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GEOMORPHOGENETICS OF THE CLASSICAL KARST - KRAS

MORFOGENETIKA KLASIČNEGA KRASA

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Ivan Gams: Morfogenetika klasičnega Krasa

V času med eocenom in pliocenom so bile s temena krednega apnenčevega antiklinorija v osrednjem in zahodnem delu planote Kras in s kozinsko-podgrajske antiklinale erodirane flišne plasti, zaradi česar se je ob splošnem zniževanju okoliške ravnine ob pogojih zajezenega krasa razširjal in zniževal ravnik na razkritih apnencih. Največji del planote Krasa predstavlja najstarejši del kraškega ravnika. Na Krasu so se v pliocenu in kvartarju pasovi ravnika hitreje zniževali v smeri proti SZ, vmesno zastajajoče ali dvigujoče se površje pa je s tem dobilo obliko vzpetin na severozahodnem robu planote. Zaradi hitrejšega grezanja vipavske sinklinale so vodni tokovi prenehali teči preko planote Krasa še preden je bil fliš, ki jim je preprečeval pot proti jugu, odstranjen zaradi grezanja severnega dela Tržaškega zaliva. Zaradi tega na Krasu ni slepih dolin ali polj. Pač pa je veliko vrtač, površje je kamnito, zaradi česar je iz Krasa nastal splošni pojem kras. Obe značilnosti sta tipični za submediteranske dinarske kraške ravnike, gosto naseljene in obdelane ter zaradi tega brez gozdov.
Ključne besede: kras, kraški ravnik, robna korozija, sestavljeni kras, morfotektonsko površje v coni grezanja, Kras, slovenski primorski kras, Tržaški zaliv, Furlanska nižina, Istra.

Abstract UDC: 551.44

Ivan Gams: Gemorphogenetics of the Classical Karst - Kras

Between Eocene and Pliocene, erosion of flysch strata on the top of Cretaceous limestone anticlinorium in the central and western part of the Kras plateau and the Kozina-Podgrad anticline uncovered and widened - and simultanously lowered - the karst plain in the conditions of dammed karst. The largest portion of Kras plateau is covered with karst plain, its oldest part. In Pliocene, the karst plain was fractured and subsided towards the NW regardless of older folded structure; during this process, several zones of elevations were formed through slower subsiding or uplifting. Due to faster lowering of the Vipava syncline, water streams stopped running over the Kras plateau before the flysch, damming the waters from the Kras plateau to the south was removed due to the subsiding in the northern Gulf of Trieste. Thus, no fossil blind valleys or poljes are found on the Kras plateau. However, there is considerable density of dolines and the surface is stony, giving the karst its original name. Both phenomena are typical of deforrested, densely populated and cultivated Submediterranean Dinaric karst plains.
Key words: karst, karst plain, border corrosion, compounded karst, morphotectonical landscape in the subduction zone, Kras, Slovenian littoral karst, the Gulf of Trieste, the Friuli Plain, the Istria Peninsula.

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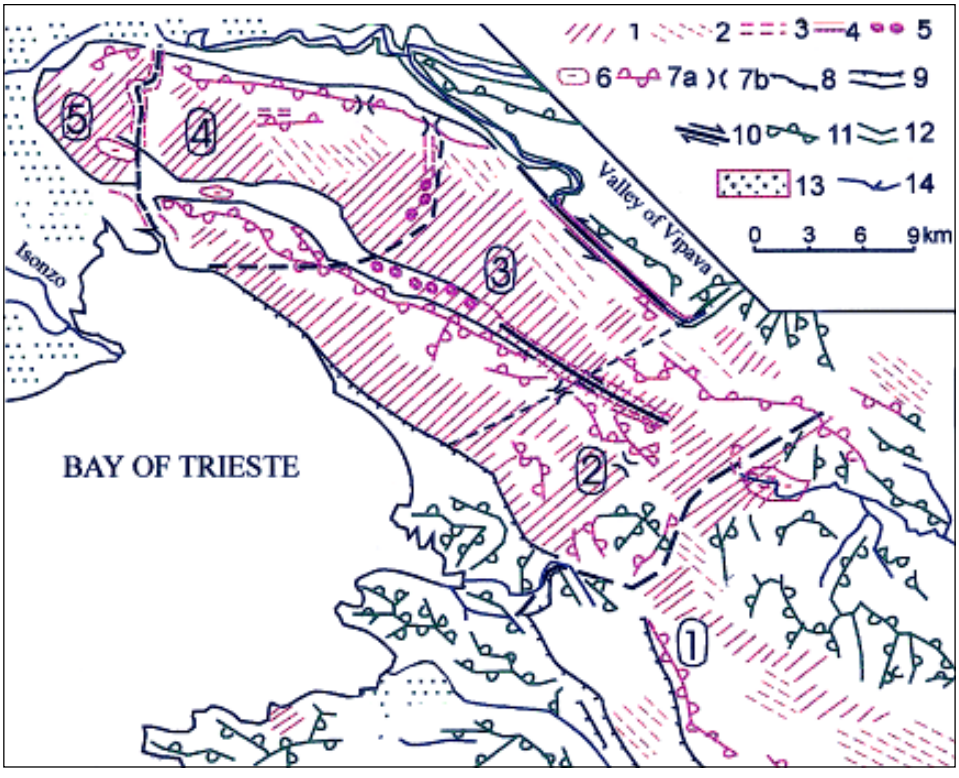
INTRODUCTION

