Sl. 6. Glavne obarvane vodne zveze
Znaki identični s slikama 1 in 4

(generally less than 10m). It is very possible, though difficult to prove, that the passages below the present water-table have been filled with fluvial sediments, and that the present rivers flow close to the top of the tiers. Evidence of "anti-gravitational" erosion is common in these caves, but its true extent is difficult to establish. Anyway, it remains evident that their origin is phreatic, the water-table having been higher than the present polje level.

SH: Swallow holes of surficial water, gathered on the non-karstic surface, and plunging down to the deep water-table directly after crossing the contact. Their appearance resembles many contact caves, or mountain caves, composed of vertical sectors and intermediate meanders.

According to this classification, Table 1 might be continued:

Table 3, poljes within the Ljubljanica basin:

Inflow		Lbl	Name:	Outflow	
Type of cave(s):	Max. len.:			Type of cave(s):	Max. len.:
CA, DS	200 m ?	B	Babno polje	CA, DS	15m
CA		C	Loško polje	CA,PS	722 m
surficial		D	Bloke	CA	
SF, surficial	420 m	E	Cerkniško polje	CA,DS,EC	8760 m
PS,SF	3012 m	L	Rakov Škocjan	PS,CA	2845 m
surficial		F	Rakovško polje	CA	
surficial		A	Pivka basin	EC	19555 m
PS,SF,CA	6156 m	G	Planinsko polje	DS,EC	158 m
surficial		H	Logaško polje	SH	450 m
CA,SF	260 m	J	Ljubljansko Barje	surficial	

Table 3 shows more clearly than detailed discussion that there is no correlation between the polje type, its position within the Ljubljanica basin, and the type and length of the caves there.

However, some other rules become evident. The ES type caves (river caves) are situated where abundant input from the surface, including mechanical load of predominantly Pleistocene origin, appears upstream. This fits quite well with the (disrupted) flow corridor, including the longest caves in the area. Because Križna jama also partly meets this condition, it is not possible to say whether a well developed conduit system was able to transmit larger amounts of mechanical load, or, the opposite, that the load itself served as an abrasive to make the caves larger. In Planinska jama, autochtonous gravel, originating from the present collapse doline of Mala Koleševka (R. Gospodarič, 1976), brought about local entrenchments at least some dozens of metres deep.

Though the direct ponor caves of the Planinsko polje are of DS type (short caves, direct extensions from the polje), some hundreds of metres from the polje flood water appears in Najdena jama (**259**, Fig. 4, 5008+m long, 121m deep), Vranja jama (**88**, 326m long, 90m deep), Logarček (**28**, 2234m long, 83m deep), and some more distant caves such as Gradišnica (**86**, 345m long, 218m deep). There is no direct connection between the polje border and inland caves, as a vertical difference of about 20m between the flood levels on the polje and those within the system remains more or less unchanged regardless of the absolute flood level (F. Šušteršič, 1982). It was concluded (o.c.) that a strong filter must exist between the polje and the inner part of the tier.

Due to the close proximity of the Idrija Fault, the outer part of the system is much modified by collapse and it is impossible to identify the positions of the presumed former main entrances to the system, much less to detect their primary geological structures. Though the inner parts of the tier are clearly recognisable and fully support S.R.H. Worthington's (1991) findings, the sites of initial phreatic descent are completely missing. More importantly, connections between the polje and the karst underground are significantly impeded, and there is no trace of where the entrances to the caves behind might be. This suggests the idea that the cave system is older than the polje, and the present connections are subsequent and unelaborated. Caverns revealed by drilling, at depths down to 100m below the present polje floor, at least do not oppose this conclusion.

The Cerkniško polje lies exactly between the displaced parts of a large stream corridor, and direct connection to the Planinsko polje and its main draining caves is not likely. It may be concluded that the two poljes could be younger than the input/output system, and that the present relationships are coincidental.

7. CONCLUSIONS

Though as yet incomplete, the discussion above permits some conclusions to be drawn:

7.1 The identification criteria for poljes arose primarily as descriptive terms and have related to a popular classification since the very beginning. Later evolution of the polje concept has been bound closely to a single genetic theory, rather than to observed facts and processes.

7.2 The connections between polje formation and Dinaric tectonics must be reconsidered in the light of modern knowledge of tectonics.

