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ALLUVIAL FANS ON CONTACT KARST: AN EXAMPLE FROM MATARSKO PODOLJE, SLOVENIA

VRŠAJI NA KONTAKTNEM KRASU: PRIMER IZ MATARSKEGA PODOLJA, SLOVENIJA

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Abstract UDC 551.448 (497.4)

Uroš Stepišnik, Mateja Ferk, Petra Gostinčar, Luka Černuta, Karmen Peternelj, Tomaž Štembergar & Urša Ilič: Alluvial fans on contact karst: an example from Matarsko podolje, Slovenia.

Several types of contact karst are found within the Slovenian karst, but the most common is the ponor type, which usually appears between flysch and limestone. The most extensive contact of this type is in western Slovenia, in the area of Matarsko podolje, where a variety of typical contact karst depression features can be found. In the northwestern part of Matarsko podolje two types of alluvial fans occur. One alluvial fan has an active process of alluvial sedimentation on its surface and is distinct in shape, just like alluvial fans in fluvial geomorphic systems. The other type represents relict alluvial fans on contact karst. They are fan-shaped surface features in carbonate bedrock. Their formation is a result of the gradual removal of alluvial cover and the chemical denudation of carbonate bedrock on areas that were covered by alluvial fans. Geomorphological features and processes on alluvial fans, and the influences of alluvial fans on the development of contact karst have been investigated in detail.

Key words: contact karst, karst, alluvial fan, relict alluvial fan, Matarsko podolje.

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Uroš Stepišnik, Mateja Ferk, Petra Gostinčar, Luka Černuta, Karmen Peternelj, Tomaž Štemberger & Urša Ilič: Vršaji na kontaktnem krasu: primer iz Matarskega podolja, Slovenija

Na slovenskem krasu je več različnih tipov kontaktnega krasa. Najpogostejši je ponorni tip kontaktnega krasa, ki se navadno pojavlja med fliši in apnenci. Najdaljši kontakt te vrste v Sloveniji je na območju Matarskega podolja v zahodni Sloveniji, kjer se pojavljajo mnoge kraške kotanje, ki so značilne za kontaktni kras. Na severozahodnem delu Matarskega podolja se pojavljata dva tipa vršajev. En vršaj z aktivnim procesom sedimentacije rečnih nanosov na površju in ima obliko, ki je značilna za vršaje v fluvialnem geomorfnem sistemu. Drug tip predstavljajo reliktni vršaji na kontaktnem krasu. To so površinske oblike podobne vršajem na karbonatni matični podlagi. Njihov nastanek je vezan na postopno denudacijo rečnih naplavin na območjih, ki so jih prekrivali vršaji, in kemično denudacijo karbonatne matične podlage. Podrobneje so bile proučene geomorfne oblike in procesi na vršajih ter vpliv vršajev na razvoj kontaknega krasa.

Ključne besede: kontaktni kras, kras, vršaji, reliktni vršaji, Matarsko podolje.

INTRODUCTION

In Slovenia the most common form of contact karst is the ponor type of contact karst, where waters from a non-karstic catchment flow onto the karst surface. Such karst has developed where the non-karstic surface is at a higher elevation or where the hydraulic gradient of water is directed into the karst and is higher than the surface gradient (Mihevc, 1991).

Surface karst features typical of the ponor type of contact karst in Slovenia are blind valleys, ponor steepheads (Mihevc, 1991), trough valleys, karst plains (Gams, 2001) and collapse dolines (Stepišnik, 2006). Caves within contact karst contain allogenic rivers and have horizontal passages of epiphreatic origin (Gams, 2004). Ex-

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tensive sections of denuded horizontal caves have been found on the karst surface (Mihevc, 2001).