In karst monographies the Kras region is usually defined as a plateau between the Gulf of Trieste on the south, flysch areas of the Vipava valley on the north, the Brkini hills on the east, and the lower alluvial gravel plain of the Soča (Isonzo) river on the west. Substantial Italian, German, and Slovene literature exists on geomorphological development of the Kras plateau (see references in Krebs, 1908, Maucci, 1960, Melik, 1960, Radinja, 1972, Habič, 1983). In German literature tectonic faults were given great attention at the beginning of this century (Kossmat, 1906). According to Krebs (1908, p. 175), as well as several earlier Italian and German geomorphologists, the formation of a karst plain in the Kras plateau can be explained by abrasion processes; Krebs also discovered several tectonic relief features on the plateau and - in its western part - the effects of young subsiding. In the second half of the 20th century, the erosion theory prevailed; according to it the plateau was formed by erosion of: a) the Reka (Timavo) river flowing on the surface in NW direction, forming a karst plain between Tržič (Monfalcone) and Divača on the northern side of the central range (the north plain) and b) a river flowing from the Podgrad-Kozina depression (half-graben), forming a karst plain between Bazovica (Basovizza), Opčine (Opicina), and Sesljan (Sistiana) on the southern side of this range (the south plain) (Maucci, 1960, Marussi, 1975, Melik, 1960, Radinja, 1967, 1969). Maucci (1953) attribut ed the formation of larger caves on the south plain to the sinks of streams flowing from the central range. The erosion theory was additionally confirmed by findings of sylicate gravels and sands, scattered all over the Kras plateau. Under the influence of a new discipline, climatic geomorphology, Radinja (1974) attributed the formation of the Kras plateau surface to the activity of the Reka river (flowing on the surface at that time), as well as rivers flowing from the northern flysch area of the recent Vipava valley which was during Pleistocene lowered below the surface of the Kras plateau due to erosion processes in cold climate which were faster than corrosion caused by the precipitation water on the Kras plateau in warmer Pliocene. Neotectonics as a primary factor was argued by Habič (1983) who delimited 34 morphotectonic units of the Kras plateau with tectonic and relief lines shown in a drawing. Recent geologists and geomorphologists from Trieste tried - among other - to establish relations between the lithology and types of the karst surface (Cucchi-Forti, 1992). They also used microerosion measurements to study recent corrosion process (Cucchi et al., 1994) and they tried to connect displaced stalactites with neotectonic movements. According to the direction of elevations and depressions in the relief of the littoral region of Slovenia, Gams (in print) established directions of the subduction of the Italo-Adriatic microplate towards the north along the edge of the fastest advancing promontory in the northern Friuli Plain. In this paper, such geomorphologic development is shown in more detail with morphotectonic drawing and schematic geological and relief profiles.

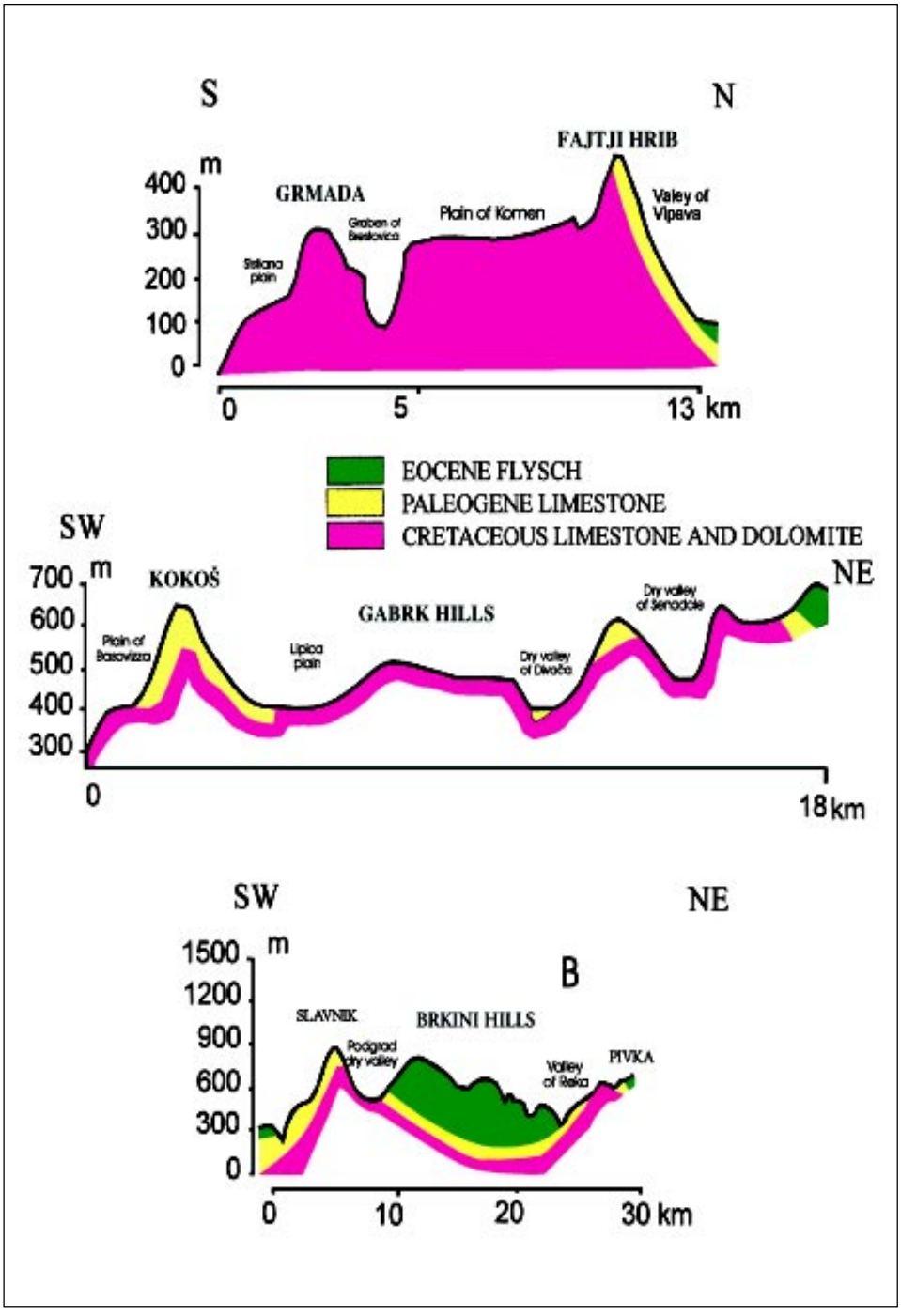
THE MORPHOGENETIC DEVELOPMENT

Basic macromorphologic elements of the Kras plateau are the karst plain and elevations in the form of ridges, ranges of ridges or larger isolated elevations, mostly hills. A subunit of the karst plain (see geomorphologic drawing) is dissected plain, i.e. higher convex or inclined plain which elongated closed depressions, dry valleys, and similar forms are found apart from dolines. Since on the plateau there are no signs of border corrosion or dry valleys on the contact between the karst

plain and elevations, which are usually common on border karst plains, and since higher remains of the plateau with dolines exist on tops of few elevations (i.e. the oval hill Grmada, 323 m, NW from Devin (Duino), the reconstruction of the relief is made on the presumption that the karst plain, formed by the corrosion, is the oldest and basic surface, developed under the conditions of dammed karst. The piezometric water level close to the surface due to dammed runoff from the karst as a precondition for the development of a wider karst plain is assumed by the majority of Slovenian geomorphologists (Gams, 1974, 1984, 1986, Radinja, 1974, Šušteršič, 1996). Where isotropic conditions for water percolation into epikarst prevail, the shape of the karst plain is preserved through many million years of surface lowering caused by the corrosive precipitation water.