7.3 Horizontal caves (or fragments of them) appear in well-expressed clusters, up to several kilometres in length, a few kilometres in width, and some hundreds of metres in depth. This pattern fits the notion of flow corridors within a single tier, as defined by S.R.H. Worthington (o.c.).

7.4 Features of at least two strings of clusters on both sides of the Idrija Fault can be correlated, and their displacements match the apparent displacement along the fault. This means that either the flow corridors were torn apart after formation, or similar structures, highly prone to similar karstification effects, had been established on both sides of a subsequent fault, and later activated.

7.5 The spatial orientation of these clusters only vaguely mirrors the present hydrogeological situation and the polje locations. There is evidence that present water flow makes use - as much as possible - of older voids, inherited from different conditions, and is only partly influenced by the poljes position.

7.6 Caves within a given tier were formed under phreatic conditions and reworked in vadose ones (in the hydrogeological sense). There are no traces of epiphreatic shaping, except in the ponor caves, where fluvial gravel is transported.

7.7 The phreatic passages are concentrated along a small number of bedding planes. In some cases it is evident that their directions do not follow any current structural framework, and that any penetration into joints was secondary. These bedding plane partings play the exact role of inception horizons, as defined by D.J. Lowe (1992). Joints and smaller faults are really important only as master structures to guide the formation of phreatic jumps within a tier, and they play an important role during its adaptation phase. More highly tectonically disrupted zones define areas of significant cavern collapse, or local slab spalling, during the subsequent decay of the cave.

7.8 Except in the direct ponor caves, where water flows on a bed of its own sediment and extensive adaptations by coarse bed load material appeared (I. Gams, 1959), no traces of fluvial organisation of the underground karst exist. Consequently, the input of fluvial bed load, rather than the position within the string of poljes, controls the further development of caves.

7.9 In at least two cases poljes appear to be younger than the presently active draining caves. The cave systems formed according to their own logic, with no influence from the poljes, and the present coincidence has caused only minor adaptations. On the other hand, formation of the poljes followed its own proper logic and the present coexistence and "co-operation" is merely incidental.

7.10 The lack of genetic connection between the poljes and their karst input/output pattern makes the idea of a previous fluvial phase, which should bring about the large mass removal, unneeded. The poljes are just oases of non-karst within the karst (J. Roglić, 1957), in the true sense of the word. Just as the appearance of groundwater at the surface in the desert is unrelated to the arid conditions, the existence of poljes within the karst has nothing to do with the karst itself.

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KRAŠKA POLJA IN JAME NOTRANJSKE

Povzetek

0. PREDGOVOR

E. Silvestru (1995, je zapisal da je kraško polje enkraten primer, kako so strokovni izrazi in njihovo pojmovno ozadje vstopali v krasoslovje. *"Neka... izredno pomembna značilnost je krasoslovju skorajda enkratna: izrazom, ki so kasneje postali temelj krososlovja, je geografija pripisala vsebino že davno prej, kot je krasoslovje postalo samostojna veda, ne da bi na osnovi novih kriterijev kdo kasneje prevetril definicije*" (Prevod F. Š.). Ljudski izraz za (kraško) polje je bil uveden kot strokovni termin, ne da bi kdo natanko premislil kaj pomeni kot tak, seveda pa še manj, kakšna bo odtlej njegova strokovna vsebina.

V svojem prispevku ne želim postavljati nove definicije kraškega polja. Na način, ki bi lahko odškrnil vrata globljemu spoznavanju odnosov med polji in okoliškim krasom, želim soočiti današnje poznavanje poljem bližnjega kraškega podzemlja in sedanje znanje o notranjskih kraških poljih.

1. UVOD

Previdevam, da so slovenskemu bralcu osnovne informacije o krasu Notranjske niso več potrebne in jih zato v povzetku izpuščam (Sl. 1).

Odkrivanje in spoznavanje notranjskih kraških polj se je odvijalo skupaj z vsebinskim razvojem strokovnega termina. Planinsko, Cerkniško in Loško polje (G, E in C kot so označena na sl..1) so bila samoumevna že J. Cvijiću (1893). F. Kossmat (1916) je dodal še Logaško (H) and Rakovško (F) polje, N. Krebs (1924) pa Babno polje. Setavljenka Kossmatove (o.c.) in J. Rusove (1925) karte (Fig. 2) je tedaj povzetek dela prva dobe. Šele A. Šerko (1948) je v svojem sistematičnem pregeldu ovrednotil vse zaprte kotanje, ki bi prišle v poštev in jih obdelal po enotnem kriteriju. Tako se je v naboru znašel tudi Rakov Škocjan, ki pa ga večina avtorjev ne prišteva k kraškim poljem.