The aim of the research was a detailed investigation of aspects of a contact karst area in the northwestern part of the Matarsko podolje in western Slovenia, where four alluvial fans have been revealed. The article describes processes on contact karst in a specific hydrological situation, where alluvial fans occur. Development processes of contact karst alluvial fans and alluvial fan-like surface features in carbonate bedrock were studied in detail. The term relict alluvial fans is used to describe fan-like surface features in carbonate bedrock that are the result of denudational processes acting on alluvial fans on contact karst.

The research included detailed geomorphological mapping of the alluvial fans and the hydrological hinterland area. Longitudinal profiles of the fans and of the Podseč stream were measured in detail. Thickness of alluvium cover was established using Earth resistivity imaging. The SuperSting R1/IP earth resistivity meter developed by Advanced Geosciences, Inc. was used for data collection. Survey was conducted with a dipole-dipole array, with a 5m separation between electrode pairs. The data were processed to generate two-dimensional resistivity models using EarthImager 2D resistivity inversion software developed by Advanced Geosciences, Inc.

One of the fans is undergoing active alluvial sedimentation, and alluvial flysch sediment is covering the limestone bedrock, forming a typical fan-shaped landform in ground plan. The other three fans are relict. Those fans are not composed of alluvial material typical of fluvial alluvial fans, but they are fan-like surface feature in carbonate bedrock. They are situated in areas that were covered by non-carbonate alluvium of earlier alluvial fans. Alluvium has been denuded from the outer sections of the fans, and the process of karstification of the underlying carbonate bedrock has begun. The result of the gradual removal of the alluvial cover and chemical denudation of newly re-exposed carbonate bedrock is a typical longitudinal profile shape that is characteristic of relict alluvial fans. To date relict fans have not been mentioned in the karstological literature as being typical surface features of contact karst.

Mihevc (1991) established that the alluvial fans in the study area are a morphologically less distinct element of contact karst. On the basis of the alluvial cover on the karst and alluvial sediments in the doline floors in the lower sections of fans, he concluded that parts of fan-like features were also previously covered by flysch alluvium. According to Gams (2004), the formation of alluvial fans on karst is related closely to the colder periods of the Pleistocene, when accumulation of water-borne sediments related to physical weathering was more intensive. Gams established the term "pseudo-alluvial fans" to describe fans on karst that lack recent accumulations of alluvium on their surface.

AREA OF MATARSKO PODOLJE

The most distinctive example of ponor type contact karst in Slovenia is the Matarsko podolje area, in southwestern Slovenia. Matarsko podolje is a planated lowland area between the Brkini Hills in the northeast, the Slavnik Mountains in the southwest, the Karst plateau in the northwest and Brgudsko podolje in the southeast. It is elongated northwest–southeast, with a length of 18 km and a width between 2 and 3 km. The elevation in the northern part, near Kozina, is about 490 m and in the southeast, near Starod, the elevation is about 640 m (Fig.1).

The northeastern part of Matarsko podolje area is the contact between flysch of the Brkini hills and carbonate bedrock of Matarsko podolje. At the contact Eocene flysch bedrock overlies Palaeocene limestones, and away from the contact these give way to Cretaceous limestones, dolomites and limestone breccias. The dip of the beds is from 20 to 60 degrees towards the northeast (Pleničar *et al.,* 1975).

Matarsko podolje has the greatest lateral extent of all the ponor contact karst areas in Slovenia. The surface is relatively flat, and rich in dolines, large collapse dolines and caves. 24 allogenic streams sink at or near the contact between the flysch and the carbonate bedrock, forming such typical ponor karst features as blind valleys and ponor steepheads (Mihevc, 1991). Caves in the hinterland of the allogenic streams ponors are mostly vadose shafts, together with longer sections of relict and active horizontal epiphreatic passages. There are also more than 80 collapse dolines (Stepišnik, 2006) and numerous longer sections of sub-horizontal denuded caves on the karst surface.

Fig. 1: The location of the study area.
Sl. 1: Lega proučevanega območja.