Legend to the geomorphologic drawing
Corrosion forms: 1 - karst plain; 2 - dissected karst plain; 3 dry valley; 4 - gorge, valley; 5 - series of dolines and elongated closed depressions; 6 - larger closed basins;
Poligenetic forms: 7a - ridge in carbonate rock; 7b - gorge breaking through a hill chain;
Tectonic forms: 8 - escarpment; 9 - half-graben-like depression, dissected karst depression; 10 - horizontal slip along the fault line;
Erosion-denudation forms: 11 - ridge in impermeable rock; 12 - river valley; 13 alluvial plain; 14 - river, stream.


S
N
FAJTJI HRIB
m
400
300
200
100
0
GRMADA
Graben of Branikovica
Plain of Komen
Valley of Vipava
Stiklana plain
0
5
13 km
EOCENE FLYSCH
PALEOGENE LIMESTONE
CRETACEOUS LIMESTONE AND DOLOMITE
SW
NE
700
600
500
400
300
KOKOŠ
GABRK HILLS
Plain of Basovizza
Lipica plain
Dry valley of Divača
Dry valley of Senadole
0
18 km
SW
NE
B
1500
1200
900
600
300
0
SLAVNIK
BRKINI HILLS
Podgrad dry valley
Valley of Reka
PIVKA
0
10
20
30 km

In this paper, the relief features are grouped in the following units:

1. Border hill chains and ridges: 1a) northern (between S.Michele and Štanjel and between Gradišče above Kobdilj and Senožeče); 1b) south-western, considerably lower, between Nabrežina (Aurisina) and Globajnar hill (454 m) above Trieste. Elevations were partly formed also as a consequence of weaker corrosion in Palaeocene limestones.
2. Central range between Medja vas (Medeazza) and Sežana and between Sežana and Divača (the latter: Taborski griči = hills).
3. Gabrk between Divača and Senožeče.
4. The karst plain. 4a) the karst plain; 4b) higher karst plain dissected by karst depressions.

The division of once obviously uniform karst plain, which is now divided by narrow hill chains, is one of the arguments to conclude that the elevations are younger than the karst plain. Except for the Istria Kras, no Eocene flysch remained on the elevations. If the streams had dissected the flysch caprock with their valleys, they would have deepened with their lower sections into the limestone bedrock in the final phase and would have been preserved there. Such valleys are not visible even in the western part of the Opčine (Opicina) karst plain where streams supposedly flowed from the elevations into the caves (Maucci, 1960). The Vilenica cave with no traces of valley on the surface is among these caves (Gams, 1984).

In the entire area of the Kras plateau Jurassic and Cretaceous carbonate rock is on the surface as well as Palaeocene and lower Eocene limestone and middle and upper Eocene flysch (sandstone and marl). Therefore, Oligocene, Miocene, Pliocene and (apart from rare exceptions) Quaternary sediments are not present which means that an erosion/corrosion phase prevailed at that time. Correlate sediments could probably be found in the Friuli Plain where, however, relatively poor data is available on the deeper sediments.

The bedrock of clastic Quaternary sediments is found at depths of 180 m under the western edge of the Kras plateau, 285 m at Grado and approximately 500 m in the Tagliamento delta. At the bottom of the Gulf of Trieste, there are not many fine-grained marine sediments. The Holocene sea reached the Kras plateau 7,000 years ago, the Istria peninsula 10,000 years ago, the Marano lagune 5,500 years ago, and the Tagliamento delta 9,000 years ago (Marocco, 1989). The analyses of the pollen taken from the bottom of fans of the Istrian rivers Rižana and Dragonja revealed only traces of steppe flora from the last glacial age, while Holocene sediments were found in the cap rock (Šercelj, 1996). On the outer margin of the Istrian carbonate plate, inclined towards the west, 1,000 m thick Pliocene fine-grained clastic sediments were found lying directly on Eocene marls half way between Venice and the Istrian coast. Accordingly, Oligocene and Miocene were there a continental phase with prevailing river erosion. There, the thickness of mid-Eocene sediments is over 500 m (Premec et al., 1998, p. 257). Istrian Jurrasic-Cretaceous carbonate plate, reaching the elevation of 400 m above the sea level on its eastern edge south of Pazin, is submerged deep under the seabed in the middle of the Gulf of Trieste.

The beginning of the karst plain development on the Kras plateau can accordingly be placed back into the time of Eocene flysch removing. However, since flysch is over 500 m thick even today i.e. in the Brkini hills, and since it has long been eroded on the central and western Kras plateau, the beginning of the karst plain development can obviously be placed in long-lasting and different geological past.

According to the age and characteristics of the surface, the Kras plateau can be divided into the following units, named mostly after the main settlements on the plateau. The study of geological development is based on Slovene - Croatian geological maps in the scale of 1:100,000 (the sheets of Gorica, Trst, Postojna, and Ilirska Bistrica), including also geological profiles.

1. Northern Istria Kras. Main direction of ridges is NW-SE due to the pressure from the SW (Gams, in print). Recent elevations range between 400 - 1028 m.

