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SMALL KARST FEATURES (KARREN) OF DUGI OTOK ISLAND AND KORNATI ARCHIPELAGO COASTAL KARST (CROATIA)

OBALNE DROBNE SKALNE KRAŠKE POVRŠINSKE OBLIKE NA DUGEM OTOKU IN KORNATIH

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Dražen Perica & Tihomir Marjanac &Branka Aničić &Irena Mrak & Mladen Juračić: Small karst features (karren) of Dugi otok island and Kornati archipelago coastal karst (Croatia)

Dugi otok Island and Kornati archipelago islands are characterized by karst morphology. Small karst features are particulary well developed along the coast in the swash zone, and significant differences can be observed due to different interaction of wave action, bedding attitude, bed thicknesses and lithology. Among other karren types, fissure- and network-type karren are particulary interesting, both of which start developing from initial root karren. The age of some of these small karst features can be estimated by their occurrence in ancient quarries, and we suggest their historic age. We can envisage the future development of these small coastal corrosion forms.
Key words: karren, grikes, solution pans, corrosion, Dugi otok, Croatia.

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Dražen Perica & Tihomir Marjanac &Branka Aničić &Irena Mrak & Mladen Juračić: Obalne drobne skalne kraške površinske oblike na Dugem otoku in Kornatih

Za površje Dugega otoka in Kornatov je značilna kraška morfologija. Drobne skalne kraške površinske oblike so najbolje razvite ob obali, v območju vpliva morskih valov. Razlike v razvitosti drobnih skalnih kraških površinskih oblik so posledica součinkovanja valov, litologije, nagiba in debeline kamninskih skladov. Med različnimi tipi drobnih skalnih kraških površinskih oblik so najbolj zanimive poklinaste škraplje in mrežaste korozijske razjede, katerih začetna oblika so biokorozijske jamice. Starost nekaterih drobnih skalnih kraških površinskih oblik lahko ocenimo glede na njihovo razvitost v antičnih kamnolomih. Predvidevamo pa lahko tudi njihov bodoči razvoj.
Ključne besede: drobne skalne kraške površinske oblike, škraplje, škavnice, korozija, Dugi otok, Hrvaška.

INTRODUCTION

This paper aims to describe types of coastal microkarst features, and their development on Dugi otok Island and Kornati Archipelago.

HISTORY OF EXPLORATION

First documented geological exploration of the study area was started by Austrian Geological Institute which was responsible for geological mapping of Dalmatia (Schubert 1902). Later geological research was conducted by the Institute of Geology in Zagreb what resulted in several General Geological maps in scale 1:100.000 which covered the Dugi Otok Island and Kornati Archipelago (Majcen & Korolija 1973; Majcen *et al.* 1970; Mamužić 1970; Mamužić & Nedela-Devide 1968, 1973; Mamužić & Šparica 1973). Stratigraphic studies were published by Kapović & Bauer (1970, 1971), Mamužić (1971), and description of deep exploration wells were presented by Tončić-Gregl & Prpić (1971). Sedimentology and biosratigraphy of Dugi otok carbonates was reported by Fuček *et al.* (1990, 1991). Karst features of Dugi Otok Island, primarily caves, were described by Poljak (1927, 1930) and Malez (1953), whereas Rubić (1936) described coastal microkarst features on Croatian coast and islands. Geomorphology of the Kornati archipelago was described by Bognar & Grizelj (1986).

GEOLOGICAL SETTING

The Dugi otok Island geologically belongs to so-called External Dinarides which are primarily made of thick sequences of platform carbonates. However, the Dugi otok Island is made of carbonates of the Cretaceous age (Fig. 1), which have been deposited in deeper environments compared to carbonates from most of other localities in coastal Croatia. These are commonly micritic-type limestones, occasionally with evidence of deposition from mass-flows, and slope instabilities.

