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SUBMERGED KARST – DEAD OR ALIVE? EXAMPLES FROM THE EASTERN ADRIATIC COAST (CROATIA)[1]

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Review
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Numerous karst features submerged by the last Late Pleistocene-Holocene transgression are found along the Eastern Adriatic (Croatian) coast. Generally, most of karstification processes cease at the base level, that is, in case of coastal karst, the sea level. However, evidence of continued karstification (corrosion) and related processes (mechanical erosion and bioerosion), as well as remarkable change in hydrogeological settings of some hydrological systems, are quite common in Croatian submarine and coastal area.

Key words: submarine karst, karstification, bioerosion, Adriatic Sea, Croatia

U podmorju duž cijele istočne obale Jadrana nalaze se brojni krški oblici potopljeni posljednjom gornjopleistocensko-holocenskom transgresijom. Općenito, većina procesa u okviru okršavanja prestaje na razini erozijske baze koja je u slučaju priobalnog krša apsolutna erozijska baza – razina mora. Međutim, u podmorju i priobalnom dijelu istočnog Jadrana brojni su primjeri gdje se i ispod morske razine djelomično nastavilo okršavanje (korozija) i okršavanju bliski procesi (mehanička erozija i bioerozija), a poznati su i primjeri značajne promjene hidrogeoloških funkcija pojedinih priobalnih hidroloških sustava uzrokovanih izdizanjem morske razine.

Ključne riječi: podmorski krš, okršavanje, bioerozija, Jadransko more, Hrvatska

Introduction

Submerged (drowned) karst on the coast can be regarded as one of the major types of relict karst. Relict karst is the one which is within the contemporary system but was removed from the situation in which it had been developed. This type of karst experienced major changes in base level, and in the case of presently submarine karst (formerly coastal), the base level refers to the absolute base, that is the sea level (FORD, WILLIAMS, 1989).

Common opinion of non-experts, supported by visual impression of sharp littoral karrens, is that sea water dissolves (corrodes) limestone, continuing the process of

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karstification even under the sea level. But, knowing that the sea water is supersaturated with $CaCO_3$ in the first 500 m (KENNETT, 1982), the resulting process could only be precipitation and not dissolution of carbonates. On the other hand, one could expect that the submergence of karst by the sea water exclusively ceases all karstification processes. However, it is well established that the groundwater circulation can extend to great depth and karst springs can resurge well bellow the sea level. Consequently, the sea level is not the ultimate base for karst dissolution (FORD, WILLIAMS, 1989).

On the examples from the Eastern Adriatic submarine and coastal localities, both of these possibilities, cessation and continuation, will be discussed. The locations of the sites encompassed by this review are illustrated in Fig. 1.

