Development and Zones of Subsidence Dolines in Case of Shore Shiftings of Regression, Transgression and Oscillation Types

Márton Veress*

Department of Geography, Eötvös Lóránd University, Szombathely 1053, Hungary

Abstract: This study deals with the karstification of coastal covered karsts with the aim of looking for a relationship between sea level changes and feature development taking place on the covered parts of carbonate karsts. This relation is manifested by the fluctuation of karst water level that is controlled by the sea level. Through further studies, shore shiftings occurring during the time of various paleokarst feature assemblages can be established. The development of suffosion dolines and dropout dolines at subsurface water level is analysed. The pattern of coast zones with dolines is studied in three cases thus, on regressive coast at non-fluctuating water level (1), on transgressive coast at non-fluctuating water level (2), and at oscillating sea level at oscillating karstwater level (3). In the first case, a solution doline zone (and/or karren zone), a mixed or compound zone (with suffosion dolines and dropout dolines) and a suffosion doline zone develops landward. In the second case a suffosion doline zone develops (this may turn into a mixed zone) and during further subsidence, a filled doline zone develops which may expand at the expense of the suffosion doline zone (mixed doline zone). In the third case, close to the shore, in the glacial a dropout doline zone and a suffosion doline zone are separated. In the interglacial, a solution doline zone develops at the uncovered surface, at the outer, seaward part of the dropout doline zone dolines with lakes are formed, the development of suffosion dolines continues in the suffosion zone.

Keywords: Doline; Doline Development Zone; Sea Level; Karstwater Level; Oscillation

DOI: 10.57237/j.earth.2022.01.003

1 Introduction

In this study, the covered karstification of coasts during shoreline shiftings is described with a focus on doline zones made up of dolines of various genetics. The significance of the study of coastal covered karsts may be that new data on events taking place on coasts such as water level changes and their triggering processes can be revealed.

Coastal karst is a specific karst type [1] its variety with cover is the covered coastal karst which is widespread on Earth [2]. These are mostly carbonate karsts, but gypsum karsts also occur [3]. There may be syngenetic karsts [4, 5] and postgenetic karsts. Among the latter, bare karst, soil-covered karst, covered karst, autogenic karst and mixed allogenic-autogenic karst also occur [6].

The peculiarity of the karstification of coastal karst is caused by shoreline shiftings and hydrological structure. The latter is a reason since karstwater due to its lower specific gravity is situated above brine which has a higher specific weight (Figure 1, [7, 8]).

A general hydrological and morphological model of coastal karsts was outlined by Choquette and James [7]

*Corresponding author: Márton Veress, veress.marton@sek.elte.hu

Received: October 4, 2022; Accepted: November 7, 2022; Published Online: December 1, 2022 http://www.earthscieng.com

and Esteban [9]. In the coastal zone, they distinguished infiltration zone (vadose zone), freshwater zone with phreatic karstwater, brackish water zone, and deep phreatic saltwater zone (Figure 1). In larger cavities, karstwater zone, brackish water zone and salt water zone also develop individually [10].

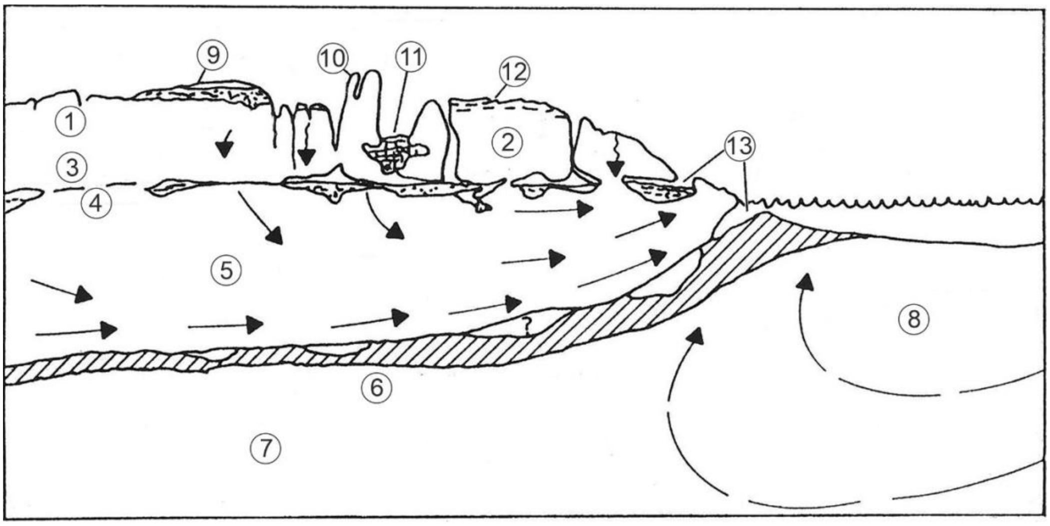

Figure 1 Hydrological relations of coastal karsts [7]

Legend: 1. Zone of infiltration and eluviation, 2. Vadose zone, 3. Zone of percolation, 4. Water table, 5. Lenticular phreatic zone, 6. Mixed-water zone (brackish), 7. Deep burial zone (saline), 8. Marine phreatic zone, 9. Soil, 10. Tower, 11. Doline, 12. Calcrete, 13. Caves