The oldest exposed are Barremian-Aptian ($K1^{3,4}$) thin-bedded to platy limestones with rare dolomite interbeds and lenses. Structurally, these limestones are biomicrites, or mudstones and wackestones after Dunham's classification. They are overlain by Albian-Cenomanian ($K_{1,2}$) well-bedded dolomites with limestone interbeds and occasional breccias. Dolomites have variable $CaMg(CO_3)_2$ content, which locally varies between 5,31-95,65% (Mamužić & Šparica 1973) and 70-90% (Majcen & Korolija 1973). Thin- to medium-bedded, locally platy Chondrodonta Limestones of Cenomanian-Turonian age alternate with dolomites. The former are structurally mud-supported types (mudstone/wackestone/ floatstone; Fuček *et. al.* 1990) and laminated mudstones organized in shallowing-upward sequences. Floatstones comprise rudistid and chondrodont fragments. Mud matrix is frequently recrystallized and irregularly dolomitized. Chondrodonta Limestones are characterized by high calcite-content ($CaCO_3$ 94,57-97,80%; Mamužić & Šparica 1973). Turnoian-Senonian ($K2^{2,3}$) rudistid limestones are well-bedded, occasionally interbeded by thin dolomites, and characterized by high $CaCO_3$ content (97-99%; Mamužić & Nedela-Devide 1973). Fuček *et al.* (1990) recognized mudstones to wackestones and cryptalgal laminites (bindstones). Mud matrix is locally recrystallized. Locally, there also occur thin- to medium-bedded mud-supported oncoidal limestones in alteration with rudist floatstones, cryptalgal laminites, and muddy limestones. In the Brbinšćica cove there occur pelagic limestones of Cenomanian-Santonian-Campanian age, some of which were deposited from gravity flows, and slumps (Fuček et al. 1991). The youngest exposed are Senonian (K23) limestones characterized by high CaCO3 content (96-98%; Mamužić & Šparica 1973) with occasional thin dolomite interbeds.

Structurally, Dugi otok Island has relatively simple composition. Its main structural elements are folds, some of which are faulted, like in the northern part of the island (Mamužić & Šparica 1973), and recumbent syncline which stretches along the most of the island (Mamužić & Nedela-Devide 1968, 1973)(Fig. 1).

KARSTIFICATION

Tectonic activity, lithology, structural characteristics, and geomorphologic, climatic, pedologic conditions, as well as seawater wetting and anthropogenic influence control abundance of karst features and their size.

A primary lithological characteristic that controls karstification and development of egzokarst as well as endokarst features is $CaCO_3$ content. This is most prominent in limestone-dominated areas, and in the studied area prevail micritic limestones of Cretaceous age.

Structural characteristics that control karstification comprise abundance of primary and secondary fissures and bedding attitude. Bedding plane inclination commonly controlled the size and shape of karst features, whereas steeper bedding promoted karstification primarily along diastromes. Tectonics formed fissures of various scale (larger - fault planes, diaclases; smaller - brachiclases, leptoclases), which conditioned genesis of karst features. The prominent characteristics of karst feature formed along secondary fissures are their elongation along fissure strike.

The frequency of individual karst features depends on slope inclination. The karst features are very varied and larger on horizontal and gently inclined (up to 12°) substrates, where predominates vertical water percolation (sinking) and corrosion is being transfered from the surface down into

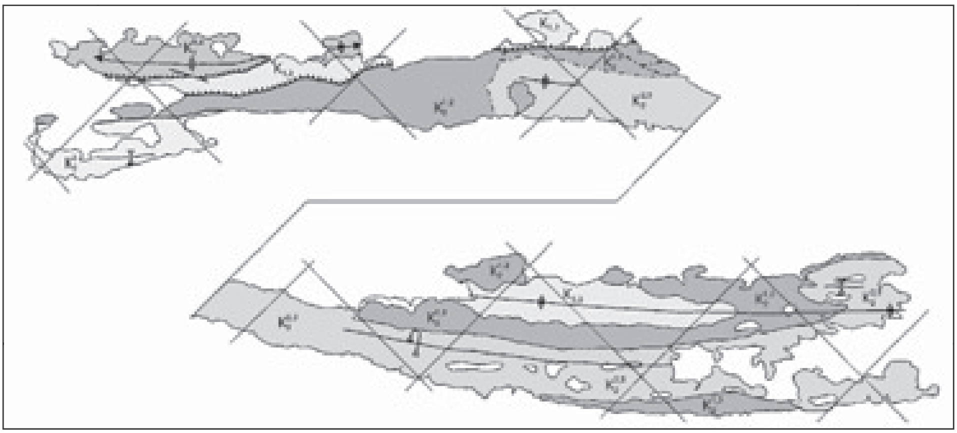

Fig. 1: Geological map of the Dugi otok Island, after Majcen & Korolija (1973), Majcen et al. (1970), Mamužić & Nedela Devide (1968) and Mamužić (1970), simplified.
Sl.1: Poenostavljena geološka karta Dugega otoka (Mamužić & Nedela Devide 1968, Mamužić 1970, Majcen et al. 1970, Majcen & Korolija 1973).