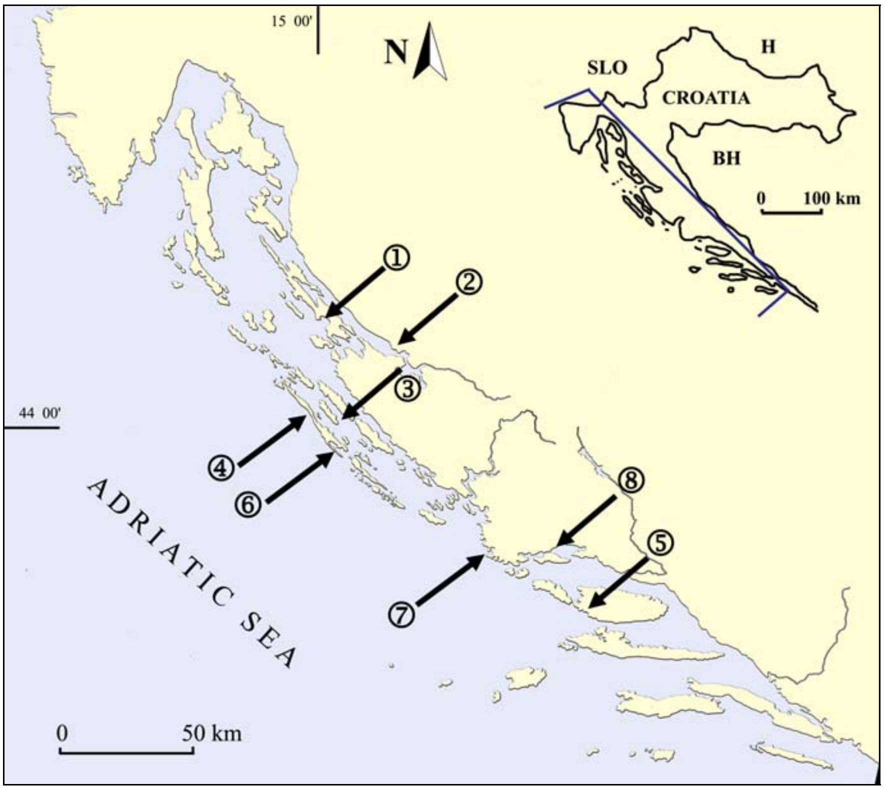

Fig. 1 Studied localities: 1 – Cave in Tihovac Bay (Pag Island), 2 – submarine spring Vrulja Zečica, 3 – Cave near Iški Mrtovnjak Islet, 4 – Y-Cave on Dugi Otok Island, 5 – Pit in Lučice Bay (Brač Island), 6 – marine lake Mir on Dugi Otok Island, 7 – marine lake Zmajevo Oko near Rogoznica, 8 – hydrological system Arbanija – Slatina – Pantan – Slanac near Trogir

Sl. 1. Istraživani lokaliteti: 1 – Spilja u uvali Tihovac (Pag), 2 – Vrulja Zečica, 3 – Spilja kraj iškog Mrtovnjaka, 4 – spilja Ipsilonka (Dugi Otok), 5 – Jama u uvali Lučice (Brač), 6 – jezero Mir (Dugi otok), 7 – Zmajevo oko (Rogoznica), 8 – hidrološki sustav Arbanija – Slatina – Pantan – Slanac kod Trogira

Geological and environmental settings

The Eastern Adriatic (Croatian) coast is one of the most indented ones and it is *locus typicus* of Dalmatian type of coast marked by geomorphological and geological structures parallel to the coast and island chains with zig-zag channels among them (FAIRBRIDGE, 1968). It is a part of Croatian Karst (External or Outer) Dinarides whose entire carbonate succession was deposited within carbonate platform environments from the Middle Permian (or even Upper Carboniferous) to the Eocene, leaving a sequence of up to 8,000 m thick carbonates (VLAHOVIĆ ET AL., 2002, 2005). Major part of this sequence belongs to the Adriatic Carbonate Platform deposited from the top of the Lower Jurassic (Toarcian) to the top of the Cretaceous with 3,500 to 5,000 m thick deposits (VLAHOVIĆ ET AL., 2002, 2005).

Intensive orogeny by the end of the Cretaceous and during the Palaeogene, caused by collision of the Adriatic plate and European continent, resulted in disintegration of the platform into separate tectonic blocks in addition to folding, faulting and overthrusting of the carbonate bedrock (JENKYNS, 1991; GUŠIĆ, JELASKA, 1993). The disintegration and uplift of the platform continued during the Younger Pliocene-Holocene with dominant orogen-parallel strike-slip faulting (PICHA, 2002). Hence, after the final uplift of the Dinarides during the Oligocene-Miocene (VLAHOVIĆ ET AL., 2002, 2005), on the tectonically fractured carbonates, uplifted and exposed to atmospheric influence, the process of karstification began. According to the lowest Quaternary sea level during the Last Glacial Maximum (LGM), that was about –120 ± 5 m (FAIRBANKS, 1989), karstification could theoretically extend down to that level. However, numerous former emersions should not be neglected, and probably the most significant among them was the 'Messinian Salinity Crisis' at the Miocene-Pliocene transition, when the Mediterranean sea level lowered by 1,500 m (AUDRA ET AL., 2004). Yet, the best preserved evidences of former sea levels and ongoing karstification could be expected from the latest events.

The last transgression during the Late Pleistocene-Holocene partly flooded the existing karstified area with its numerous erosional and depositional karst features (Figs. 2 and 3). Nevertheless, in spite of thousands of years within marine environment, most of the karst features (caves and pits with belonging speleothems, dolines, poljes, karrens etc.) can still be found along the coast. The prevalence of easily soluble carbonate rocks in the drainage area of most of the rivers debouching along the Eastern Adriatic coast, with only approximately 20% of river-born material in suspended (particulate) form, is probably the main reason for very slow sedimentation. Additionally, cyclonic sea-current circulation (ORLIĆ ET AL., 1992) preserves the Eastern Adriatic Sea from intensive input of suspended matter delivered by the Po River and Apennine rivers whose catchment areas are predominantly in clastic rocks (CORREGGIARI ET AL., 1996).

Aforementioned setting enabled the establishment of specific environmental conditions that result in processes which affect the submarine and coastal karst features quite differently.