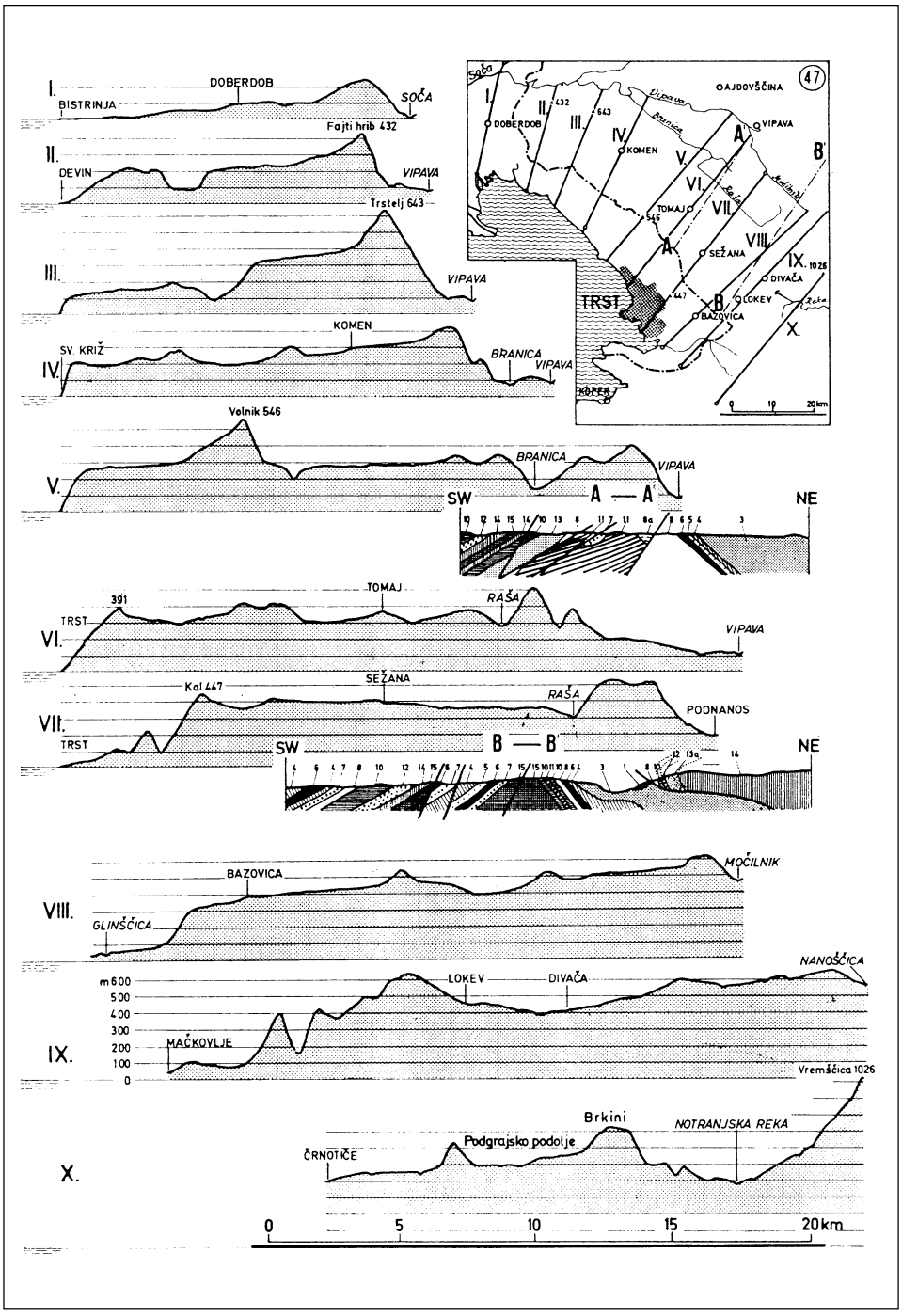
a) Folding and partial overthrusting of younger strata by older strata, which started after the deposition of Eocene flysch.

b) Erosion phase probably lasted more than 20 million years in Oligocene and Miocene. This can be concluded from the erosion and corrosion (flysch is partly carbonate!) of several hundred meters thick flysch and in some places Palaeogene limestones of the same thickness, removed from the anticlines. The narrow karst plain which developed on their top has been widening and lowering along with general lowering of the flysch surroundings. The anticline is now uncovered in the Kozina - Podgrad depression. Flysch in the Brkini hills towards the north is subsided several hundred meters into syncline depression, while towards the south, in Koper Littoral, flysch forms the hills in the Trieste syncline. On the transverse section across Materija, the limestone plate is now 12 km wide.

c) The phase of Pliocene fracturing of the lithosphere along vertical or inclined fault planes of mostly Dinaric direction; increasingly faster subsiding of karst plain zones and partially the whole area towards the NW, increasing of relative relief of the intermediate zone now forming the Slavnik ridge (1028 m). Waters flowing in from the Brkini hills were deepening and planating the subsiding depression between Kozina and Starod, where the PalaeoReka river supposedly flowed. Because allochthonous rivers are not flowing into the SW part of the limestone plate in the area of Podgorje and Socerb Kras, the lowering of the surface has been there less intense, resulting in preservation of Palaeogene limestones and remains of Eocene flysch on the surface.

Rocks of different age are found on the Slavnik ridge formed on the SW side of the Kozina - Podgrad anticline. In some locations on the top and uninterrupted on the SW slope, limestone of Palaeocene and Eocene age is preserved, while on the opposite slope Cretaceous limestone is found. On less subsided Podgorje Kras where the surface was initially planated to the same height as tops of flysch ridges in Koper hills (Kokole, 1956), only a several km wide trench is subsided between the Bazovica (Basovizza) karst plain and the Socerb Kras as a promontory of the Trieste sincline, filled with Eocene flysch. The river system of Rosandra (Glinščica) is found there. Its bedrock, Palaeogene limestones, is rising in steps towards the SE reaching also the Podgorje Kras, but the karst plain around Petrinje has not been dissected considerably by erosion.

Faster subsiding in the northern flysch area of Brkini between Vreme and Ilirska Bistrica basin drew the main water course - the Reka river - into recent, relatively narrow valley. The formation of the Vreme valley - the largest blind valley on the margin of Brkini (Radinja, 1964) - can be attributed also to flysch erosion in the initial phase: the contact of flysch with Palaeogene limestone in the bedrock is rising in steps towards west. From 360 m, near Vremski Britof, this contact rises to 424 m in Škocjan, 3 km away. Before the development of the Vreme valley, waters from the Brkini hills flowed over the border limestones and then underground towards the SE, i.e. towards the subsided flysch area between Bazovica (Basovizza) and the surroundings of Dolina (San Dorligo). Above this village, 200-300 m high steep Palaeocene and Eocene limestone escarpment was formed along