interior of the carbonate rock complex. On the other hand, karst features are much more rare on steeply dipping substrates, and that is in the first place a consequence of rapid surface drainage and decreased intensity of corrosion. Intensity of karstification is highest in the coastal zone, where seawater wetting contributes a large amount of water all year round, but is subdued in other areas because of seasonal water supply. Thus, most of the karst features are developed on the outer island coast.

Climatic conditions are important because of the length and intensity of corrosion, where precipitation, temperature, and wind pattern represent most important factors. Wind action is specific as a generator of waves, which are responsible for coastal wetting, and its influence is controlled by topography of various parts of the coastline.

KARREN TYPES

Formation of various types of coastal karren is controlled by coast inclination, lithology of the substrate rocks, and degree of their fracturation. Their shape is controlled by the relationship of slope and bedding inclination, degree of vegetative and soil cover/degree of denudation of the carbonate substrate, and intensity of evaporation. This conditioned how the corrosion operated; a) directly by meteoric water, b) by soil-percolated water, c) interstitial water, and most importantly d) by seawater flushing. Lithology also plays a major role in formation of karren; they are absent or very rare in thin-bedded rocks, but well developed and frequent in thin-bedded ones.

It is common to see mixing of two or more types of karren, and there exist various transitional types. Variations in process of karstification caused by slope denudation/overgrowth, seawater wetting, climatic changes, or changes in slope dip, commonly result in different genesis and, consequently, types of karren. In this way polygenetic karren forms, and occasionally type of karren may completely change.

Ford & Williams (1994) differentiate: a) microkarren which are smaller than 1 cm, b) karren which are 1 cm -10 m large, and c) kluftkarren which are larger than 10 m. Microkarren are typically developed in homogeneous, fine grained rocks, where some forms were created by capillary pressure-pushed water corrosion. This type of karren is shaped as irregular grooves, sometimes meandering, what confirms their genesis by corrosion by capillary waters. Biocorrosion by bacteria, lichens and mosses is also very important in microkarren formation. Cyanobacteria form small holes about 1mm deep, and their place is being repopulated by other species that support corrosion process by their organic acids and CO_2 production (Verges, 1985). Cyanobacteria are also very important in formation of coastal karst features (Folk *et al.* 1973).

Rillen karren

Two kinds of rillen karren can be differentiated by their genesis; a) those created by direct corrosion of atmospheric water and seawater spray, and b) karren formed by biogenic CO2-enriched water. The rillen karren formed by direct corrosion by atmospheric water are characteristic for steep (> 20°) denudated slopes made of karbonate rocks, and occur at small surfaces measuring only a few sq. decimetres (Fig. 2).

These are formed by wetting of inclined bare carbonate rocks by atmospheric water enriched by atmospheric CO2. The water intensively corrodes exposed carbonate substrate, and is being drained down slope along most favorable direction. Rillen karren are very common on carbonate faces, which are inclined 30-70°. Although the draining water is enriched in dissolved $CaCO_3$, it is still aggressive due to the inflow of rain. Consequently, grooves are being widened and deepened down flow, whereas their margins are becoming narrower (Bögli 1980). Corrosion-formed longitudinal fractures, which occur down flow from the rillen karren, also document water aggressiveness. Where groove inclination changes,their dimensions (width and depth) also changes. A steeper slope causes grooves to deepen, and on even steeper slopes they become wedge-shaped. That is a consequence of slower lateral, and faster regressive water corrosion, what is caused by faster specific discharge and higher concentration in groove bottom. Unlike the described model, lowering of the slope steepness and slower specific discharge lead to enhanced lateral corrosion, where grooves widen and become shallower and finally achieve gently rounded shape.