F. Kossmat (o.c) je opazil, da se pravkar našteta polja nizajo v skoraj ravni črti vzdolž Idrijskega preloma, znotraj proge znižanega sveta, ki ji danes pravimo Notranjsko podolje (Sl. 2, 3). Navidezne podobnosti s Čepovanskim dolom so ga napeljale k misli, da je nastanek kraških polj v bistvu stopnja v zakrasevanju prvotno površinske reke. Ne glede na to, ali posamezni avtorji to stališče sprejemajo eksplicitno ali ne, in kljub zgodnjim opozorilom, da dejansko stanje ne ustreza šabloni, se je v ozadju razprav o notranjskih kraških poljih ohranilo kot aksiom takorekoč do danes.

2. POREČJE KRAŠKE LJUBLJANICE

Računska ploščina porečja Ljubljanice znaša 1779 km^2. 1100 km^2 od tega je na kraških kamninah, tako da je razvodnica ponekod določena samo približno (Sl. 1). Kraško zaledje vrhniških izvirov meri 1108,78 km^2 (K. Žibrik et al, 1976). Povprečni pretok za leta 1972 do 1975 znaša tam 38,60 m^3 s^{-1}, pri specifičnem odtoku 34,8 l s^{-1} km^{-2}. I. Gams (1966 a) je izmeril povprečen iznos denudacije 65 m^3 km^{-2} a^{-1}.

Kraški kamnini v osnovi sta večinoma mikritni, ponekod oolitni apnenec in dolomit, pretrežno mezozojske starosti. Značilna je njuna velika čistost, saj je netopnega ostanka večinoma manj kot 5%, ponekod celo manj kot 0.1%. Skupna stratigrafska debelina karbonatne skladovnice je okrog 6850m (J. Čar, 1996). Med nekraškimi kamninami se v pomebnejšem obsegu javlja le eocenski fliš.

Za geološko strukturo so značilni številni narivi (V. Placer, 1981; U. Premru, 1982) v smeri od severovzhoda proti jugozahodu, ki so nastali kot posledica kolizije jadranske podplošče z evropskim kontinentom. Postopno spreminjanje smeri potovanja plošč je povzročilo nastanek idrijskega desnega zmika (preloma) (Sl. 5, manjša karta). Terensko kartiranje (J. Čar, 1982; J. Čar and R. Gospodarič, 1984; I. Mlakar, 1969; F. Šušteršič, 1989) je pokazalo, da idrijski prelom ni popolnoma enovit in prem. Gre za več vzporednih prelomev, med katerimi je tektonsko močno poškodovana cona in znotraj katere se posamezni bloki premikajo precej neodvisno.

3. KRAŠKA POLJA NOTRANJSKEGA PODOLJA

V vzdolžnem prerezu (Fig. 4) se kaže Notranjsko podolje kot niz kotanj ob idrijskem prelomu (Sl. 2, 3).

Kljub stoletnim prizadevanjem, da bi pojasnili nastanek kraških polj, pravega odgovora na to vprašanje še nimamo. R. Gospodarič in P. Habič (1979, p.25) sta podala izčrpen pregled tolmačenj nastanka Cerkniškega polja. Misli gredo od čistega tektonskega spusta prek fluvialne erozije do korozije. Četudi je njuno delo doslej najbolj izčrpno, sta se končnemu odgovoru ognila in navajata le dejstva, ki vsako po svoje podpirajo katero izmed prej navedenih

Tabela 1, polja, ki jih prečka glavni tok (Sl. 1, 3):

Oznaka	Ime	Nadm. v.	Klasifikacija	
			Šerko (1948)	Gams (1994)
B	Babno polje	750 m	uvala	border polje
C	Loško polje	575 m	periodično poplavljeno polje	prelivno polje
E	Cerkniško polje	550 m	priodično jezero	robno polje
	Rakov Škocjan	500 m	periodično poplavljena uvala	/
G	Planinsko polje	450 m	periodično poplavljeno polje	prelivno polje

Tabela 1, Dodatek (sosednja polja, Sl. 3):