I.
DOBERDOB
BISTRINJA
SOČA
Fajti hrib 432
II.
DEVIN
VIPAVA
Trstelj 643
III.
VIPAVA
IV.
SV. KRIŽ
KOMEN
BRANICA
VIPAVA
V.
Volnik 546
BRANICA
VIPAVA
SW
A — A
NE
VI.
TRST
391
TOMAJ
RAŠA
VIPAVA
VII.
TRST
Kal 447
SEŽANA
RAŠA
PODNANOS
SW
B — B'
NE
VIII.
GLINŠČICA
BAZOVICA
MOČILNIK
IX.
MAČKOVLJE
LOKEV
DIVAČA
NANOŠČICA
Vremščica 1026
X.
ČRNOTIČE
Podgrajsko podolje
Brkini
NOTRANJSKA REKA
0
5
10
15
20km
AJDOVŠČINA
47
DOBERDOB
KOMEN
VIPAVA
TOMAJ
SEŽANA
DIVAČA
LOKEV
BAZOVICA
TRST
KOPER
0
10
20km

Cross-profiles and geological structure of the Kras.
Geological profile: 1. Quaternary, 3 - 6. Tertiary, 7 - 13. upper Cretaceous, 14 - 16. lower Cretaceous. 3 - flysch , 8a - 11: calcareous shalles with flints, 12. littoral formations, 13a - 14. dolomite. The rest - limestone: 6. Cosina formation, 7. Danian, 8. Senonian, 9 - 11. Turonian, 12 - 14. Cenomanian limestone. (According to: M. Pleničar, Stratigrafski razvoj krednih plasti na južnem Primorskem. Geologija 6, Ljubljana 1961).

the Socerb Kras. The road construction after 1995 revealed the cave passages also directed towards the SE (Mihevc - Zupan, 1996). Deeper passages in the Kačna jama cave and the Claudio Skilan cave, however, are directed towards the NW.

In Quaternary, the same tectonic processes continued - faster subsiding in the Friuli Plain and subsiding in the Gulf of Trieste advancing towards the north, which uncovered the flysch dam on the southern side of the limestone Kras plateau, however with no hydrologic effect because deeper underground waters under the Kras plateau were already flowing towards the NW. This caused the drop of the karst water level under the surface in the Kozina - Podgrad depression and enabled the streams which were carrying more gravel from the Brkini hills in colder Quaternary climate - together with the tectonic uplift at the reactivated fault line - to start at the ends of deepening valleys to widen the sinks into blind valleys along the straight-lined fault line on the contact with Palaeocene limestone. The depth of blind valleys is therefore increasing towards the ESE (Mihevc, 1994), while their volume is related to the amount of water carried by the streams and their carbonate hardness (Gams, 1962).

2. Basovizza, Divača and Senadole Kras. It contacts the previously discussed unit along the line Dolina (San Dorligo) - Rodik - Škocjan - Vremščica, while its western border runs along the line Villa Opicina (Opčine) - Sežana - Veliko polje pri Senožečah. The WNW - WSW to NW - SW direction of ridges prevails.

Phase a) In this area the role of flysch in the upperVipava valley and flysch in the Gulf of Trieste was similar to the role of the Brkini flysch area in the formation of the karst plain in Kozina-Podgrad depression. Initially, streams flowed across the Kras plateau on the surface and later underground towards the south. Ceilings of their caves, filled with mostly sylicate clastic sediments, were uncovered by the construction of the motorway; in other cases, ceilings collapsed themselves after the corrosion lowered the surface (Mihevc - Zupan, 1996). Eocene flysch and afterwards limestones were removed and the karst plain was formed in which Cretaceous and Palaeocene-Eocene limestones appear in belts.

Phase b) After the Pliocene faulting and differentiated tectonic movement of stripes along the faults in WNW-ESE direction, the series of elevations divided Basovizza (Bazovica) and Divača karst plains as well as the dissected karst plain near Senožeče and a dry valley near Senadole. Corrosion removed only upper Cretaceous limestones and dolomites from the surface of Gabrk elevation, while Palaeocene-Eocene limestone cover remained. On the top of Vel. Gradišče (741 m), a geological dome where strata are falling in concordance with the slope in all directions,

the contact of Palaeocene limestone and Eocene flysch cap rock remained 600 m above the sea level, which is several hundred meters above the surrounding limestone surface. The hill is situated 13 km from flysch near Bagnoli (Botač) where its bedrock is several hundred meters below the sea level. In Grotta del guano cave in the Rosandra valley, a 9 cm move of strata (probably from the postglacial III) towards the NE was discovered, which is transverse to the Kras plateau structure (Cucchi-Forti-Semeraro, 1979). In the area around Kačiče - in the extention of the Brkini ridge - the dissected karst plain between Divača and Kozina is convex. Other development phases were subject to similar processes as shown in Northern Istria Kras, however, without formation of blind valleys.

3. Central Kras. The NW border runs from Sistiana (Sesljan) over Veliki Dol to Branik. In this part of the plateau, the northern karst plain reaches maximum width (up to 8 km). The NW-SE to WNW-ESE direction of ridges prevails. In this and in the westernmost parts of the Kras plateau only Cretaceous limestone and dolomite remained on the surface. Before the formation of 11 km long straight narrow gorge of the Raša stream along the Raša Dinaric fault line, streams from the Vipava valley were flowing onto the Kras plateau (Radinja, 1974). The edge of the karst plain, stretching towards the SE to the contact with Eocene flysch, was cut off by the Raša valley. Streams from the flysch area flow onto the limestone only in the 4 km long section in the Senožeče dissected karst plain. Streams from theVipava valley did not form blind valleys and large caves, because their water is more mineralized (the mineralization of those presently flowing into Senožeče karst plain is between 170-200 mg $CaCO_3$/l) (Radinja, 1972). Streams flowing from the Brkini hills are less mineralized. The plateau is inclined towards the south, which also holds for the southern tectonically inclined karst plain, narrowing towards the west, where near Sistiana (Sesljan) the border part subsided below the sea level.