Locally, on coastal slopes where pedogenic- and vegetation cover occur above swash zone, we can see covered karren. It is made by corrossion of water that is secondary enriched in biogenic CO_2. Covered karren generally occur individually on gently inclined slopes. They are gently rounded semicircular forms, wide and shallow, and where they occur in groups they are separated by rounded margins. This form is a consequence of slow and long water percolation through the soil, which causes uniform wetting and corrosion, but also documents limited concentration of water. The width/depth ratio of grooves is identical as for the rillen karren.

Network-type karren

Network-type karren are frequently developed on gentle slopes (< 12°), and two morphological types can be differentiated; a) network-type karren (Fig. 3, 4) and b) fissure karren (Fig.5). These can be formed by: a) corrosion of bare rocks by atmospheric water and/or sea-spray, and b) subcutal corrosion under the vegetation cover. The shape of karren is also controlled by lithology, so fissure-type karren is more frequently developed on medium- and thick-bedded limestones, whereas network-type

Figure 2: Rillen karren developed in micritic limestones, Dugi otok Island Brbinščica cove.
Slika 2. Mikrožlebiči na mikritnem apnencu; Dugi otok, uvala Brbinščica.

Figure 3: Network-type karren in micritic limestones, Dugi otok Island Brbinščica cove.
Slika 3: Mrežaste korozijske razjede na mikritnem apnencu; Dugi otok, uvala Brbinščica.

Figure 4: Network-type karren in micritic limestones, formed on bedding plane exposed in an antic coastal quarry. Dugi otok Island.
Slika 4: Mrežaste korozijske razjede na mikritnem apnencu, nastale na čelu sklada, v antičnem kamnolomu; Dugi otok, uvala Brbinščica.

Figure 5: Fissure karren. Ravni Žakan Island, Kornati archipelago.
Slika 5: Poklinske škraplje. Ravni Žakan, Kornati.

Figure 6: Debris karren, see geological compass for scale. Ravni Žakan Island, Kornati archipelago.
Slika 6: Griža (glej geološki kompas za merilo). Ravni Žakan, Kornati.

karren is commonly developed on breccias. The genesis of fissure-type karren in bedded limestones is primarily confined to brachiclases and diaclases, whereas the network-type karren are related to brachiclases and leptoclases (Bognar & Blazek 1986).

Intensive fracturation of substrate, differences in size and hardness of cemented debris, and solubility of breccia matrix favour extensive development of network-type karren on breccias. Thus, breccia-related network-type karren is irregularly shaped, unlike those formed on bedded limestones that are more regularly shaped (Perica 1998). The latter are formed primarily on steeper surfaces, where corrosion acted along diastromes and secondary fissures. Karren grooves that are formed along diastromes are markedly longer, and commonly deeper than other, vertical grooves.

Coastal debris karren

The last phase in karren generation is debris karren (Fig. 6). They are most common in areas with reduced wave action and negligible gravitational transport. Debris karren is created by corrosion which acts laterally along diastromes, and in final case it forms loose rubble, which may be gravitationally transported to form colluvial aprons on steep slopes.

Root karren

Root karren (Fig. 7) are small pits that range from few millimetres up to several centimetres in size. They are created by biocorrosion, but two types can be differentiated; a) formes created under vegetation cover by corrosion of plant-roots, and b) forms created on bare rock surfaces by corrosion of bacteria, lichens, and mosses. The first type of root karren is rather rare, and is created by

Figure 7: Root karren, Dugi otok Island.
Slika 7: Biokorozijske jamice, Dugi otok.

humus acids produced by plant roots. They have rather small preservation potential, as the meteoric water corrosion will be completely overprinted during denudation, and Bögli (1980) states that they will be indistinguishable after 100 years of exposure. Larger depressions favour accumulation of atmospheric water which foster continued corrosion, and represent an initial stage in formation of other karren types. The second type of biocorrosion features is typical for bare rock surfaces which are inhabited by exolithic and endolithic organisms (primitive algae, fungus, lichens, and mosses) in seawater swash and spray zone (Fig. 8). The CO_2 in surface water comes from metabolism of cyanobacteria and algae in addition to atmospheric CO_2 dissolved in meteoric water (Ford & Williams 1994), but the progress of corrosion is frequently suppressed by clay residue.