ALLUVIAL FANS ON CONTACT KARST

The area studied in detail is situated in the northwestern part of the Matarsko podolje. In general it consists of three geomorphological units; a higher flysch area to the northeast, an area of active alluvial fan and three relict alluvial fans on the contact between flysch and limestone, and the karst plain of Matarsko podolje.

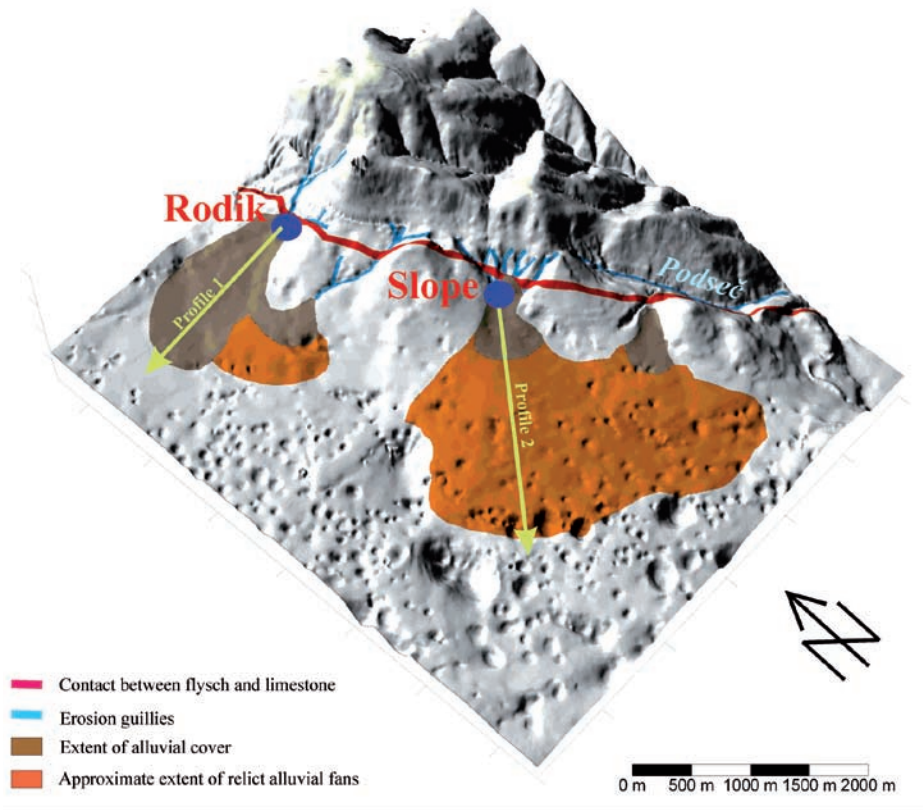

Fig. 2: Sketch of the alluvial fans area.
Sl. 2: Slika območja vršajev.

In the flysch area a fluvial geomorphological system is present, with many erosion gullies on the steep flysch slopes. The flysch crest in the area is 300 m higher than the lower karstified surface of Matarsko podolje. The feeder channels terminate at or near the contact between the flysch and limestone, where the apices of four alluvial fans are situated. Although water flow is only periodic at present, fan deposits cover the local area of Palaeocene and Cretaceous carbonate bedrock near the contact. The Podseč stream, which drains eastwards to the Brezvica

blind valley, has beheaded most of the feeder channels in the hinterland of the relict alluvial fans.

The studied alluvial fans lie along a 2.3 km section of the contact karst between the flysch and limestone bedrock. In the northwestern part of the area, near the village of Rodik, is an active alluvial fan covering an area of approximately 0.3 km^2. A smaller relict fan, with an area of approximately 0.18 km^2 is situated farther southeast. Near the village of Slope is an extensive relict alluvial fan about 1.14 km^2 in area. In the southeastern part of the study area a smaller relict fan, with an area of about 0.41 km^2, is situated at the bottom of the wide fossil valley of Bilendol (Fig. 2).