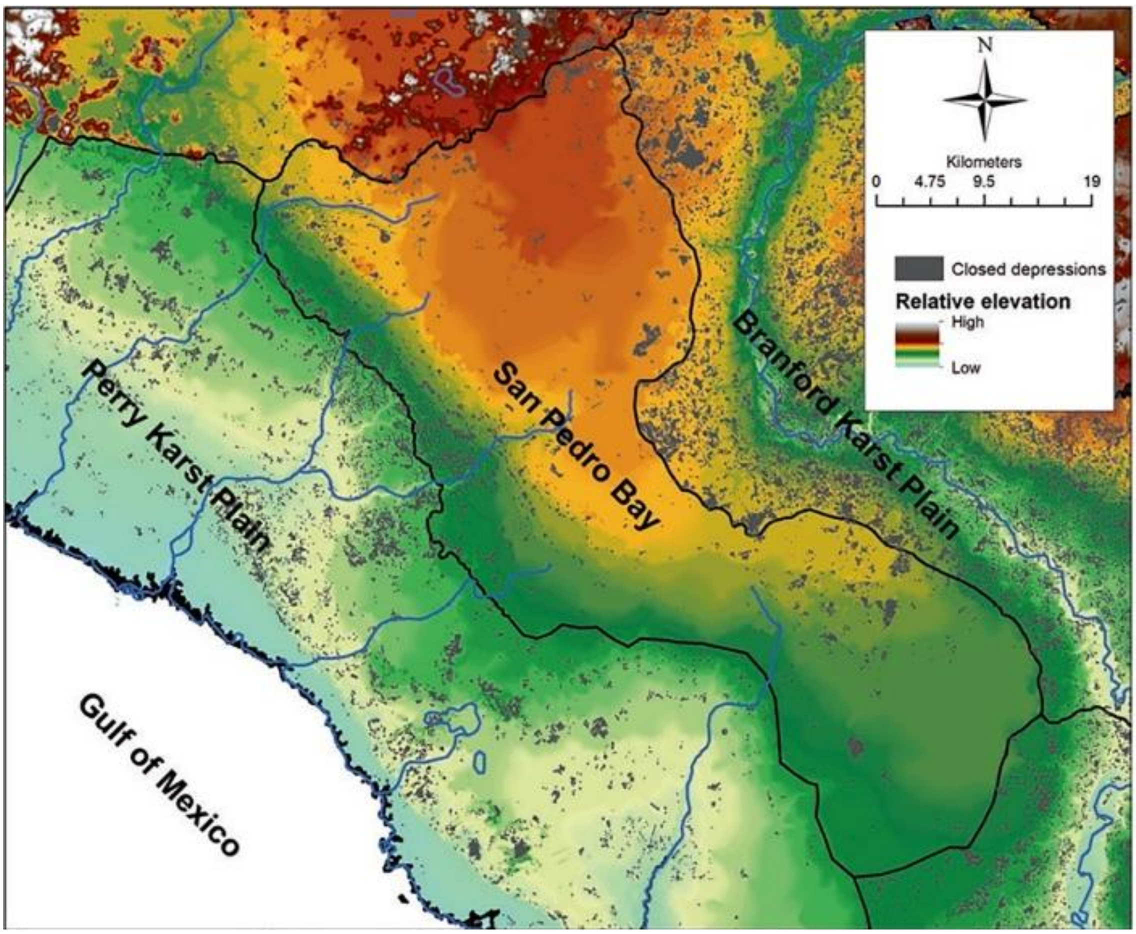

Figure 2 Depressions of the coastal karst of Florida [24]

Features and phenomena of coastal karsts are karren of diverse origin) [11-18], notches, pinnacles, benches [17], caves of various genetics [6, 19-22], vadose shafts which may also get under water are the blue holes [23], and various dolines [24, 25], such as cave failure [6] collapse dolines [21], which are especially widespread on the Yucatan Peninsula [10] in depressions permanent lakes, fluctuating lakes and intermittent lakes [24, 25], calcareous sinter forms [26], cave lakes [8], karst springs [2], and lakes below sea level [22]. Below sea level brackish water cavities and below water level karst springs [2, 25] are common. Carbonate islands have especially diverse landscape [6], where syngenetic karstification frequently takes place, and collapse dolines develop by the collapse of caves such as on Bermuda Islands [21]. However, the landscape of karst inselberg is also diverse where caves of various types (notch caves, foot caves partially flooded with sea water), closed valleys partly flooded with sea water, dolines of various types and depressions functioning as ponors occur [20].

Coastal covered karsts can be studied at several places on Earth thus, in Florida (Figure 2, [24, 25]), on the Adriatic coast [27], and on the karst inselberg coasts of the Ha-Long Bay (Vietnam, [20, 28]). The Yucatan Peninsula is also worth mentioning where horizontal caves and cenotes are characteristic [29], but this area is not covered karst.

Gvozdetskiy [30] made an early classification of karsts according to coveredness, while Sweeting [31] gave a definition of covered karst. Quinlan [32, 33] improved the classification of covered karsts and distinguished several karst including subaqueous karst. Some part of transgressive coastal covered karst is of this type. Veress [34] distinguished cryptokarst when the cover is consolidated and impermeable rock, and concealed karst when the cover is unconsolidated and permeable.