Coastal solution-pan

Solution pans ("kamenitzas") are a few centimeters - up to several meters wide, and few- to several tens of centimeters deep. Gams (1974) differentiates two types of solution pans; a) those formed by subcutal corrosion under vegetative cover, and b) those formed on bare carbonate surface. The first type of solution pans is created by biocorrosional deepening of primary depressions. These are commonly characterized by semicircular section, and completely lack over hanged margin. Formation of the second type of solution pans ("true solution pans" of Gams 1974, "solution pits" of Sweeting 1966, and Ford & Williams 1994) is related to pre-existing depressions on flat or gently dipping slopes that were formed by subcutal corrosion. Sweeting (1966) estimated that these

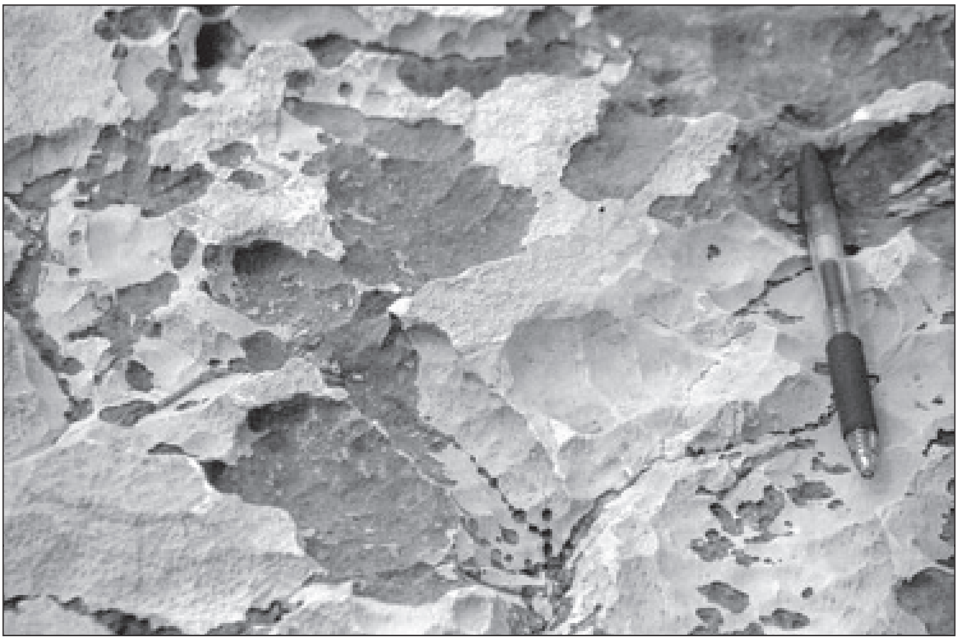

Figure 8: Root karren, second type, Dugi otok Island Brbinšćica cove. These scallops are made by endolithic and exolithic organisms in water swash and spray zone.
Slika 8: Biokorozijske jamice (drugi tip), Dugi otok, uvala Brbinšćica. Jamice nastanejo kot posledice delovanja mikroorganizmov v plimski coni in coni delovanja valov.

Figure 9: Solution pits, first phase, tectonically controlled on moderately inclined bedding planes. Dugi otok Island Brbinščica cove.
Slika 9. Škavnice – prva faza. Njihov nastanek pogojuje tektonika in blago nagnjeno čelo sklada, Dugi otok, uvala Brbinščica.

Figure 10: Solution pits, second phase. Dugi otok Veli Rat.
Slika 10: Škavnice – druga faza. Dugi otok, Veli Rat.

depressions might grow as much as 3-5 cm in 10 years. Solution pans are commonly developed on inhomogeneous rocks, and therefore are irregularly shaped (Ford & Williams 1994).

Solution pans of the second type, formed on bare carbonate surfaces ("true solution pans" of Gams 1974) are formed in four phases, the first two being constructive and the other two destructive. Their size (diameter) primarily depends on surface dip, thus they are much larger on horizontal or gently dipping surfaces, compared to the steep surfaces. Gavrilović (1964) quoted solution pans developed on surfaces as steep as 35°. Coastal solution pans commonly accumulate seawater that becomes over saturated with salts due to evaporation, so salts as well as insolvable residue accumulate in their bottoms. It is not uncommon to see solution pan bottoms inhabited by halophyte flora and fauna, which contribute in their development.