The only alluvial fan in the area is the fan near Rodik. From the flysch bedrock an erosion gully with periodic water flow extends on to the upper section of fan area. There are no karst features on the surface of the fan, which consists of flysch alluvium. The outer sections of the fan merge into the flattened karst surface, which is covered with surface karst features, that increase in density with distance from the fan. Grikes become bigger and their density increases, and dolines become greater in number, with steeper slopes. Near the outer sections of the fan are some sub-horizontal sections of cave passages, partly filled with flysch pebbles and loam. Those caves might have functioned as ponors for alluvial fan waters, so sediment fill and the morphology of the caves should be studied in detailed in the future.

In the area of the relict alluvial fans and their hinterlands are traces of relict erosion gullies and valleys. Most of the tributaries to the relict alluvial fans were beheaded by the Podseč stream, which now drains to the nearby Brezovica blind valley (Fig. 3). Comparison of an equilibrated longitudinal profile and the actual longitudinal profile of the Podseč stream reveals distinct anomalies in the area of beheaded fossil valleys and erosion gullies upstream of the relict alluvial fans.

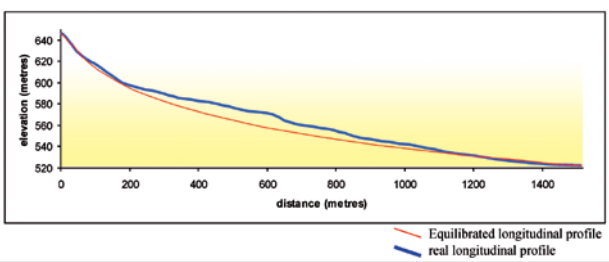

Fig. 3: Equilibrated and actual longitudinal profile of stream Podseč.

Sl. 3: Uravnotežen in dejanski podolžni profil potoka Podseč.

The upper sections of the three features that are defined here as relict alluvial fans are covered with flysch-derived alluvium from the Brkini hills. Carbonate bedrock is exposed on the central and outer sections of the fans and surface karst features such as grikes and dolines are present. Short sections of relict riverbeds are also apparent on the parts of the fan surface that are covered with alluvium. The outer and central sections of the fans are convex, whereas the upper sections are concave in longitudinal slope profile.

According to geomorphological texts, alluvial fans are river accumulation landforms that are cone-shaped in longitudinal profile and fan-shaped in ground plan. They are formed where feeder channels leave a narrow valley and enter a wider valley or plain. The velocity of the stream and its transportation capacity are decreased, and much of the load is deposited (Summerfield, 1996; Goudie, 2004). There are many sub-types of alluvial fan, according to their shape and age of development (Gams, 1964; Gams, 2001; Sauro, 2001; Goudie, 2004), but the sedimentation of alluvial fans is a specific process. The decrease in water flow velocity results in the deposition of larger sediment clasts in the upper sections and finer sediment in the lower sections. A typical alluvial fan has a concave longitudinal profile with a slope inclination of up to 10 degrees in its upper sections and from 1 to 5 degrees in its lower sections (Bull, 1977; Summerfield, 1996; Goudie, 2004).

As mentioned above, there are two types of alluvial fan in the study area. The first type is represented by a single fan undergoing active alluvial sedimentation near Rodik. The thickness and structure of the alluvium and the longitudinal profile correspond to alluvial fans of fluvial geomorphological systems. The upper section of the fan has an inclination of 4 degrees, with the inclination decreasing with increasing distance downslope from the upper section. The thickness of alluvium, established using electrical resistance imaging techniques, is more than 30 m in the upper section of the fan. The structure of the fan profile in this upper part consists of layers of gravel, sand and loamy material. The thickness of alluvium in the middle section of the fan is about 25 m and the slope of the longitudinal profile is gentler. The outer section of the fan is flattened and limestone bedrock is exposed; lower parts of the karst surface are covered with loamy alluvium. The surface of the underlying carbonate bedrock seems to be lower under the upper section of the alluvial fan, suggesting that the fan might cover a relict blind valley. This should be investigated in detail in the future.