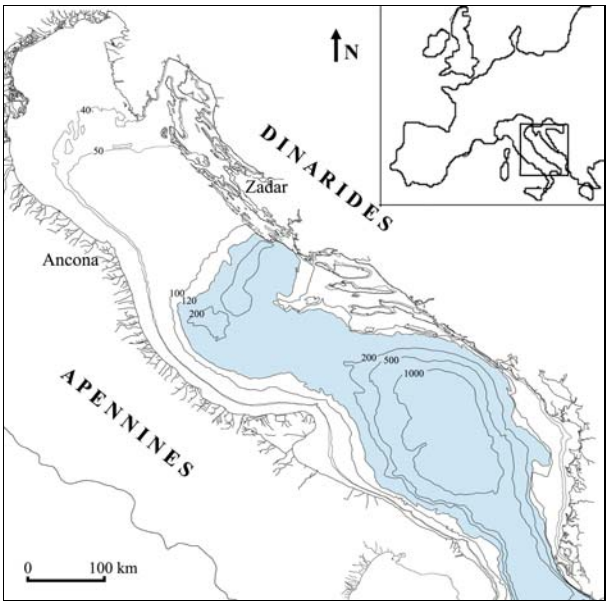

Fig. 2 Presumed distribution of land and sea during LGM, when the sea level was 120 m lower than the modern (modified after CORREGGIARI ET AL., 1996)
Sl. 2. Pretpostavljeni raspored mora i kopna tijekom posljednjeg glacijalnog maksimuma s morskom razinom nižom 120 m (prerađeno iz CORREGGIARI ET AL., 1996.)

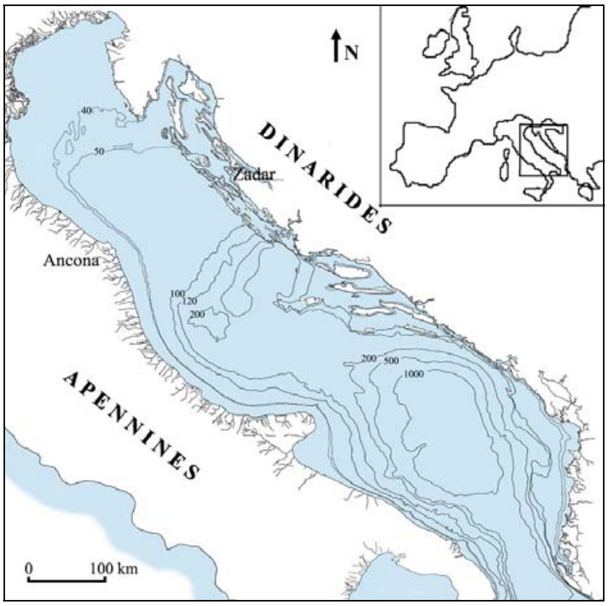

Fig. 3 Modern distribution of land and sea
Sl. 3. Današnji raspored mora i kopna

Records of recent karstification within the submarine features

All along the mountain massif of Velebit and other coastal Dinaric mountains, submarine karst springs (vruljas) are quite common features (ALFIREVIĆ, 1969). They canalize the groundwater from the hinterland throughout the karstified mountains toward the absolute base – the sea, partly along the pathways formed during the lower sea-level stands. Presently, they discharge water either through former speleological features (pits or caves), or in the form of disperse seepage at the sea bottom (MILANOVIĆ, 1979).

Submarine spring Vrulja Zečica near Starigrad keeps records of several phases of its development (Fig. 4). Speleothems found at the depth of 41.5 m are the evidence of its subaerial phase with flowstone deposition. Cessation of their growth was probably caused by submergence, primarily by the groundwater raised by sea-level rise and subsequent ingression of the sea water (SURIĆ ET AL., 2005a). Nonetheless, one of the processes that is not directly defined as a karstification but is relatively common in speleogenesis, is still present in this speleological feature. It is **mechanical erosion** that is quite important factor in main phase of cave forming (but also can be reactivated) when the water circulating through the channels carries clastic material that contributes in cave/channel widening (KUHTA, 2002).