On uncovered (or soil-covered) karst, solution dolines and collapse dolines, while on covered karst, caprock dolines (on consolidated rock) and subsidence dolines (on unconsolidated rock) develop [29, 35, 36]. The latter may be dropout dolines (primarily on cohesive cover), suffosion dolines (on non-cohesive cover) and compaction dolines [29, 35, 36].

Dropout dolines (Figure 3) develop by the collapse of the cavities of the bedrock or the cover [36], if water level decreases in the cavities [37-39] and the ceiling of the cavities is thin, but collapses are favoured by earthquakes [40], point-like burden [41], vibration [40] and the increase of pore water pressure in the material of the cover [42]. However, cover cavities may also develop by suffosional material transport [36]. There is a great chance of the collapse of bedrock cavities if they are horizontally well-developed [43-45]. Collapse development without suffosion may be of two kinds. The collapse of bedrock cavities may spread onto the cover where a cavity is formed and then it collapses (indirect doline development), or the collapse of the bedrock cavity and the cover happen simultaneously and doline development is direct. The collapse of the bedrock cavity is triggered by low karstwater level [46].

Figure 3 Dropout doline with lake (Mouth of River Neretva, Croatia)

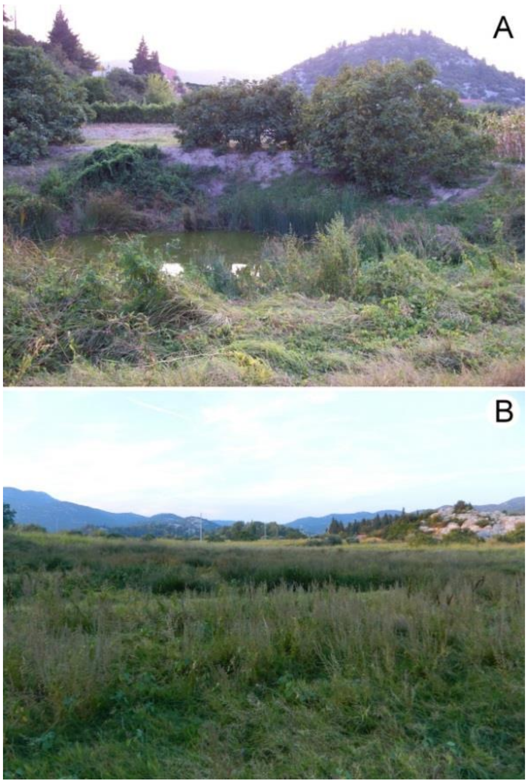

Figure 4 Suffosion dolines with lakes A: transition towards dropout doline, B. typical suffosion doline, (at the village of Ploče, close to the Adriatic coast, Croatia)

Suffosion dolines (Figure 4) develop by suffosion and grain fall. During these processes, the cover is transported into the passages and cavities of the bedrock [29]. On coastal karsts, since the water level is close to the surface, intermittent lakes or permanent lakes that developed in subsidence dolines are common (Figures 2, 5).

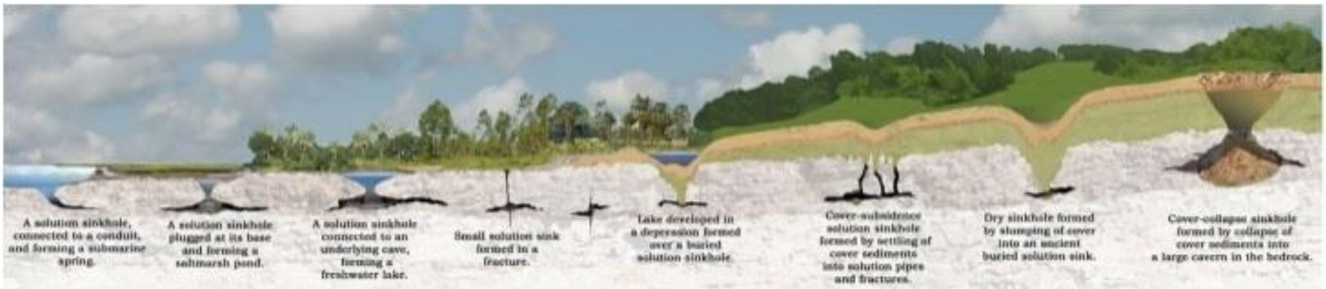

Figure 5 Dolines of various types of the coastal karst of Florida along a conceptual cross-section [25]

2 Factors Influencing the Development and Characteristics of Coastal Covered Karsts

The appearance, development, and characteristics of coastal covered karsts are affected by the following factors.

(1) Superficial deposit has to be present. This is primarily marine (lacustrine) sand, and loess, fluvial sediment, moraine, and weathering residue. Their thickness, composition, and water transportation capacity is important. Even if there was cover at coastal covered karsts, in the intertidal zone, wave activity created bare surfaces is larger and smaller bands by destroying the cover. Thus, covered karst is mainly aligned by bare karsts from the sea.

(2) The coast should not be steep. If it is steep, there is a smaller chance of the survival of the cover and the karstwater is at an extreme depth. If indeed coastal karst develops on steep coast, it will be narrow and homogeneous (as we will see later, there are only suffosion dolines). On gentle coast, covered karst can change between some hundred metres and some thousand metres at given time.