Three alluvial fans of the second type, or relict alluvial fans on the karst, are situated near Slope. Their ground plan shapes are fan-like, but the longitudinal profiles are distinct in shape. Their upper sections are concave but in the middle and outer sections they become convex. The

slopes of the upper sections reach 7 degrees, whereas the middle sections are relatively flattened. Surface slopes in the outer sections of the fans reach up to 6 degrees. The thickness of the alluvium in typical active fluvial alluvial fans decreases with distance from the upper sections. Alluvial deposits cover only the upper sections of the relict alluvial fans, where their longitudinal profile is concave. The outer sections of the fans are convex in shape and the limestone bedrock does not have alluvial cover. The density of surface karst features increases with distance from the edge of the alluvial cover.

The characteristic longitudinal profile of relict alluvial fans of this type is a result of cessation of deposition of flysch-derived residual sediment in the fan area. Denudation effects on the residual cover appear to be less intense than those on the neighbouring karst surface where limestone bedrock is exposed. Thus, on alluvial fan surfaces that are covered with flysch-derived deposits lowering appears to be less rapid than on the adjacent fan-shaped karst surface. This difference in erosion rates results in the distinctive shape of the longitudinal fan profiles. These fans exhibit typical longitudinal profiles only in their upper sections, where thick alluvial cover is preserved. In the areas with denuded alluvial cover the dynamics of limestone bedrock corrosion are intense and thus surface lowering is also more intensive. Alluvial cover thickness diminishes with distance from the uppermost section of the fan, so the alluvial cover on the outer sections the fan will be the first to be denuded, exposing the bedrock to the process of corrosion. Subsequently, sediment will gradually be removed and carbonate bedrock will be exposed towards the upper sections of the fan, which results in development of a convex longitudinal profile where bedrock is exposed (Fig. 4).

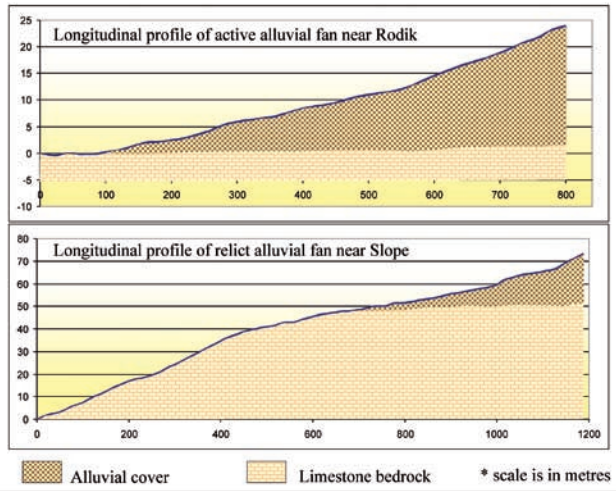

Fig. 4: Longitudinal profiles of the alluvial fans near Rodik and near Slope.

Sl. 4: Podolžni profili vršajev pri Rodiku in Slopah.

CONCLUSIONS

Detailed investigation of the contact karst in the northwestern part of Matarsko podolje revealed that the process of alluvial fan formation is in general the same on karst as in non-karstic fluvial geomorphological systems. An alluvial fan is concave in shape if the dynamics of sedimentation of the fan are greater than the dynamics of the sediment cover denudation. Where the sedimentation dynamics of the fan are lower or completely static the sediment cover is gradually denuded. The thickness of alluvial cover is lowest in the outer sections of the fans and thus the period of limestone bedrock exposure to chemical denudation will be longest in these areas. The result of this process is the formation of a convex longitudinal profile in the outer sections of relict alluvial fans. The final outcome, if all of the alluvial cover is denuded, is a geomorphic feature that is fan shaped in ground plan and convex in longitudinal profile.

The alluvial fans in this part of the Matarsko podolje have formed because the Brkini Hills stand high above the flat karst surface. Intensive erosional processes on the high ground resulted in generation of flysch debris and input of alluvial material to the karst. Due to the concentrated material input the waters deposit alluvial fans rather than forming blind valleys.