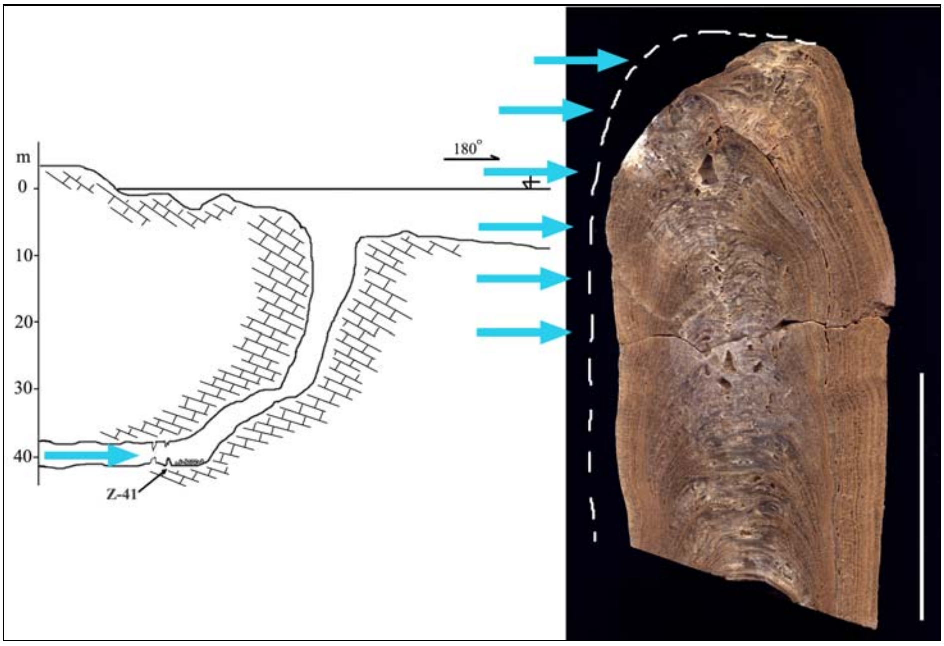

Fig. 4 Cross-section of Vrulja Zečica (modified after BAKRAN-PETRICIOLI, PETRICIOLI, 1999) and the longitudinal section of stalagmite mechanically eroded on the side oriented toward the freshwater flow (blue arrow – direction of groundwater flow)

Sl. 4. Profil Vrulje Zečice (modificirano prema BAKRAN-PETRICIOLI, PETRICIOLI, 1999.) i posljedice mehaničke erozije stalagmita (uzdužni presjek) na strani okrenutoj prema smjeru dotoka podzemne vode (plava strelica – smjer dotoka podzemne vode)

That particular effect is present in Vrulja Zečica submarine spring and its consequences could be seen on the sampled stalagmite (Fig. 4). Namely, the speleothem surface facing the groundwater outlet is obviously mechanically eroded. The exterior is scratched and the layers are abraded. It was eroded by the clastic material carried by the water during the strong seasonal groundwater waves from the hinterland. Pebbles and boulders of that origin can be found not only in the channel where the speleothems are located, but even in shallower part of the vrulja at -35 m (BAKRAN-PETRICIOLI, PETRICIOLI, 1999) what indicates very powerful outflow. Intensity of discharge can be noticed during the huge groundwater waves as up to 30 cm high bulge above the vrulja's entrance (BAKRAN-PETRICIOLI, PETRICIOLI, 1999).

Mixing of the sea and fresh water can be an important agent of accelerated dissolution of carbonates (FORD, WILLIAMS, 1989). Even if both, fresh and marine water, are saturated with respect to $CaCO_3$, their mixture is undersaturated with respect to $CaCO_3$. In addition, the presence of organics in the water allows oxidation that produces further CO_2 that drives carbonate dissolution (MYLROIE, CAREW, 2003). The indication of such dissolution can be found in Y-Cave in Brbinjšćica Cove on the off-shore side of the Dugi Otok Island (Fig. 5). Walls of the remote shallow part of the cave (Fig. 6), are not covered with endolithic marine organisms that are quite common in such caves (exclusively animals; biocenosis of caves and ducts in complete darkness). The reason for that absence could be periodical ground(fresh)water discharge, which is unfavourable for marine organisms. Moreover, recent freshwater **corrosional** traces (sharp, indented edges) are inferred on the channel surface in that mixing zone, as indicated in Fig. 6 (JURAČIĆ ET AL., 2002).

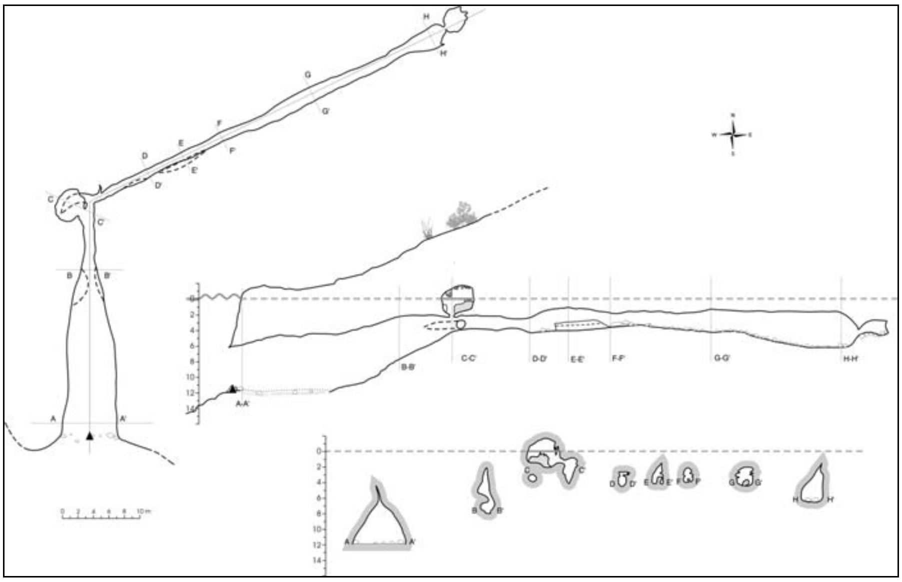

Fig. 5 Plan of the Y-Cave with longitudinal profile and characteristic sections (surveyed by D. Petricioli) (from JURAČIĆ ET AL., 2002)