(3) The shifting of the shoreline determines the heterogeneity of the landscape of coastal karst. This can be traced back to two reasons: to the tectonic movements of the dry land and to eustatic sea level changes. The effect of both can be manifested in regression and transgression. To the effect of shoreline shiftings, covered karstification is shifted with constituting zones together, but the number and width of zones may change (see below).

(4) The proportions of the coast are affected by coast structure (the coast is either concordant or discordant). The structure, with the vertical movements of the land (and eustatic sea level changes) and the developing river valleys affects the density, size and shape of bays. There is a greater chance for the accumulation and survival of superficial deposit and for a wider development of the cover at bays. Therefore, for example on discordant, sinking coast, primarily bays are the sites of covered karstification (or it may become wider at these sites).

(5) The position of karstwater level (groundwater) as compared to the surface and to the bedrock, its steepness, the elevation difference of high and low water levels. Cavity formation below the karstwater level increases the chance of sediment reception of the bedrock particularly if its level is close to the surface of the bedrock. The degree of its fluctuation influences the expansion of suffosion processes, while its frequency affects the duration of suffosion (see below). Its steepness affects the width of expansion of subsurface cavities.

(6) The rate of shoreline shifting. Its value determines whether covered karstification takes place. If it is too fast, for example at transgression, burial already occurs at the beginning of feature development.

(7) Former extent of cavity formation of coastal rocks (paleokarstification), the solubility of the rock. The already existing cavities promote the transportation of superficial deposit into the karst.

(8) Abrasion platforms favour karstification. The

reason for that is the great chance of infiltration on its low-inclined surface and the small chance of cover denudation. Below the low-inclined surface of the platform if the karstwater level is close to the surface, phreatic cavity formation takes place in a wide zone. The effect of abrasion platforms to karstification is not only manifested at present coasts such as in Florida [24], but also on karsts where no coast can be found any more. Thus, for example in the Mecsek Mountains (Hungary) where two abrasion platforms of various age can be detected on the karst. The older is of Middle-Miocene, while the younger is of Pannonian age [47-49]. Doline density is high particularly on the lower Pannonian platform where the dolines are older, inactive solution dolines and recent suffosion dolines [50]. The doline density on the Pannonian platform reaches 80 dolines/km^2 [51], and at some places it is 380 doline/km^2 [52].

3 Doline Development

Farther from the shoreline and at surfaces with a higher and higher altitude, a series of features develops which have a marine, marine-terrestrial and terrestrial character regarding their coveredness, the composition of the water and the genetics of the features (Figure 5). The features may be arranged into zones of various width.

The development of various doline types and thus, of their zones is controlled by karstwater level (its position as compared to the surface, its fluctuation and steepness), but this is characteristic feature is not specific of coastal karst. Subsurface karstwater level occurs on polje karst [31], or on the intermountain plains of fenglin karst too [36, 53]. Doline development is possible by the material loss of the cover. This may take place if there are sediment receiving passages and cavities in the bedrock. Suffosional material transport is possible if the cover gets into the passages and shafts situated above the karstwater level or into the phreatic cavities that got above the karstwater level and then into the karstwater through them.

At suffosion doline development, suffosion is possible at that part of the cover which is above the water level if there is precipitation. However, rainfall also increases the karstwater level, which decreases the duration of suffosion. Theoretically, the following cases are possible.

1) The karstwater level and groundwater level are always in the cover, there is no suffosion and suffosion doline development.
2) The karstwater level is always in the bedrock. Suffosion and thus, doline development may take place at these sites during the whole year.
3) High karstwater level is in the cover (wet season) and low karswater level is in the bedrock (dry season). Suffosion and doline development is possible if the dry season (the karstwater level is in the bedrock) is disrupted by precipitation falls.
4) High karstwater level may also reach the surface. As a result of karstwater fluctuation, katavotra develop with permanent lakes of fluctuating water level or with intermittent lakes [31]. A similar situation is characteristic of coastal karsts. If the karstwater level continuously reaches the surface, there are permanent lakes in the dolines (which may be solution dolines too), if it only reaches the surface temporarily, intermittent lakes develop. Either at permanent lakes or intermittent lake, the elevation of lake water levels changes at the same places and their composition (freshwater, brackish water, salt water) alters at various places. Rising water level creates passages opening onto the surface and then suffosion and thus, doline development take place through the passages when the water level gets below the surface of the bedrock.

Dropout doline development is more closely related to water level. In this case, the ways of doline development are the following.

1) If the water level is in the cover (high karstwater level or high groundwater level), dropout doline development may also take place independently of the bedrock if the water level decreases in the cavity [39].
2) If the water level is in the bedrock, doline development takes place at least in two ways which are the following.
   a. In the cover, passages and cavities develop by suffosion and grain fall. The collapse of these cover cavities result in dropout doline development [36].
   b. If the karstwater level gets even deeper in the bedrock, its cavities will be completely or partly dry. The more developed the cavity horizontally, and the thinner the ceiling, their precondition is present at karstwater level being close to the bedrock surface [43], the greater the chance for

its collapse. The collapse can be inherited onto the surface with cover by the collapse of the cover (direct doline development) or it causes cavity development in the cover and a doline develops by the collapse of this cavity (indirect doline development).