Oznaka	Ime	Nadm. v.	Klasifikacija Gams (1994)	Opombe
F	Rakovško polje	520 m	robno polje	znotraj cone, glavni tok gre mimo
H	Logaško polje	480 m	robno polje	zunaj cone, glavni tok gre mimo
A	Pivška kotlina		periferno polje	flišno ozemlje, izven cone
D	Bloke		robno polje	izven cone
K	Loški potok		/	izven današnjega porečja Ljubljanice
M	Zadlog		/	izven današnjega porečja Ljubljanice

opcij. To lahko pomeni, da grešimo že v samem pristopu, ali pa da zaključkov še ne znamo potegniti. Vsekakor pa moremo, kot opozorilo za vnaprej, izpostaviti nekaj šibkih točk v dosedanjem znanju.

3.1. Od prvih časov zanstvenega pristopa velja kras, in z njim polja, za nekaj prehodnega. Poglavitne kraške oblike naj bi bile na svoj način preoblikovane podedovane fluvialne. Kossmatovi (o.c.) nasledniki niso preverili njegovega, na analogiji temelječega sklepanja in ugotavljali, ali pričakovano fluvialno logiko lahko odkrijejo kje na terenu, ampak se odpravili na lov za "suhimi dolinami" (N. Krebs, 1924; J. Rus, 1925; A. Melik, 1928; R. Gospodarič in Habič, 1979), kjerkoli se je v tlorisu pokazala vzdolžna reliefna globel. Prodor klimatske geomorfologije je doprinesel le nove možne mehanizme za transformacijo samih kotanj. Zato so polja morala ostati tak ali drugačen produkt kraške piraterije.

3.2. Od začetka velja za samoumevno, da je današnja funkcionalna povezava kraških polj in jam tudi genetska, in misel, da bi bilo sovpadanje lahko naključno, se še ni pojavila. Velik delež takšnjega razmišljanja gre na račun "samoumevnosti", češ da so jame med polji nastale v epifreatičnih pogojih, da so takorekoč rečne struge, ki se jim bregovi stikajo v strop, ob enem pa neogibno navezane na "terase" ki naj bi se ohranile na površju. V slednje je sicer posredno podvomil že I. Gams (1963), vendar misli ni razvijal dalje.

3.3. Nadalnji nedokazani, a vedno prikrito navzoči "aksiom" pravi, da so procesi, ki oblikujejo pobočja okrog kraških polj, identični procesom, ki so izoblikovali samo kotanjo. Tako ni nepričakovano, da se se je preučevanje nastanka kraških polj izrodilo v preučevanje njihovega kvartarnega preoblikovanja (A. Melik, 1955; I. Gams, 1965; R. Gospodarič in P. Habič, 1979). Raziskovalci so spregledali dve dejstvi, samoumevni s stališča Modela čistega krasa (F. Šušteršič, 1986 a, 1996): a) delež pobočij, ki bi jih lahko imeli specifična za polja, je zanemarljiv v primeri z deležem tistih, ki se pojavljajo kjerkoli v okolici, b) položaj "v zaprti globeli"za kras ni nekaj izjemnega, in kakršnakoli zaprta globel, ki jo je izdelala endodinamika, ostane v krasu nezapolnjena. S stališča polij je tedaj pomebno edino vprašanje, zakaj postane v stiku z nihajočo podtalnico dno tako ravno.

3.4. Zgodnje teorije o nastanku polj, ki so jemale tektoniko kot bistveno, so spodrsnile zato, ker se zamišljena struktura ni ujemala s stanjem na terenu (R. Gospodarič in P. Habič, 1979, p.25). Novejše geološko kartiranje (Glej navedke zgoraj!) je postreglo s popolnejšimi podatki, ki odpirajo nove možnosti tolmačenja. V tej zvezi je potrebno poudariti, da se dosedanji raziskovalci nikoli niso povsem otresli logike sicer že davno ovržene kontrakcijske terorije, ki navpične premike izvaja iz radialne tektonike. Spoznanja o tektoniki plošč so pokazala, da zaprte globeli natajajo tudi pri tangencialnih premikih, kar je uspešno uporabil (M. Vrabec, 1994).

3.5. Prevelika pozornost se je usmerjala v majhno število "pomebnih" jam, neposredno povezanih z današnjim navodnjavanjem/odmakanjem polj. Odlomki obsežnih sistemov v neporedni soseščini so ostajali v senci, dlje od polj pa se sploh nihče ni obregnil vanje. Zato se niti ni moglo pokazati, ali se jamski sistemi morda ravnajo po svoji lastni logiki, ki se sploh ne ozira na polja in da je skupno pojavljanje zgolj slučajno.