Sl. 5. Nacrt i uzdužni profil spilje Ipsilonke s karakterističnim poprečnim presjecima (iz JURAČIĆ ET AL., 2002.)

Fig. 6 Corrosionally sculptured channel in mixing zone of Y-Cave, approximately at section F-F' (photo by D. Petricioli) (from JURAČIĆ ET AL., 2002)
Sl. 6. Korozijom oblikovan kanal spilje Ipsilonke u zoni miješanja, približno kod presjeka F-F', (fotografirao D. Petricioli) (iz JURAČIĆ ET AL., 2002.)

In other submarine caves, which are located in completely marine environment with stable ecological conditions (salinity, temperature etc.), the overgrowth of living marine organisms along with their anorganic remnants, can be found all over the cave interior (Fig. 7).

Fig. 7 Marine biogenic overgrowth on stalactites inside the Cave near Iški Mrtovnjak Islet (photo by M. Kvarantan)
Sl. 7. Marinski biogeni obraštaj na stalaktitima u Spilji kraj iškog Mrtovnjaka (fotografirao M. Kvarantan)

The full marine conditions inhibit the corrosion, but support another process of rock destruction. It is **bioerosion**, the process of removal of rock by organisms. Although this process is the most important in tropical seas due to abundance of benthic organisms and calcareous substrates (MASSELINK, HUGHES, 2003), it is also characteristic for the Eastern Adriatic Sea.

Generally, bioerosion comprises two groups of processes: **biochemical** as chemical weathering by products of marine organisms, and **biophysical** as physical removal of rock by grazing and boring organisms. Algal overgrowth of the rock surface is responsible for biochemical part of bioerosion since products of their metabolism cause the chemical erosion of rock substrate underneath the algal mats (MASSELINK, HUGHES, 2003). Of course, due to the absence of light, there are no algae in caves. But, besides algae, sponges and other epibiontic animals also bore and scrape carbonate surface (FORD, WILLIAMS, 1989; JURAČIĆ ET AL., 2002; BENAC ET AL., 2004). Grazers that feed on epibiontic organisms additionally abrade the rock surface contributing to the bioerosion by their biophysical role. Consequently, the carbonate rocks, including speleothems, suffer relatively significant damage. Speleothems that experienced such destruction are found in several speleological objects (SURIĆ ET AL., 2005a; 2005b), including the samples from Pit in Lučice Bay (Brač Island) and from Cave in Tihovac Bay (Pag Island) (Figs. 8 and 9).

Fig. 8 Longitudinal section of a stalagmite from Pit in Lučice Bay (Brač Island) (-28 m) extremely bored by marine organisms. Scale bar 5 cm.
Sl. 8. Uzdužni presjek stalagmita iz Jame u uvali Lučice (Brač) s 28 m dubine značajno oštećen ubušivanjem marinskih organizama. Linearno mjerilo 5 cm.

Fig. 9 Longitudinal section of a stalactite from Cave in Tihovac Bay (Pag Island) (-23 m). Original calcite of stalactite in some parts completely destroyed (lower part) and in other perfectly preserved (upper part). Scale bar 5 cm.
Fig. 9. Uzdužni presjek stalaktita iz Spilje u uvali Tihovac (Pag) s 23 m dubine. Dijelom je sigovina potpuno uništena (donji dio), a dijelom odlično sačuvana (gornji dio). Linearno mjerilo 5 cm.

As in the whole nature of karst, here is also evident a permanent problem that even in a small scale the processes are not uniform. In a single speleothem, within the distance of only a few centimetres, differences in actual processes can be enormous, as shown in Fig. 9. While one (upper) part of the speleothem stays unaffected, the other part (lower) is almost completely destroyed.

Bioerosion as a process is not related only to speleological features. It is also present on every carbonate bedrock covered with biogenic overgrowth and it is probably the most intense in the zone of tidal notches within the intertidal zone (BENAC ET AL., 2004). Namely, the borers enhance the area of the rock surface exposed to physical and chemical processes and make the rock substrate more susceptible to wave erosion (MASSELINK, HUGHES, 2003). This leads to another process that should not be neglected while discussing interaction between the sea and karst. It is abrasion – scouring of the rock surface by wave-induced flow laden with sediment. The impact of waves on rocks induces pressure variations that weaken the rock by causing and widening capillaries and cracks (MASSELINK, HUGHES, 2003). As the karst bedrock is already fractured (one of prerequisite conditions for karstification) and additionally weakened by aforementioned biogenic activity, the effects of abrasion will be even more pronounced on karstic coasts.