4 Zones of Doline Development

In the coastal zone, marine and terrestrial sedimentation and the evolution and development of subaerial karst surfaces take place in connection with sea level changes [54]. Korpás and Juhász [55] described the wedging out of phreatic levels moving away from the coast in relation to regression and the superimposed paleokarst horizons on coastal karsts.

Below, recent doline development zones are described on coasts in relation with one-way changes of the sea level (regressive and transgressive shifting of the shoreline take place) or with long-term oscillation changes of the sea level by also taking into consideration the short-term oscillation changes of the karstwater level due to precipitation fall. Since the development of the coastal karst features and their zonal pattern are traced back and interpreted by these processes (shoreline shifting and karstwater level fluctuations).

4.1 Doline Zones at One-Way, Regressive Shoreline Shifting and at Non-oscillating Karswater Level

In case of regression, a coastal platform or platforms develop which get above the sea level. During sediment transportation from the sea, the platforms become partially or completely covered with marine sand or also with marine (older) sediment from the land or with terrestrial sediment.

Closest to the shoreline, solution dolines and/or a karren zone develops with caves at the uncovered surface. This is the solution doline zone or karren zone. The karstwater level sinks therefore, the phreatic cavities below the inactive water level become dry. At sites where the inactive bedrock cavities are close to the bedrock surface, cover cavities develop by their collapse, which are inherited onto the surface (indirect dropout doline development), but dropout dolines may also develop by collapse of the bedrock and the subsequent collapse of the cover (direct dropout doline development). A dropout doline zone is formed (Figure 6b).

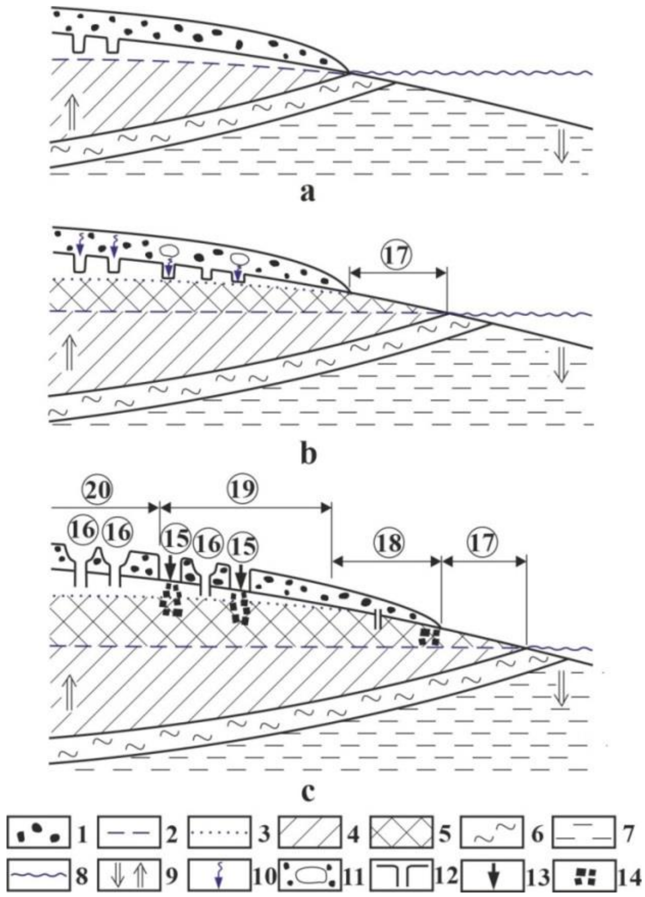

Figure 6 Doline development on regressive coast

Legend: a. primitive state, b. intermediate state (cavity formation), c. developed state (dolines and their zones), 1. superficial deposit, 2. active karstwater level, 3. former karstwater level, 4. zone of active phreatic cavities, 5. zone of inactive phreatic cavities, 6. brackish water. 7. salt water, 8. sea level, 9. rise, subsidence, 10. suffosion, 11. cavity in the cover, 12. bedrock passage above the water level, 13. collapse, 14. collapsed material which developed by the collapse of the bedrock cavity, 15. dropout doline, 16. suffosion doline, 17. zone of karren, 18. zone of buried karren, where newer subsidence dolines may develop, 19. mixed (dropout and suffosion doline) zone, 20. zone of suffosion dolines

Farther from the shoreline, where the karstwater level is deeper as compared to the bedrock, the cavities of the bedrock do not collapse since the ceiling of the cavities is thicker. Here, passage development happens in the bedrock (this is also promoted by the phreatic cavities) and thus, suffosion takes place. The suffosion doline zone develops (Figure 6c). This zone is widening towards the land until there is superficial deposit. As a result of further regressive, the subsidence of the karstwater level continues and this enables the development of suffosion dolines in the dropout doline zone as well. The dropout doline zone is transformed into a mixed zone (Figure 6c).

4.2 Doline Zones at One-Way Transgressive Shoreline Shifting and at Non-oscillating Karstwater Level

In case of transgression, karstification does not take place on abrasion platform or if it does, then it is of older development than the present transgression. The steepness of the coast depends on the processes taking place there, while the position of the karstwater level depends on the steepness of the surface and the water level as compared to the surface. The cover can be of marine origin in this case too. Karst zones close to the shoreline do not develop at all or if they do, they become partially covered with water as for example in the case of the Croatian Umag (Figure 7).