4. Kostanjevica Kras. The prevailing ridge direction is W-E. From the phase of Pliocene diferentiated tectonic faulting and vertical movement, Trstelj (643 m) is the highest ridge on the northern border between the most subsided western part of theVipava valley and Komen - Kostanjevica karst plain. Its northern slope is also the slope of the Cretaceous anticlinorium. From the top, Palaeocene and Eocene limestone, as well as lower Eocene flysch follow toward N, while on the southern side only Cretaceous limestone and dolomite are found. In the pediment, there is a parallel, much lower ridge between Temnica and Kostanjevica villages with a dry valley in between, while further to the south, obliquely uplifted dome-shaped dissected Komen karst plain follows between Kostanjevica, Vojščica and Sveto. On its southern end, Brestovica half-graben is found, 7.5 km long, up to 80 m deep and up to 1.4 km wide dry valley with locally even floor. In its eastern part, the terrace named Žekno is preserved on both sides at the same elevation as the Komen karst plain - witnessing the younger formation of the half-graben between them.

5. Doberdo Kras. From the highest northern range with the 275 m peak, the plateau inclines to the south where it is gradually transformed into the karst plain 80-100 m above the sea level (Radinja, 1969). Further to the south, the uneven surface lowers and to the east of Monfalcone gradually becomes a ridge-and-valley type of karst. Its lowest valleys are subsided under the Quaternary alluvium. The Kras plateau rises above the Soča gravel plain like an arc-shaped escarpment, gaining height towards the north.

A GENERAL OVERVIEW OF THE KRAS PLATEAU DEVELOPMENT

From the five described parts of the Kras plateau, the initial phase is best preserved in the Istria Kras. In other parts of the Kras plateau, the role of the Brkini flysch region in this phase was taken by Eocene flysch in theVipava valley, while the role of flysch in Koper Littoral was taken by the higher flysch area on the northern edge of the Gulf of Trieste, i.e. in the Trieste flysch syncline. Still active processes and forms of karst surface planation on the eastern border of the flysch trench in the Glinščica (Rosandra) basin, where shallow flysch cover is still found in shallow depressions of the Podgorje Kras, are the same as they were elsewhere on the Kras plateau at the final phase of limestone uncovering after the flysch cover had been eroded. After that, the role of planation was taken by water streams presumably running to the south across the Kras plateau. The carbonate Cretaceous anticlinorium remained the widest (6.5 km) in the Istria Kras. In the central part of the plateau, it narrows to 5.5 km, on Kostanjevica Kras to 4 km and on Doberdob Kras to 3 km. Due to advancing of Italo-Adriatic plate, the pressure has been increasing on the eastern and northern borders of the geologic structure. The area of mostly mountainous Southern Limestone Alps and the Dinaric Alps is 180 km wide along the Trieste - Kranj - Podjuna (Jauntal) line, while it is only 60 km wide from the northern border of the Friuli Plain, which is a geotectonic subduction zone, to the Austrian Weissensee. Between the Idrija fault line and the only paraautochtone, i.e. Western Istrian carbonate plate, the total horizontal movements of strata packs amounts to 67 km (Placer, 1981). This is mostly the consequence of growing compression due to the advancing of Italo-Adriatic plate towards the north. Therefore, the direction of ridges, valleys and trenches in the Julian, the Karnian, and the Gail Alps is W-E. The Kras plateau retains this direction only in its westernmost part, in Doberdo and Kostanjevica Kras. In the remaining, border part, the direction of ridges is Dinaric (NW-SE) or adapted to Dinaric (WNW-ESE). Along two fault lines with the Dinaric direction the horizontal slip towards the NW is visible on the Gorica geological map. At Divača fault line near the village of Povir, a part of Palaeocene has been teared-off and moved 9 km towards the NW, to the village of Kreplje. Similar is true for the Raša fault line: a patch of Cretaceous limestone, teared-off in the curve of the Raša valley, was moved 2.5 km towards Štanjel. The compression of the Kras plateau caused rising of ridges and hills and simultaneous subsiding of intermediate sections which remained mostly planated.

The karst plain on the Kras plateau therefore started to develop in different geological periods after the erosion and partial corrosion of Eocene flysch. The corrosion planation of the carbonate rock is still continuing. Comparing to neighbouring river basins and considering the annual precipitation or specific water runoff from the Kras plateau, current corrosion activity is approximately 50 microns a year. At current intensity of the corrosion, the surface could have been lowered by 1250 m in 25 million years (after mid-Oligocene). However, due to scarce steppe vegetation in cold Pleistocene periods and more intensive evapotranspiration in warmer Neogene climate, while the effects of aridization of mid-Pliocene climate in the Mediterranean are unknown, the corrosion appears to have been much weaker. 600-1000 m of sediment was removed from the top of anticlinorium on the western Kras plateau (see geological profile of the Kras plateau in the drawing!). Using the equipment for microcorrosion measurement, lowering of the stony surface in the range 0.03 - 3.01 (the average of 0.02) mm a year was established in the Trieste part of the Kras plateau (Cucchi, Forti, Ulcigrai, 1994).

Initially, the karst plain of the Kras plateau was developing in a narrow belt between two flysch areas in a vast plain comprising also a neighbouring flysch area. This belt has been widening along with the lowering of the karst plain and the surrounding area.

The contact of fractured limestone anticlinorium with Eocene flysch of the Vipava syncline has the shape of an arc, while in the south the contact with the Trieste flysch syncline is straight-lined in the Dinaric direction. In the NE of the plateau the inflow of rivers to the Kras was interrupted by faster flysch lowering in theVipava valley and by the young narrow valley of the Vipava river tributary Branica together with the straigh-lined Raša. In the W-E directed northern hill chain, three streams formed two gorges. The first gorge (NE-SW direction) is 60-160 m deep and 1.8 km long; it cuts through the hill chain at the elevation of 298 m between peaks Sv. Martin (475 m) and Galerija (383 m). After its formation the edge of the northern karst plain was deepened by additional hundred meters. Along the fault line where the gorge is situated, a 1.5 km long dry valley with the N-S direction was formed between the SW end of the gorge and the village of Mali dol, followed in the same direction by a series of elongated closed depressions to the village of Gabrovica where they surround Ježmarca hill (267 m) in a semi-circle. A deeper uninterrupted dry valley continues and deepens below Vočji Grad and Kregulišče towards the Brestovica half-graben. The other gorge (N-S direction), named Železna vrata (Iron Gate), is 60 - 160 m deep and 0.75 km long and is located between the peaks of Trstelj (643 m) and Kačnik (500 m). On the edge of the northern karst plain, there is only a shorter series of dolines from the gorge towards the SE in the direction of Škrbina. The third stream from the north formed a 12 km long dry valley between the villages Miren and Jamlje (Iamiano). On the contact of Doberdo Kras with Kostanjevica Kras, in the proximity of Italian-Slovenian border, there is a 8 km long series of deep dolines and two uvalas and in the north, a 1.5 km long dry valley. South from Iamiano (Jamlje) it continues into the lowlands near the Timavo river spring. According to one theory, the Miren - Jamlje depression is an abandoned blind valley of the Soča or the Vipava rivers (Krebs, 1907, Gams, 1974, Melik, 1960); the other opinion is that these are connected uvalas and dolines (Radinja, 1969). But these dolines, elongated closed depressions and uvalas (the latter near the villages of Visintini and Devetaki) form only lower parts of the depression. In higher parts, the depression appears in the form of a 1 km wide continuous curved dry valley inclined towards the north. This means that the deepening of closed depressions started at the bottom of the abandoned river valley, coming from the north. A curved fault line runs along the dry valley which is demonstrated by increasing elevation difference towards the north between the higher edge of the Kostanjevica Kras and the lower Doberdob Kras. Because uneven vertical movement probably took place along curved subvertical fault line, the tectonic divergence on both sides of the fault line is understandable in terms of recent tectonic geomorphogenesis in the subduction area (see Summerfield, 1991).