Changes of hydrogeological functions due to sea-level rise

The rising sea level does not only change the coastline, but it also influences the hydrogeological functions of coastal hydrological systems. There is a well-known example of hydrogeological system near Trogir, which consists of two submarine springs (Vrulja Arbanija and Vrulja Slatina) at the depths of 32 and 35 m, respectively, the permanent brackish coastal spring Pantan located 400 m inland at the elevation of 2.7 m, and the intermittent brackish spring Slanac at 30 m a.s.l. (Fig. 10) (HERAK 1972; FRITZ 1981, 1992, 1994; FRITZ, BAHUN, 1997).

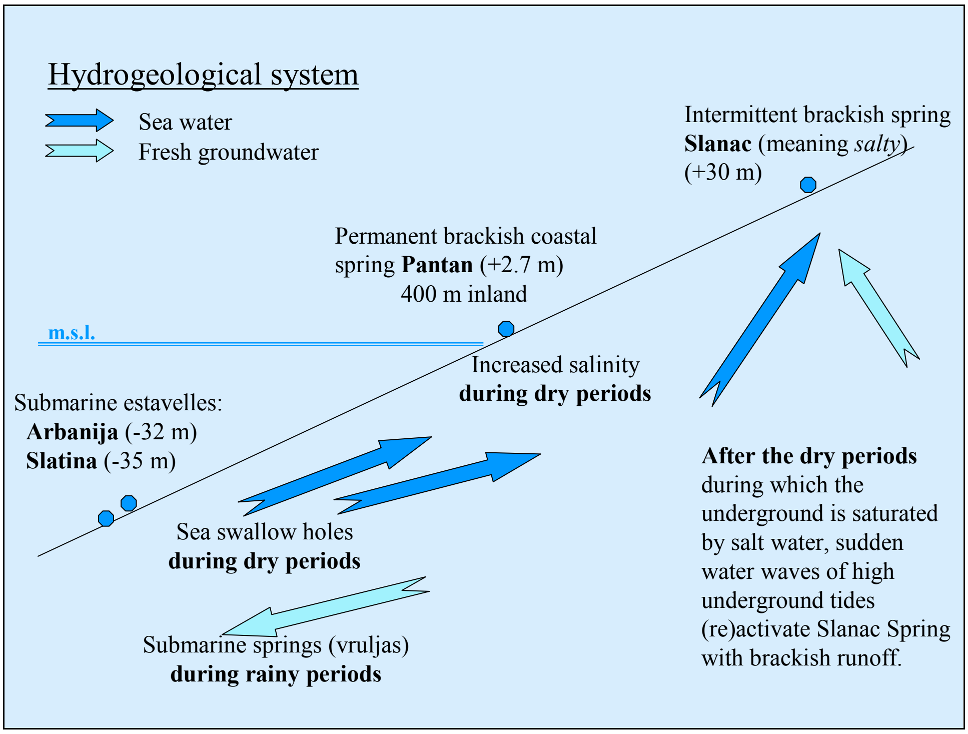

Fig. 10 Scheme of Arbanija – Slatina – Pantan – Slanac hydrogeological system
Sl. 10. Shematski prikaz hidrogeološkog sustava Arbanija – Slatina – Pantan – Slanac

During the sea-level low-stands, submarine springs Arbanija and Slatina operated as coastal springs discharging water from the hinterland. Late Pleistocene-Holocene sea-level rise transformed them into submarine springs with decreased runoff while the function of the coastal (brackish) spring was taken over by the permanent spring Pantan (HERAK 1972; FRITZ 1981, 1992, 1994, FRITZ, BAHUN, 1997). During the rainy period discharge of vruljas is considerable while in dry periods they act as swallow holes so their hydrogeological function can be determined as (submarine) estavelles. At the same time, during dry periods, the salinity of Pantan spring increases significantly. The consequence of such regime is increased salinity of groundwater. Such water appears intermittently at Slanac spring, and this happens due to sudden water waves of high underground tides from the hinterland, which suck groundwater saturated by sea water and eject it to the surface only a few times a year, not even every year (FRITZ, 1992). Salinity of water during this intermittent outflows is extremely high at the beginning and decreases with time (FRITZ, 1994). Such intensive mixing of fresh and sea water undoubtedly induces substantial corrosion inside channels connecting these features, and moves the border of the mixing zone far inland in horizontal and vertical directions.