Relict alluvial fans embossed on the karst surface have not previously been interpreted as landforms typical of contact karst, even though the process of their formation is exclusively related to contact karst. The alluvial fans in the study area can be used as an example for the interpretation of alluvial fan formation mechanisms on other dynamic karst surfaces.

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POVZETEK

Najbolj značilen primer ponornega kontaktnega krasa v Sloveniji je Matarsko podolje, ki je relativno uravnana pokrajina med Slavniškim pogorjem in Brkini. Nahaja se v jugozahodnem delu Slovenije. Dolgo je 18 kilometrov, razpotegnjeno v smeri severozahod – jugovzhod, in sega od Kozine, kjer dosega nadmorsko višino okoli 490 metrov, do Staroda, kjer so nadmorske višine okoli 640 metrov. Širina podolja je od 2 do 5 kilometrov. Na jugovzhodu meji na nižje Brgudsko podolje, na severozahodu pa preide v Matični kras (Sl. 1).

Površinsko in podzemeljsko je Matarsko podolje zakraselo, v grobem je uravnano in prepleteno z velikimi udornicami, vrtačami in jamami. Na severozahodnem obrobju Matarskega podolja med fliši Brkinov in apnenci Matarskega podolja ponira 24 ponikalnic. Stik med fliši in apnenci je pogojeval nastanek niza večih slepih dolin in ponornih zatrepov (Mihevc, 1991). Med jamskimi rovi v zaledju slepih dolin prevladujejo brezna, ki so nastala v vadozni coni, ter daljši odseki fosilnih vodoravnih rovov.

Proučevano območje leži na skrajnem severozahodnem delu Matarskega podolja, med najvišjim severozahodnim delom flišnih Brkinov, pobočjem Videža na zahodu in uravnanim delom Matarskega podolja pri Kozini na jugu. Na severozahodnem delu je na flišnih kamninah izoblikovan fluvialni geomorfni sistem. Flišni greben je 300 m nad kraško uravnavo Matarskega podolja. Na strmih flišnih pobočjih so izoblikovani erozijski jarki, ki odvajajo vodo in flišno preperelino proti zahodu in jugozahodu na kraško površje. V erozijskih jarkih je voda prisotna le ob večjih količinah padavin. Erozijski jarki se končujejo na stiku eocenskih flišov in paleocenskih apnencev. Pod njimi so na območju razviti štirje večji vršaji, ki z nanosi prekrivajo paleocenske in kredne apnence Matarskega podolja (Sl. 2).

Proučevani vršaji so razporejeni na kontaktu fliša in apnenca v razdalji 2,3 km. Na severozahodnem delu območja pri naselju Rodik je vršaj s površino okoli 0,3 km^2. Jugovzhodneje se pod večjo erozijsko grapo, ki prečka greben paleocenskih apnencev, nahaja manjši vršaj s površino 0,18 km^2. Dalje proti jugovzhodu pri vasi Slope leži velik vršaj s površino 1,14 km^2. Na skrajnem jugozahodu se ob zaključku fosilne doline Bilendol nahaja manjši vršaj z velikostjo 0,14 km^2.

Na proučevanem območju se nahajata dva tipa vršajev, na podlagi katerih je mogoče tolmačiti razvoj teh

oblik kontaktnega krasa v dinamičnem kraškem površju. Prvi tip predstavlja vršaj pri Rodiku, na katerem je še aktivna sedimentacija alohtonega materiala. Ta vršaj po globini naplavine, velikosti delcev v naplavini, oblikovanosti podolžnega profila in tlorisni oblikovanosti ustreza vršajem v fluvialnem geomorfnem sistemu. Naklon v vrhnjem delu je največji in dosega do 4° ter se z oddaljenostjo od vrha vršaja zmanjšuje. Globina naplavine, ki je bila ugotovljena z meritvami profilov električne upornosti tal, v vrhnjem delu presega globino 30 m. V tem delu se v nanosih menjavajo plasti proda, peska in ilovnate prepereline. Globina nanosov v osrednjem delu vršaja je 25 m, prav tako se zmanjša tudi naklon. Ob koncu vršaja je površje popolnoma uravnano in ilovnati nanosi zapolnjujejo nižje dele kraškega površja.