3.6. J. Rus (1925) je opazil, da ležijo notranjska kraška polja na kontaktih apnenca in dolomita. Mehanizem za nastanek polj, ki ga je izvedel iz te ugotovitve, se nam kaže danes naiven, vendar je osnovno misel nepričakovano podprl H. Lehmann (1959). I. Gams (1973 b) je dopolnil Lehmannovo klasifikacijo z lastnimi opažanji ter jo utemeljil tudi teoretsko. Tako se je, kljub temu da je popolnoma funkcionalna, do danes popolnoma uveljavila in se takorekoč vsaka razprava o nastanku kraških polj razbije ob stavku, da *polja pač nastajajo na kontaktih*. Koincidence se ne da zanikati. Vendar je potrebno dodati, da polja na popolnoma enakih kontaktih v bližnji soseščini niso nastala, niti ne kaže, da kdaj bodo.

4. PREGLED "VODORAVNIH" JAM

Pred nadalnjo obravnavo sem 1534 registriranih jam v porečju Ljubljanice razdelil v naslednje skupine:

Tabela 2:

V	Nastale izključno v neprežeti coni ("navpične jame")	39.59 %
H	Nastale vsaj delno v prežeti coni ("vodoravne jame")	35.04 %
U	Razpoložljivi podatki ne zadoščajo, da bi opredelili pogoje nastanka	6.23 %
C	Podorno popolnoma spremenjene	2.27 %
A	Umetno popolnoma spremenjene	0.08 %
M	Podatki so pomanjkljivi	16.79 %

Kljub splošnemu prepričanju, da je "navpičnih jam" (skupina V) vsaj dvakrat več kot "vodoravnih" (skupina H), je število skoraj enako, zdi pa se, da bi pri se pri boljših podatki lahko celo zasukalo v prid "vodoravnih". V nadaljevanju članka nas zanimajo samo slednje in če ne bo posebej naglašeno, tudi sama besedica "jama" pomeni predstvanika skupine "H".

Podroben študij je pokazal, da jih lahko glede na dolžino in globino razdelimo v štiri skupine.

Posebej izstopa četrta skupina, kjer so zbrane izključno vodne jame, ki napajajo / odvodnjavajo kraška polja. Njihovo današnje stanje odgovarja tretjemu ali četrtemu stanju D.C. Fordovega in R.O. Ewersovega (1978) modela, vendar slednje ni doseženo nikjer. Splošni vzdolžni vzorec teh jam je navpično cikacakanje freatičnih kanalov, v katere se krajevno zajedajo plitva abrazijska korita. Le na nekaterih mestih je bilo vrezovanje tako obilno (Planinska jama, kat. št. **748**, Sl. 1), da je bilo mehansko ravnotežje sten porušeno in je prišlo do podiranja. Potapljanje v "sifone" je pokazalo, da večinoma ne gre za kratka, poplavljena kolena, temveč da so zaliti veliki deli svežnja, tudi če sami kanali ne segajo prav globoko pod gladino podatlnice.

Izračunavanje paragenetskega praga s pomočjo S.R.H. Worthingtonove enačbe (1991, 73, En. 5.9), na osnovi znanih pretokov in prerezov je pokazalo, da današnji prevodniki ne še niso dosegli kritičnih izmer, da pa jih skupni prerezi v vsem svežnju temeljito presegajo. To kaže, da so jamski sistemi nastajali v pogojih ki so se od današnjih temeljito razlikovali.

5. PROSTORSKA RAZMESTITEV JAM

Na osnovi prej navedenih številk lahko izračunamo, da zanaša v porečju Ljubljanice gostota jam 1.38 na km^2. Ker v tem primeru ne upoštevamo jam onstran razvodnice, je tak račun v njeni bližini lahko zelo pristranski. Da bi se temu izognil, sem upošteval 2489 jam južne Slovenije, na 4231.39km^2 ploščine kraških kamnin. Gostota se s tem zmanjša na 0.8 jame na km^2 - statistično vplivno območje jame tedaj pokrije 1,25 km^2 - kar pa razmerij, ki nas prvenstveno zanimajo, ne spremeni. Poenostavljeno prostorsko statistiko prikazuje slika 5. Posamezno šrafirana polja pomenijo:

a in b: območja, kje so znotraj statističnega vplivnega območja najmanj po štiri jame skupine "H" in skupine "V" (glej Tabelo 2!),;

a: število "H" / število "V" > 1;
b: število "H" / število "V" ≤ 1;

c: število "H" < 4, ne glede na število jam skupine "V".

d: ni jam skupine "H".