Figure 7 Inactive karren of sinking coast which are covered with water (Umag, Croatia): A-B. grikes, C-D. pinnacles (with recent, active karren on them)

If the karstwater level is deeper as compared to the bedrock surface, passage development takes place above the water level in the whole expansion of the covered coastal karst. A uniform suffosion doline zone develops on the coastal karst by suffosion (Figure 8b). During transgression, the homogeneous suffosion doline zone become differentiated in the following way.

1) Its outer, littoral part gets under water and suffosion dolines become filled with marine sediments. Similarly, the karren, shafts, caves, solution dolines or collapse dolines of the bare part of the coast become filled with water or sediments (Figure 7).
2) The karstwater level gets close to the bedrock surface farther from the shoreline too. If this is a slow process, dropout dolines develop since material is transported from the cover into the bedrock passages by suffosion. The dolines are formed by the collapse of cover cavities. At that part of the suffosion doline zone where this process takes place, is transformed into a mixed doline zone. Close to the shoreline, a zone of dolines with lakes develops (Figure 8b). Both the zone of dolines with lakes and the mixed zone become wider by subsidence. If the suffosion doline zone is not able to widen (for example because the cover is wedging out), the mixed doline zone and the zone of dolines with lakes may completely use up the suffosion doline zone.

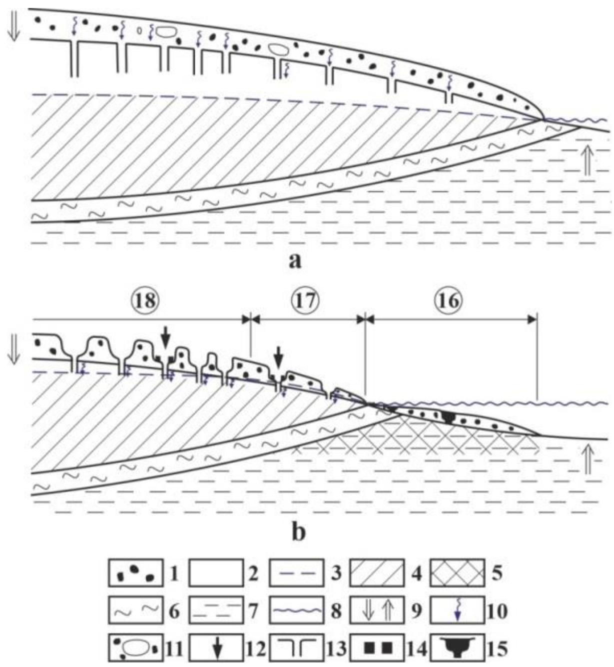

Figure 8 Doline development on transgressive coast

Legend: a. primitive state, b. state that developed during transgression, 1. superficial deposit, 2. limestone, 3. active karstwater level, 4. zone of active phreatic cavities, 5. zone of inactive phreatic cavities, 6. brackish water, 7. salt water, 8. sea level, 9. subsidence, rise, 10. suffosion, 11. cavity in the cover, 12. collapse, 13. passage in the bedrock, 14. collapsed material, 15. doline fill, 16. underwater doline zone, 17. zone of dolines with lakes, 18. mixed doline zone

4.3 Doline Zones at Oscillating Shoreline Shifting and at Oscillating Karstwater Level

In case of oscillation, the platform is covered by water again thus, the cover may also be marine sediment. A repeated cavity formation may take place below the karstwater level at the same level or the already existing cavities may continue their development when they get below the water level. At high and low karstwater level, a wide zone of cavities below water level develops (epiphreatic cavities), which lose their water when the water level sinks. Therefore, their sediment receiving capacity increases, which effectively promote subsidence doline development in the cover.

In the glacial (Figure 9), a solution doline zone develops in the band of the coast without cover. Cavity formation occurs in the fluctuating karstwater level zone of the band that is close to the shoreline and covered with superficial deposit. The cavities may be formed in the bedrock (by dissolution below the water level) or in the cover (by suffosion). At low water level, dropout dolines develop directly or indirectly by the collapse of cavities. Suffosion doline development already begins in the dropout doline zone and beyond as well. The zone becomes mixed. (The development of suffosion dolines is of various intensity since the quantity of precipitation may also be diverse in areas of various climate.)

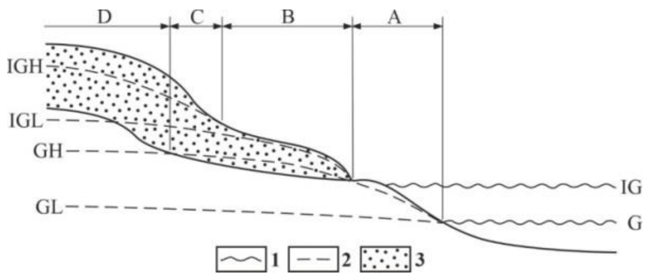

Figure 9 A possible model of doline development on coastal karst in the glacials and interglacials