Drug tip so reliktni vršaji na območju naselja Slope. Reliktni vršaji so le površinske oblike v karbonatni matični kamnini, ki so se razvili iz fluvialnih vršajev. V tlorisu so tipične pahljačaste oblike, v oblikovanosti podolžnih profilov pa se kaže dvojnost. Do osrednjega dela so v profilu konkavnih oblike, ki po uravnanem osrednjem delu preidejo v konveksne oblike. V zgornjih konkavnih delih nakloni dosegajo vrednost do 7°. V osrednjih delih so uravnani, v spodnjih konveksnih delih pa nakloni dosegajo vrednost do 6°. Debelina naplavine bi se teoretično morala zmanjševati z zmanjševanjem naklona. Pri tem tipu vršajev preperelina prekriva le zgornje, konkavne dele, medtem ko v spodnjih konveksnih delih prepereline ni, oziroma se na površju pojavlja le izjemoma. V spodnjih konveksnih delih vršajev so razvite površinske kraške oblike, kot so škraplje in vrtače. Gostota površinskih kraških oblik narašča z oddaljenostjo od fluvialne naplavine, ki prekriva zgornje dele vršajev.

Na območju reliktnih vršajev in njihovem zaledju je večje število erozijskih jarkov in fosilna dolina. Večina pritokov na reliktne vršaje je bila obglavljenih s potokom Podseč, ki odvaja vodo proti jugovzhodu v smeri slepe doline Brezovica. Primerjava podolžnega profila in uravnoteženega podolžnega profila potoka Podseč, kaže izrazito nepravilnost v območju podolžnega profila, ki leži v bližini območja reliktnega vršaja pri fosilni dolini Bilendol (Sl. 3).

Dvojnost podolžnih profilov reliktnih vršajev je nastala zaradi prekinitve procesa akumulacije fluvialnih sedimentov na vršaje. Oblika podolžnega profila reliktnih vršajev kaže na to, da je dinamika procesa denudacije flišne prepereline manjša od dinamike denudacije okoliškega kraškega površja, zato se na območjih vršajev, ki jih prekriva flišni nanos, površje znižuje relativno počasneje. Proces se postopoma nadaljuje proti vrhnjemu delu vršaja. Posledica je izrazita konveksna oblikovanost v spodnjem delu podolžnega profila vršaja (Sl. 4).

Na podlagi podrobnega proučevanja vršajev v severozahodnem delu Matarskega podolja lahko zaključimo, da je proces oblikovanja vršajev na krasu v grobem enak kot na fluvialnem geomorfnem sistemu. Dokler je dinamika nanašanja materiala na vršaj večja ali enaka dinamiki denudacije akumuliranega materiala, bo vršaj ohranil tipično konkavno obliko. V primeru, da je nanašanje manjše ali pa da se popolnoma ustavi, bo nanesen material, ki prekriva kraško površje, postopoma denudiran. Najmanjša debelina nanosov je na robovih vršaja, zato bo kraško površje tam najprej izpostavljeno kemični denudaciji. Ker je dinamika kemične denudacije kraškega površja večja od denudacije flišnih nanosov, ki prekrivajo apnence, se površje ob koncu vršajev hitreje znižuje, kar ima za posledico konveksno obliko spodnjega dela fosilnega vršaja. V skrajni obliki, ko je denudiran celoten alohton material vršaja iz kraškega površja, ostane površinska oblika na kontaktnem krasu, ki je v tlorisu pahljačaste oblike, v profilu pa je konveksna.