Posamezna nakopičenja so povsem očitna in da bi olajšali razpravo, so skupine oštevičene. Posebnega pomena so:

Št. 1: Ozemlje Ljubljanskega vrha, ki sem ga že prej spoznal (F. Šušteršič, 1994) kot najvišji, opuščeni sveženj v neposrednem zaledju vrhniških izvirov.

Št. 2: Nakopičenje v območju Grčarevca, kjer so sicer manjši jamski prostori, večinoma zelo poškodovani zaradi podiranja. Navpični razpon svežnja presega 300 m.

Št. 3 in št. 4: Nakopičenji, ki očitno sodita skupaj. Vanju spadajo nekatere najdaljše vodne jame v porečju Ljubljanice: Postojnska jama (**747**), Planinska jama (**748**), Tkalca jama (**857**) in Zelške jame (**576**) (Sl. 1, 5). Le ozek presledek loči to kopico od območja tik ob severozahodnem kotu Cerkniškega polja, kjer se nahajajo Karlovice (**87**, **171**), ki so naravno nadaljevanje Zelških jam. R. Gospodarič (1976) in F. Šušteršič (1978 b) sva mnenja, da je vsaj v delu tega sistema današnja smer vode zasukana glede na predhodno.

Št. 5: Nakopičenje, ki v vseh pogledih spominja na št. 2.

Št. 10: Nakopičenje, ki zajema tudi obe Križni jami. Čeprav manjše, spominja na coni št. 3 in 4.

No. 11. Nakopičenje na severovzhodnem obrobju Snežniškega masiva. Dandanes tu vlada neprežeta cona, kjer lahko nastajajo edino "navpične" jame. "Vodoravne" jame so sorazmerno majhne in drugotno precej spremenjene. Pojavljajo se v višinskem razponu prek 1000 m, kar bi lahko bilo posledica neotektonske aktivnosti na območju Snežnika.

Primerljiva nakopičenja, oštevičena s 2 in 5, pa 4 in 10) deli idrijski prelom. Medsebojhni razmiki se ne krijejo le s smerjo, ampak tudi z iznosom tlorisnega premika. Verjetno velja isto tudi za cono št. 11, katere nadaljevanje bi tedaj ležalo že na Hrvaškem.

Če pomaknemo podobna nakopičenja v njihovo predvideno prvotno lego, tako da izločimo posledice idrijskega zmika, se območja največjih jem zlijejo v en sam niz. Ta "mega" koridor je tudi najbogatejši z krajšimi jamami, to je odlomki sistemov. Verjetno sta oba niza nastala istočasno, v pogojih, ki so se povsem razlikovali od današnjih. Če je temu res tako, potem sta oba niza sterejša od idrijskega preloma.

6. POLJA IN JAME

Danes aktivne jame, ki so v neposrednem stiku s poplavnimi ravnicami polj, lahko razdelime v naslednje skupine:

CA: Popolnoma nedostopne jame: navpični izviri med bloki na dnu lijakastih kotanj; navpični ponori v dnih kraških polij.

SF: Vzpenjajoče se zalite freatične jame z ali brez zračnih mehurjev.

DS: Kratke jame, neposredni podaljški tokov na polju. V primeru izvirov kaže, da se podaljšujejo vzvodno; ponori se po Ewersovi shemi (cf. Ford in Williams, 1989, 251, 7.5) razcepljajo v manjše cevi, katerih prerez upada skladno z Atkinsonovimi (1968) računi.

PS: Deli večjih sistemov, ki jih kraška kotanja gladko seka, ne da bi se kazalo medsebojno učinkovanje s poljem.

EC: Epifreatični, tunelski rovi, preoblikovani kot posledica transporta velikih količin pleistocenskega grušča (I. Gams, 1959). Ne glede na to je freatična zasnova mnogokrat še razvidna.