The first phase in development of solution pans (Fig. 9) is characterized by accumulation of meteoric water and its corrosion in depressions left behind by denudation. They are usually only a few centimeters in diameter, and a few millimeters deep. Corrosion is prograding down into central and lower part of the depression because of gradual loss of water by evaporation, and enhanced biocorrosion due to decay of organic material (plant leafs, grasses, algae, mosses and lichens). In this way the depression margins become progressively steeper. The water absorbs atmospheric CO2 at the surface, so the solution pan is progressively widening laterally. Evaporation-induced lowering of the water level, and increasing concentration of dissolved carbonate suppress corrosion, so the solution pan is getting narrower towards its bottom. Simultaneously with solution pan development, starts development of its groove in lowermost pan margin only during short periods of outflow that follow excessive rainfall.

The second phase in solution pan development is characterized by pronounced lateral widening (Fig.10). Its vertical development is stagnant or negligible because of clay accumulation at the bottom. At the same time, an outflow groove accelerates entrenching. Gradually, groove entrenching overruns deepening of the pan, and when the two become levelled this phase of solution pit development ends. By the end of this phase, the water level in the solution pan is being significantly lowered due to evaporation and pronounced outflow, whereas the water becomes more saturated with dissolved carbonates. The speed of groove entrenching controls the size (diameter) of a solution pan. It is a slower process on gentle dipping surfaces because the water flows out through a wide section, compared to steep surfaces, which favours development of wider solution pans. When the solution pan bottom and groove become levelled, its development stops, and degradation starts.

The third phase in solution pan development is characterized by onset of its degradation, because of widening of the outflow groove by lateral corrosion, and destruction of the overhanging solution pan wall by retrogressive corrosion of the atmospheric water. The pan margin gradually looses its overhanging profile, which becomes rounded, and the outflow groove widens further achieving a trough shape.

The fourth, final phase is characterized by disappearance of the overhanging wall, extensive widening of the outflow trough which commonly reaches the width of the solution pan. The solution pan thus achieves shape of an amphitheatre. New grooves commonly become cut in places of the previous overhanging wall, and these become meandering grooves along the flat solution pan bottom.

The development of solution pan can be aborted sooner, if a fissure is encountered during its deepening phase. The water preferentially corrodes along the fissure, and can widen it so that a tube channel will be formed, through which the water can drain out.

CONCLUSION

The researched area of Dugi otok and Kornati archipelago is an area with numerous coastal karst fhenomena. The geological characteristics show the prevalence of Cretaceous micritic limestones. Together with the tectonic features, inclination of bedding planes as well as with the geomorphologic, climatic and pedologic conditions, seawater wetting and also antropogenic influences, various types of karst features have been defined.

The research focuses on various types of costal karren that were mostly researched in ancient quarries. On the basis of known historical era in which the quarries were active the age of small karst surface features can be estimated.

In the costal zone of Dugi otok Island and Kornati archipelago different types of rillen karren have been researched, differentiated by their genesis. The network-type karren are distinguished by their morphology and can be formed on a bare rock by the corrosion of atmospheric water or they can be a result of subcutal corrosion under the soil cover.

The last phase of karren genesis is debris karren that can be found in areas with very poor wave action.

The biocorrosion process influences the appearance of root karren, typical for bare rock surface. The coastal zone is also typical for its solution pans (kamenitzas) that can be very different by the size. There are four phases defined in the solution pan genesis with the first phase being characterized by accumulation of meteoric water and corrosion in small depressions on a rock surface. The second phase is lateral widening of the solution pan and clay accumulation on its bottom. The third phase is already degradation of the form due to widening of the outflow groove by lateral corrosion and destruction of the overhanged solution pan wall. The last, fourth phase, is a disappearance of overhanging wall and the solution pan achieves a shape of an amphitheatre.

REFERENCES

Bognar, A. & Blazek, I. 1986: Geomorfološka karta područja V. Paklenice 1 : 25 000. Simp. o kraškem površju, Postojna 1985., Acta Carsologica 14-15, 197-206, Ljubljana

Bognar, A. & Grizelj M. 1996: Geomorfološke značajke arhipelaga Kornata. Kornati Ekološke monografije 7, 53-66, Zagreb

Bögli, A. 1980: Karst Hydrology and Physical Speleology. Springer Verlag, 1-284, Berlin, New York

Folk, R. L., Robert, H. H., & Moore, C. M. 1973: Black Phytokarst from Hell. Cayman Islands, West Indies, Geol. Soc. Americ. Bull. 84, 2351-2360

Ford, D. & Wiliams, P. 1994: Kars Geomorphology and Hydrology. Chapman and Hall, 1-601, London

Fuček L., Gušić V., Korolija B. & Oštrić N. 1990: Stratigrafija gornjokrednih naslaga jugoistočnog dijela Dugog otoka i njihova korelacija s istovremenim naslagama otoka Brača. Geol. vjesnik 43, 23-33, Zagreb.