Where the surface inflow of water from the direction of theVipava valley stopped before the flysch in the Trieste syncline, damming the Kras plateau on the opposite side, was removed, blind valleys and karst poljes were not formed by the tributaries from the north. After the lowering of the surface towards the west, rivers were deepening the cave passages and during the process they formed (among others) a 8470 m long and 278 m deep multi-level Kačna jama cave west of Divača and 5 km long and a 346 m deep Claudio Skilan cave near Basovizza (Bazovica). The profile of the underground Reka river is interrupted, with the nickpoint at the pothole of Labodnica (Grotta Trebiciano) where it flows 12 m above the sea level. Before the nickpoint, the profile inclination is

Ph. 1: Karst plain in the central Kras plateau beyond the lower part of the straight Raša valley.
Foto 1: Kraški ravnik onkraj spodnjega dela ravne doline Raše.

Ph. 2: Karst plain south of the settlement of Štanjel is one of the most planated and vast karst plains in the Kras plateau.
Foto 2: Ravnik južno od naselja Štanjel je je med najbolj uravnanimi in obsežnimi na Krasu.

Ph. 3: On the inclined karst plain south of Divača the cave which is also inclined was uncovered during the motorway construction. Both are affected by younger tectonical movement.
Foto 3: Med gradnjo avtoceste je bila na nagnjenem ravniku južno od Divače odkrita nagnjena jama. V obeh primerih so vzrok nagnjenosti neotektonski premiki.

Ph. 4: A dry valley where the village of Senadole is situated. In the valley and its surroundings there are no traces of impermeable sediments. Thus, the fluvial development is questionable and tectonic explanation is more acceptable.
Foto 4: Suha dolina vasi Senadole. V njej in v okolici ni nobene sledi vododržnih sedimentov. Tako je fluvialni nastanek vprašljiv in tektonika bolj sprejemljiva.

greater than the surface inclination of the karst plain, while from there to the Timavo river springs at the coast (23 km distance), the profile inclination is smaller. In this lower part the majority of its passages is subsided under the sea level due to inclined subsiding of the Kras plateau. Its westernmost and the most subsided part is covered with clastic sediments of the Soča river; only a limestone hill of Sv. Anton outcrops from the sediments near Therme di Monfalcone. It is not out of the question that Doberdob Kras is (in geological terms) the following phase of the faster subsiding on the edge of the Friuli plain which is in the process of subsiding and spreading. The formation of the Miren - Iamiano (Jamlje) fault line can be explained in this context, as well as a series of depressions between Branik and Tublje pri Komnu as the most recent phase. More intense subsiding also reaches as a promontory from Doberdob Kras across the Doberdob closed depression into Brestovica half-graben. On the eastern side of the depression between Miren and Iamiano, a relatively straight-lined and steep, weakly dissected slope appears with the local name reber (escarpment), commonly meaning formation at the fault line also in other parts of Slovenia. The escarpment near Iamiano turns from northern to eastern direction and continues on the northern side of Brestovica half-graben. This is a 14 km long and on average 1 km wide tectonic trench (half-graben) with a flat bottom (according to geological map, the anticline is at the bottom!), at first of W-E and later NW-SE direction. The northern slope at the edge of the karst plain is up to 160 m and the southern slope up to 180 m high. From the eastern end near Pliskovica a series of deep uvalas and dolines continues along the Sežana fault line towards the SE in the bottom of the shallow and up to 1.5 km wide non-distinctive dissected depression whose southern slope, part of the central range, is higher than its northern slope on the edge of the karst plain. Towards the SE the depression continues below Dutovlje and Šmarje through Dane (it means bottoms!) to Žirje. From here to Divača, it has a shape of up to a 1.5 km wide dry valley between Gabrk hills and Tabor hills. The karst plain in its bottom connects Komen karst plain with the Divača karst plain. It is connected to 12 km wide Basovizza-Vilenica karst plain through less than 1 km wide passages near Sežana and Lokev.

In the first half of the 19th century the Kras plateau became a symbol of a stony, barren landscape full of dolines. However, this was the case only on karst plains, while not on uplands. Stones outcropping from the ground were more visible because forests were removed almost entirely from the densely populated karst plain.

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MORFOGENETIKA KLASIČNEGA KRASA