1. sea level, 2. karstwater level, 3. superficial deposit, G. sea level in the glacial, IG. sea level in the interglacial, GL. low karstwater level in the glacial, GH. high karstwater level in the glacial, IGL. low karstwater level in the interglacial, IGH. high karstwater level in the interglacial, A. zone of solution dolines, B. zone of dropout dolines that developed in the glacial, which dolines are transformed into dolines with lakes in the interglacial, C. zone of dropout dolines that developed in the glacial, D. zone of suffosion dolines that developed in the glacial which is transformed into a mixed zone in the interglacial

In the interglacial, solution dolines are partially covered with sea water, they begin to be filled with marine sediment. Karren formation takes place in the uncovered rest band of the coast. Intermittent lakes or lakes with fluctuating water level develop in the dolines of the dropout doline zone, but no lakes develop in the dolines of the dropout doline zone at the farther part of the shoreline where the high karstwater of the interglacial does not reach the surface. In the area of the suffosion doline zone, the development of suffosion dolines continues with higher intensity. Dropout dolines may also appear in this zone subordinately (particularly if the cover is cohesive). In this case doline development is caused by the collapse of cover cavities. The development of these cavities is enabled by suffosional material transport.

5 Conclusions

(1) On coastal karsts and thus, also on covered karsts, karstification takes place in the epikarst. However, the phreatic zone contributes to this with its inactive cavities. The vadose zone is not of a significant thickness, it may be completely used up at the rise of the karstwater level (at transgression).

(2) At one-way, regressive shoreline shifting, at non-oscillating karstwater level, a dropout doline zone and a suffosion doline zone develops towards the centre of the land. The dropout doline zone is transformed into a mixed doline zone subsequently. At one-way, transgressive, non-oscillating karstwater level, the uniform suffosion doline zone becomes differentiated gradually. On the seaward side, an inactive, filled suffosion doline zone is separated towards the land. At the littoral part of the suffosion doline zone, a dropout doline zone may also develop and a zone of dolines with lakes is formed gradually. In the glacial at oscillating shoreline shifting and at oscillating karstwater level, a solution doline zone may develop in the uncovered band, beyond which a dropout doline zone is formed landwards then the suffosion doline zone develops. In the interglacial, the solution doline zone partially gets under water, the part of the dropout doline zone being closer to the shoreline is transformed into a zone of dolines with lakes and the suffosion doline zone may develop into a mixed zone.

(3) One-way shoreline shiftings and cyclic shoreline shiftings may have affected the karstification of the coasts together in the Pleistocene ice age. However, in the Postglacial, one-way shoreline shiftings were influential.

(4) The effect of karstwater level oscillation is of different degree at various coast sections regarding either the transgressive or the regressive coast. The difference between the high and the low karstwater level may be very different at various sites as a result of the various degree of cavity formation of the karstic rock and of the effect of precipitation

with different quantity and distribution.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, [Márton Veress], upon reasonable request.

References

[1] Veress M 2020. Karst Types and Their Karstification, Journal of Earth Science 31 (3) pp. 621-634.

[2] Fleary, P., Bakalowicz M., Marsily de G. 2007: Submarine springs and coastal karst aquifers: A review – Journal of Hydrology 379: 79-92.

[3] Van Everdingen, R. O., 1981. Morphology, Hydrology and Hydrochemistry of Karst in Permafrost near Great Bear Lake, Northwest Territories, Paper 11. National Hydrological Research Institute of Canada, Saskatoon. 53.

[4] Jennings J. N. 1964. Geomorphology of Punchbowl and Signature Caves, Weé Jasper New South Wales – Helectite 2: 494-498.

[5] Grimes K. G. 2004. Syngenetic Karst – In: Gunn J. (ed.): Encyclopedia of Caves and Karst Science, Fitzroy Dearborn, New York pp. 717-719.

[6] Mylroie, J. E., Carew S. L. 2000. Speleogenesis in Coastal and Oceanic Settings – In: Klimchouk et al. (edits): Speleogenesis, NSS, Huntsville, 226-233.

[7] Choquette P. W., James N. P. 1988. Introduction – In: Choquette P. W., James N. P. (eds.): Paleokarst – Springer Verlag, New York – Berlin – Heidelberg – London – Paris – Tokyo pp. 3-24.

[8] Palmer A. N. 1977: Geology and origin of the caves of Bermuda – Proc. 7th Int. Spel. Congress, Sheffield, UK 336-339.

[9] Esteban M. 1988. Basal Tertiary Unconformity – Unconformities and Paleokarst – Paleokarst reservoirs in unconformity plays: Exploration production, Strategies and cave histories – Kézirat.

[10] López-Martínez, Rafael; Fernando Gázquez; José M. Calaforra; Philippe Audra; Jean Y. Bigot; Teresa Pi Puig; Rocío J. Alcántara-Hernández; Ángel Navarro; Philippe Crochet; Liliana Corona Martínez; and Raquel Daza Brunet. 2020. Bubble trail and folia in cenote Zapote, Mexico: petrographic evidence for abiotic precipitation driven by CO_2 degassing below the water table. *International Journal of Speleology*, 49: 173-186.

[11] McLean R. F. 1974. Geologic significance of bioerosion of beachrock in Proceedings of the 2nd International Coral Reef Symposium, Great Barrier Reef Committee, Brisbane, December pp. 401-408.