Fuček L., Jelaska V., Gušić I., Prtoljan B. & Oštrić N. 1991: Padinski turonski sedimenti uvale Brbišnica na Dugom otoku. Geol. vjesnik 44, 55-67, Zagreb

Gams, I. 1974: Kras. Slovenska matica, Ljubljana

Gavrilović, D. 1964: Kamenice – Mali korozivni oblici na krečnjaku. Glasnik SGD 44/1, 53-60, Beograd

Kapović B. & Bauer V. 1970: Sedimentološke, biofacijelne i ambijentalne karakteristike gornjokrednih naslaga otoka Premuda i Dugog otoka. Nafta 21/12, 561-572.

Kapović B. & Bauer V. 1971: Rezultati stratimetrijskih snimanja gornje krede Dugog otoka i otoka Premude. Nafta 22/4-5, 467-471.

Majcen Ž., Korolija B., Sokač B. & Nikler L. 1970: Osnovna geol. karta SFRJ 1:100000, List Zadar L 33-139, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Majcen Ž. & Korolija B. 1973: Osnovna geol. karta SFRJ 1:100000, Tumač za list Zadar L 33-139, 5-44, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Malez, M. 1953: Strašna peć na Dugom otoku. Naše planine 5/10-12, 309-315.

Mamužić P. & Nedela-Devide D. 1968: Osnovna geol. karta SFRJ 1:100000, List Biograd K 33-7, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Mamužić P. 1970: Osnovna geol. karta SFRJ 1:100000, List Molat L 33-138, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Mamužić P. 1971:Geologija SZ dijela Dugog otoka. Nafta 22/4-5, 463-466.

Mamužić P. & Nedela-Devide D. 1973: Osnovna geol. karta SFRJ 1:100000, Tumač za list Biograd K 33-7, 5-27, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Mamužić P. & Šparica M. 1973: Osnovna geol. karta SFRJ 1:100000, Tumač za listove Molat L 33-138 i Silba L 33-126, 5-45, Inst. geol. Istraž. Zagreb, Savezni geol. zavod, Beograd.

Perica, D. 1998: Geomorfologija krša Velebita. Doktorska disertacija, Geografski odsjek PMF-a Sveučilišta u Zagrebu, 1-251, Zagreb

Perica, D. & Kukić, B. 1992: Karren on the Sout Velebit Range. International Symposium "geomorphology and Sea", Mali lošinj 1992., 153-157, Zagreb

Poljak, J. 1927: Prirodoslovna istraživanja na otoku Dugom. Ljetopis Jug. akad. znan. umj. 40 (1925-1927),156-160.

Poljak, J. 1930: Geomorfologija otoka Dugoga. Prirodosl. istraž. kralj. Jug.16, 3-32, 7 tab.

Rubić, I. 1936: Mali oblici na obalnom reljefu istočnog Jadrana. Geografski vestnik, br. 12-13, 3-53, Ljubljana

Schubert, R. 1902: Der geologische Bau des Inselzuges Morter, Vergada, Pašman und der sie begleitenden Scoglien auf Blatt 30, Zone XIII (Zaravecchia-Stretto). Verhandl. der k.k. geol. Reichsanst. 16, 375-387.

Sweeting, M. M. 1966: The weathering of limestones, with particular reference to the Carboniferous Limestones of northern England. In Essays in geomorphology, G. H. Dury (ed.) 177 - 210, Heinemann, London

Tončić-Gregl R. & Prpić N. 1971: Litološke, petrofizičke, biostratigrafske i kronostratigrafske karakteristike dubokih istražnih bušotina Ravni Kotari-3, Dugi otok-1 i Premuda-1. Nafta 22/4-5, 472-484.

Verges, V. 1985: Solution and associated features of limestone fragments in calcareous soil (lithic calcixeroll) from southern France. Geoderma 36, 109-22