SH: Požiralniki površinskih voda, zbranih na nekrasu. Voda se skuša po najkrajši poti spustiti do gladine podtalnice, zato so zančilni meandri in skoki, kot jih sicer najdemo v visokogorskih jamah.

Odnose s polji prikažemo tabelarično:

Tabela 3, kraška polja v porečju Ljubljanice:

Vtok			Ime	Odtok	
Tip jam(e)	Max. dlž.			Tip jam(e):	Max. dlž.
CA, DS	200 m ?	B	Babno polje	CA, DS	15m
CA		C	Loško polje	CA,PS	722 m
površinski		D	Bloke	CA	
SF, površinski	420 m	E	Cerkniško polje	CA,DS,EC	8760 m
PS,SF	3012 m	L	Rakov Škocjan	PS,CA	2845 m
površinski		F	Rakovško polje	CA	
površinski		A	Pivška kotlina	EC	19555 m
PS,SF,CA	6156 m	G	Planinsko polje	DS,EC	158 m
površinski		H	Logaško polje	SH	450 m
CA,SF	260 m	J	Ljubljansko Barje	površinski	

Iz Tabele 3 je popolnoma razvidno, da ni nikakršne zveze med položajem polja znotraj porečja Ljubljanice in tipom pritočnih/odtočnih jam.

7. ZAKLJUČKI

7.1 Kriteriji za definicijo polij so nastali kot opisni pojmi. Kasnejši razvoj se je preveč držal ene same genetske teorije in se premalo oziral na drobna terenska opazovanja.

7.2 Zvezo med nastankom polj in tektoniko Dinaridov je potrebno ponovno proučiti s stališča sodobnega pojmovanja tektonike.

7.3 Vodoravne jame, oz. njihovi odlomki, so zbrane v jasno izraženih kopicah, ki so dolge več kilometrov, nekaj kilometrov široke in dosegajo navpični razpon več sto metrov. Ta vzorec se popolnoma sklada z S.R.H. Worthingtonovo (o.c.) zamislijo svežnja.

7.4 Medsebojno primerljiva sta vsaj po dva para nakopičenj jam na obeh straneh idrijskega preloma in njihov razmik se sklada z tlorisnim premikom ob idrijskem prelomu. To pomeni ali da sta dva pretočna koridorja v resnici pretrgana, ali pa da so na obeh straneh preloma že pred premikom nastale strukture, zelo primerne za kasnejši razvoj kanalov, in bile po premiku aktivirane.

7.5 Prostorska orientacija teh nakopičenj se le slabo sklada s sedanjimi hidrogeološkimi razmerami. Zdi se, da današnji tokovi le uporabljajo - kolikor se pač da - starejše kanale.

7.6 Jame znotraj posameznega svežnja so nastale v freatičnih pogojih prežete cone, nato pa bile preoblikovane v neprežeti coni. Sledov preoblikovanja v epifreatičnih pogojih ni, z edinimi izjemami jam, kamor voda vnaša (je vnašala) večje količine proda.

7.7 Freatični rovi so nastali vzdolž manjšega števila lezik. V nekaterih primerih je očitno, da se ne ravnajo po nobenem od tamkajšnjih strukturnih vzorcev, kar pomeni, da so bili vsaj zasnovani pred orogenom. Nosilne lezike imajo v vsem vlogo začetnih horizontov, kot jih je definiral D. J. Lowe (1992). Razpoke in manjši prelomi so mesta, kjer so nastali freatični skoki med začetnimi horizonti znotraj sistema.

7.8 Razen v primerih neposredno ponornih jam, kjer teče voda po lastnem nanosu in je prišlo do obsežnejše mehanske erozije (I. Gams, 1959), nikjer ni sledov fluvialnih vplivov v podzemlje. Oblikovanost ponornih jam torej odreja značaj plavja, ne pa položaj polja v nizu.

7.9 Vsaj v primeru dveh polj kaže, da sta mlajši od sosednjih jamskih sitemov. Jame se oblikujejo po lastni logiki, ne glede na soseščino polj in danjašnja povezava povzroča le manjša prilagajanja. Po drugi plati pa ima tudi nastajanje in oblikovanje polj lastno logiko, sedanja povezava in sodelovanje pa sta predvsem posledica slučaja.

7.10 Ker ni dokazov za genetsko povezavo jam in polj, odpade tudi potreba po "predkraški" fazi. Polja so slučajne "oaze nekrasa v krasu", kar je povedal že J. Roglić (1957).