Less dynamic, but not less interesting are the features known as marine lakes (BAKRAN-PETRICIOLI, PETRICIOLI 1997; VANIČEK ET AL., 2000). They were formed, also due to Late Pleistocene-Holocene transgression, by submergence of coastal karst depressions, either solution or collapse dolines. Recent features of that type are marine lakes Mir on the Dugi Otok Island (Fig. 11) and Zmajevo Oko near Rogoznica (Fig. 12). The latter, with specially steep banks (walls), could be formed by roof collapsing of the cavern induced by the loss of buoyant support that was provided by the sea water during the highstands.

Fig. 11 Marine lake Mir on the Dugi Otok Island. Red lines present the groups of cracks (28 in total) where the notable circulation was recorded (after LJUŠTINA, VITAS, 2002)
Sl. 11. Morsko jezero Mir na Dugom otoku. Crvene linije označavaju grupe pukotina (ukupno 28) na kojima je primjećena cirkulacija (prema LJUŠTINA, VITAS, 2002.)

In the Early Holocene, a deeply indented bay that consists of two submerged depressions – Malo Jezero and Veliko Jezero on the Mljet Island, existed in form of two marine lakes, until ca. 4,000 years ago (not earlier than 4 kyr B.P.) when the rising sea level connected the lakes to each other, linked Veliko Jezero with the open sea through a shallow channel (0.5-1.0 m, recently artificially deepened to 2.5 m), and transformed them into a single marine bay (GOVORČIN ET AL., 2001). Since the sea water from the bay still communicates with open sea through the karstified underground, these features are still regarded as marine lakes (VANIČEK ET AL., 2000).

The existing marine lakes Mir and Zmajevo Oko are separated from the open sea by more than 90 m thick karstified bedrock barrier, which allows free circulation of sea water through it (Figs. 11 and 12). Apparently, together with sea water, migration of marine organisms through fissures and joints is also possible, so the processes of bioerosion by marine organisms are present in these inland features as well.

Fig. 12 Marine lake Zmajevo Oko near Rogoznica probably formed by roof collapsing due to the loss of buoyant support
Sl. 12. Morsko jezero Zmajevo oko kraj Rogoznice, vjerojatno nastalo urušavanjem zbog gubitka uzgonske potpore

Conclusion

The examples of various karst forms from the Eastern Adriatic Sea presently submerged by the rising sea, support the idea that there are typical karstic and some related processes in the submarine environment that could affect the existing submerged karst forms. These processes are:

- corrosion in the mixing zone of fresh and sea water either inland or below the sea surface
- bioerosion (biochemical and biophysical) by boring and grazing marine organisms
- mechanical erosion (abrasion) by clastic material driven by underground floodwaters
- remarkable transformation of hydrogeological function of former inland/presently coastal and former coastal/presently submarine karst features.

From this point of view, submerged (submarine) karst could be regarded as 'alive' specially in mixing zones of fresh and sea water onshore. However, knowing that every karst feature is a result of almost unique combination of geological, geomorphological and hydrogeological settings, none of these processes generated by interaction between karst and sea water should be taken as general, so an individual approach should be required for each locality, feature or event.

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SAŽETAK

Maša Surić: Potopljeni krš – živ ili mrtav? Primjeri s istočne obale Jadrana (Hrvatska)

Potopljeni krš jedan je od glavnih tipova reliktnog krša. Nalazi se u današnjim uvjetima, ali odvojen iz sredine u kojoj je nastao. Potopljene egzo- i endoforme karakteristične su za gotovo cijelo dužobalno i otočno podmorje hrvatskog Jadrana, gdje su se našle zbog posljednje, gornjopleistocensko-holocenske, transgresije kad se morska razina digla za 120 ± 5 m (Sl. 2. i 3.) i dijelom potopila okršene ostatke Jadranske karbonatne platforme. Zahvaljujući malom udjelu (20%)

suspendiranog materijala u vodi hrvatskih krških rijeka, te ciklonalnom režimu morskih struja koje nanos talijanskih rijeka distribuiraju duž talijanske obale Jadrana, krški se oblici neprekriveni sedimentom još uvijek mogu naći na morskom dnu istočnog Jadrana.

Iako "nagrizena" krška obala ostavlja dojam da je more intenzivno otapa, u području do dubine od oko 500 m morska je voda prezasićena na kalcijev(II)karbonat, te se može očekivati jedino njegovo taloženje, a ne otapanje. S druge strane, uvriježeno je mišljenje da ispod površine mora prestaju svi procesi okršavanja. Međutim, brojni primjeri iz istočnojadranskog područja pokazuju da se nakon izdizanja morske razine pod morskom površinom i u kopnenom dijelu gdje je prisutna intruzija morske vode odvija i okršavanje (korozija) i procesi bliski okršavanju (mehanička erozija, bioerozija), kao i bitne promjene hidrogeoloških odnosa u priobalju.