Povzetek

Ta morfogenetska analiza planote Kras izhaja iz oblik kraškega površja, iz stratigrafije globinskih terciarnih sedimentov v Furlanski nižini in Tržaškem zalivu in geološke sestave površinskih skladov na planoti. Dokazuje erozijsko fazo v oligocenu in miocenu, saj sredi južnega Tržaškega zaliva, kamor so odtekale vode s Krasa, v vrtinah med eocenom in kvartarjem ni teh sedimentov, klastični pliocenski in kvartarni sedimenti v krovnini pa so čez 1 km debeli (Marocco, 1989, Premec et al., 1998, Šercelj, 1996). Po odložitvi eocenskih flišev je erozija s korozijo (fliši so delno karbonatni!) s temena antiklinorijuma Krasa in antiklinale v Podgrajskem podolju (Kozina - Starod) odstranila flišni pokrov in ob splošnem zniževanju okoliške ravnine ob pogojih zajezenega krasa razširjala in zniževala ravnik na razkritih apnencih. Zaradi izotropnih razmer na ravniku je ta na planoti do sedanjosti tudi po znižanju za 600- 800 m ohranil uravnanost. Kot v sosednjem slovenskem Primorju na vzhodnem robu ugrezajoče se Furlanske nižine so se tudi na Krasu v pliocenu in kvartarju pasovi ravnika hitreje zniževali v smeri proti SZ, kamor so se zato usmerili površinski in pozneje podzemeljski vodni tokovi, vmesno zastajajoče ali dvigujoče se površje pa je s tem dobilo obliko hrbtov, slemen in izoliranih vzpetin na severozahodnem robu planote (s Trsteljem, 643 m), v srednjekraškem nizu Griža (127 m) -Volnik (546 m) - Stari tabor (603 m, v Taborskih hribih) in v nižji jugozahodni Veni (z Grižo, 368 m). Pobočni procesi so na vzpetinah uničili ostanke ravnika, razen J in JV od Brestovice (Grmada, 323 m, Vrh Gnojil, 143 m). Na kupolastem Velikem Gradišču (741 m), ki ga geološka karta označuje za domo, je ostal v n.v. približno 600 m stik paleocenskega apnenca s krovnim eocenskim flišem. Če bi na drugih vzpetinah ostal flišni pokrov, bi erozija v apnencih zapustila do danes razpoznavne, v apnence vrezane spodnje dele teh dolin, ki pa jih ni. Domneve o nastanku jam ob potokih z bližnjih, nekdaj s flišem pokritih vzpetin so zato manj gotove kot mnenje, da so vzpetine nastale po eroziji fliša in so torej mlajše tvorbe od ravnika. Dele do 8 km širokega ravnika povezujeta le dve okoli 1 km široki prodorni dolini, v Sežani in Lokvi, obe v srednjekraškem nizu vzpetin. Doberdobski Kras je vzdolž Dola Devetakov (Devetacchi) ugreznjen za 10 - 50 m bolj kot Kostanjeviški ravnik. Ugreznjenje na južnem robu Doberdobskega Krasa, ki ga je med dolinami izvirnic Timava zasula naplavina, se ob rebri, to je tektonsko nastali brežini, nadaljuje v Brestoviški dol, ki je tektonsko “pol-jarek”. Nad njegovim južnim robom je v isti višini korelat kostanjevišjega ravnika v predelu Žekenca. Vmesni Dol je torej mlajši. Ta tektonski “pol-jarek” se do Pliskovice konča, a se proti vzhodu v severnem podnožju t..i. srednjekraške vzpetine ob divaški prelomnici nadaljuje v obliki neizrazitega, do 1,5 km širokega podolja, ki povezuje Divaški in Komenski ravnik. Ob dinarski divaški prelomnici pri Povirju in ob raški prelomnici pod Štanjelom je zmik za 2 - 3 km razmaknil kredne sklade.

Istrski del Krasa je bolj ohranil ostanke prvega, predpliocenskega razvoja površja, kar kaže

prečni geološki profil. V dnu Podgrajskega podolja so odstranjeni mlajši kredni apnenci in breče, kar kaže na pospešeno korozijo domnevne Pra-Reke kot glavne odvodne žile Brkinov, dokler je ni mlajše grezanje med Vremsko dolino in Ilirskobistriško kotlino prestavilo proti severu v današnjo ozko dolino. Na severovzhodni strani hrbta Slavnika so na površju kredni, na nasprotnem pobočju pa paleogeni apnenci, ker je hrbet ob srednjepliocenskem tektonskem razlamljanju nastal na jugozahodnem krilu antiklinale. V Podgorskem Krasu pri Petrinji erozija še zdaj odstranjuje plitvo odejo eocenskega fliša s paleogenega apnenca. Poševno grezanje Podgrajskega podolja je omogočilo brkinskim potokom ob ravni tektonski prelomnici v paleogenih apnencih izdelati proti jugovzhodu vse globlje slepe doline. Teh ni na ostali planoti Krasa, ker se je Vipavska dolina znižala pod raven kraške planote prej kot je mladopleistocensko grezanje v Tržaškem zalivu doseglo rob Krasa.

V dvigajočem se nizu severnih vzpetin so od severa pritekajoče reke izdelale prodorni dolini nad Branikom in v Železna vrata. Južno in jugozahodno od prvo imenovane se ob isti prelomnici zvrstita dve suhi dolini in niz vrtač ter dolov. Tak a bolj izrazit niz zaprtih kotanj je nastal tudi v dnu prvotno rečne, nato suhe doline med Mirnom in Jamljami.

Današnje površje Krasa so torej ustvarili poligenetski procesi, med katerimi sta v ospredju korozija in tektonika. Slednja je, po površinskih oblikah sodeč, ustvarila relief, značilen za območje kompresije ene plošče z drugo in stiskanja trde litosfere nad bolj plastično astenosfero, kot to ugotavljajo v novejši geomorfologiji (Summerfield, 1991). Hitrejše napredovanje italijansko-jadranske mikroplošče v furlanskem, v Alpah najbolj potresnem pomolu in razširjanje proti vzhodu, je prineslo najzahodnejšemu delu Krasa orografsko smer Z-V in najhitrejše grezanje. Doberdobski Kras zahodno od Dola Devetakov bo v geološki prihodnosti z ugreznenjem pod erozijsko terminanto sledil potopljenemu najzahodnejšemu delu kredne plošče, ki le še z osamelcema San Martino (475 m) in Galerija (383m) štrli na površje sredi prodne soške ravnine.

Korozijsko zniževanje apneniške planote odkriva strop vodnih jam. Že prej dostopne ali pri gradnji avtocest razkrite jame so izvotlili pritoki s ponori na več sto metrov višjem ravniku (Mihevc & Zupan, 1996) pred nastankom vzpetin. Etažni, 8470 m dolgo in 276 m globoko Kačno jamo ter 5 km dolgo in 346 m globoko jamo Claudio Skilan pri Bazovici so v Divaškem Krasu izvotlili z Brkinov pritekajoči vodni tokovi po poševni premaknitvi Krasa.

Goste vrtače in kamnito površje, ki so osnova nastanka pojma kras iz prve polovice preteklega stoletja, so povsod v submediteranski klimi značilni za gosto poseljene in obdelane ravnike.