Na primjeru stalagmita s 41,5 m dubine iz Vrulje Zečice kraj Starigrada (Sl. 4.) vidljiv je učinak mehaničke erozije na strani sige okrenutoj prema dotoku slatke vode koja sobom nosi klastični materijal. Osim toga, i sam sifonalni oblik vrulje te periodični snažan dotok slatke vode iz zaleđa ukazuju na moguću koroziju ispod morske razine. Nadalje, u području miješanja slatke i slane vode, iako obje mogu biti prezasićene na kalcijev(II)karbonat, prisutno je intenzivno otapanje karbonata. Primjer korozije u zoni miješanja očit je u spilji Ipsilonki u uvali Brbinjšćica na vanjskoj strani Dugog otoka (Sl. 6.). U podmorskim speleološkim objektima u kojima u potpunosti vladaju marinski uvjeti kao što je Spilja kraj iškog Mrtovnjaka (Sl. 7.), ili Jama u uvali Lučice na Braču i Spilja u uvali Tihovac na Pagu, odakle su analizirani uzorci siga (Sl. 8. i 9.), karakteristična je bioerozija. Biofizičkim i biokemijskim procesima uklanja se karbonat posredstvom životinja koje se ubušuju ili prijanjaju na podlogu, te organizama koji se hrane tim životinjama. Kako ovaj proces nije vezan samo za speleološke objekte već općenito za karbonatnu podlogu prekrivenu marinskim obraštajem, bioerozija je iznimno izražena i u intertajdalnoj zoni, gdje organizmi slabe ionako već oštećenu stijensku masu, te ju čine još podložnijom destrukciji abrazijom.

Promjena morske razine uzrok je i značajnim hidrogeološkim promjenama na okršenoj obali. Poznat je hidrogeološki sustav kraj Trogira koji se sastoji od dvije vrulje, Arbanija (-32 m) i Slatina (-35 m), stalnoga bočatog priobalnog izvora Pantan, udaljenog 400 m od mora na visini od 2,7 mnm, i povremenoga bočatog izvora Slanac na visini od 30 mnm (Sl. 10.). Vrulje su za nižih morskih razina funkcionirale kao priobalni izvori, a dizanjem morske razine postale su podmorski izvori. Odnosno, točnije, za vrijeme kišnog perioda funkcioniraju kao vrulje, dok za sušnog perioda imaju ulogu ponora koji kanalizira morsku vodu prema kopnu, te su zapravo morske estavele. Tijekom sušnih perioda, dakle za smanjenog dotoka slatke vode iz zaleđa, podzemlje se saturira morskom vodom te se na priobalnom izvoru Pantan povećava salinitet. Povremeno, nakon nakon naglih i jakih oborina, u slučaju nailaska znatnih količina podzemne vode iz zaleđa, aktivira se i povremeni izvor Slanac, izbacujući vodu povišena saliniteta – morsku vodu pomiješanu s podzemnom vodom iz zaleđa. S vremenom salinitet vode na izvoru Slanac opada. Taj je izvor aktivan tek nekoliko puta godišnje i to ne svake godine, i izniman je primjer pomaka granice miješanja slatke i morske vode u priobalju i u vertikalnom i horizontalnom smjeru. Time se pomiče i ranije spomenuta zona intenzivne korozije u području miješanja slatke i slane vode.

Gornjopleistocensko-holocenskom transgresijom na istočnoj obali Jadrana formirana su tzv. morska jezera – depresije u priobalju ispunjene morskom vodom – koja kroz okršenu stijensku masu komuniciraju s otvorenim morem. Veliko i Malo jezero na Mljetu su do prije oko 4000 g. bili odvojeni od otvorenog mora, a daljnjim dizanjem morske razine bili su pretvoreni u duboko uvučen morski zaljev. Recentni primjeri morskih jezera, Mir na Dugom otoku (Sl. 11.) i Zmajevo oko kraj Rogoznice (Sl. 12.), ostvaruju cirkulaciju morske vode kroz okršeno podzemlje i pukotine u tolikoj mjeri da, osim što su zamjetne dnevne oscilacije, omogućuju i naseljavanje morskih organizama i bioerozijske procese i iza obalne crte.

Svi ti navedeni primjeri ukazuju da potapanjem, odnosno u interakciji s morem, krš u priobalnom dijelu nije u potpunosti reliktna forma, već se različitim intenzitetima nastavljaju neki krški i okršavanju bliski procesi, ali – kao i uvijek kad je o kršu riječ – nema uniformnosti, već je svaki lokalitet specifičan i traži individualni pristup pri istraživanju.