[12] Trudgill S. T. 1976. The marine erosion of limestones on Aldabra Atoll, Indian Ocean, Zeits für Geomorph., supplementary issue, 26. 164-200.

[13] Jennings JN 1985. Karst Geomorphology. Basil Blackwell, New York.

[14] Viles, H. A. - Spencer, T. (1996): "Phytokarst", blue-green algae and limestone weathering - In: FORNÓS, J. J. - GINÉS, Á. (szerk.): Karren Landforms p. 115-140, Universitat, de les Belears, Palma de Malllorca.

[15] Lundberg 2009. Coastal karren. In Ginés A., Knez M., Slabe T., Dreybrodt W (eds): Karst Rock Features. Karren Sculpturing Zalozba ZRC. Institut za raziskovanje krasa ZRC SAZU, Postojna, Ljubljana, Carsologica, 9. pp. 249-264.

[16] Gómez-Pujol L and Fornós JJ 2009. Coastal karren in the Belearic Islands. In: Ginés A, Knez M, Slabe T, Dreybrodt W (eds): Karst Rock Features. Karren Sculpturing Zalozba ZRC. Institut za raziskovanje krasa ZRC SAZU, Postojna, Ljubljana, Carsologica, 9. pp. 487-502.

[17] Taboroši D., Kázmér M. 2013. Erosional and Depositional and Textures and Structures in Coastal Karst Landscapes – In: Lace M. J, Mylroie J (eds.): Coastal Karst Landforms, Springer, Dordrecht DOI. 10.1007/978-94-007-516-62.

[18] Veress M. 2019. The karren and karren formation of bare slopes. Earth-Science Reviews 188 272-290.

[19] Gines A, Fiol L. A. 1981. Estratigrafia del yacimiento de la Cueva del Fum – Endins. 8: 25-42.

[20] Móga J., Tombor E. 2016. A Ha Long-öböl karsztos szigettengerének felszínalaktani vizsgálata (The geomorphological examination on the karstic archipelago of Ha Long bay – Karsztfejlődés XXI: 5-24. DOI: 10.17701/16, 5-24. (in Hungarian).

[21] Takács Bolner K. 2007. A Bermuda-szigetek korallhomokkő-barlangjai (Bermuda’s coral sandstone caves) – Karsztfejlődés XII: 303-313. (in Hungarian).

[22] Bakran-Petricioli T., Petricioli Donat 2008. Habitats in submerged Karst of Eastern Adriatic Coast – Creation Natural Heritage- Croat. Med. J. 49 (4) pp. 455-458.

[23] Mylroie J. E 2004. Blue Holes in the Bahamas In: Gunn J. (ed.): Encyclopedia of Caves and Karst Science, Fitzroy Dearborn, New York pp. 155-156.

[24] Upchurch S., Scott TM., Alfieri MC., Fratesi B, Dobecki TL. 2019. Epigene and Hypogene Karst – The Karst Systems of Florida Cham, Springer pp. 359-441.

[25] http://www.dep.state.flius/geology/geologictropics/sinkhole.htp

[26] Charlier R. 2010. Slovenia – In: Bird. E. C. F. (eds). Encyclopedia of the World's Coastal Landforms, Dordrecht https://doi.org/10.1007/978-1-4020-8639-7-123 pp. 455-458.

[27] Cvijič J. 1918. Hydrographie souterraine et evolution morphologique du karst 6 (4): 375-426.

[28] Hoang Thank Thuy 1973. Karsztos szigethegyek Észak-Vietnamban (Karst inselbergs in Northern Vietnam) – Karszt és Barlang I-I: 13-16. (in Hungarian).

[29] Williams P. W. 2004. Dolines. In: Gunn J. (ed.): Encyclopedia of Caves and Karst Science, Fitzroy Dearborn, New York pp. 304-310.

[30] Gvozdetskiy NA 1965. Types of Karst in the U.S.S.R. Separatum, Prob. Speleol. Res. (Prague) 47-54.

[31] Sweeting MM 1973. Karst Landforms. Columbia University Press, New York, 362 p.

[32] Quinlan JF 1967. Classification of karst types: A review and synthesis emphasizing the North American literature 1941-1966-Natl. Speleol. Soc. Bull 29 pp. 107-109.

[33] Quinlan JF 1978. Types of karst, with emphasis on cover beds in their classification and development. PhD Thesis, Geology, University of Texas Austin.

[34] Veress M 2016. Covered Karst. Springer, Berlin, Heidelberg, New York 536 p. DOI 10.1007/978-94-017-7518-2.

[35] Waltham AC, Fookes PG 2003. Engineering classification of karst ground conditions. Quarterly Journal Engineering Geology Hydrogeology 36: 101–118.

[36] Waltham T, Bell F, Culshaw M. 2005. Sinkholes and Subsidence. Springer Berlin Heidelberg, 382 p.

[37] Xu W, Zhao G 1988. Mechanism and prevention of karst collapse near mine areas in China. Environmental Geology Water Science, 12: 37-42.

[38] Currens IC, Paylor RL, Beck FG, Davidson B 2012. A method to determine cover – collapse frequency in the Western Pennyroyal karst of Kentucky. Journal of Cave and Karst Studies 74 (3): 292-299.

[39] Jia, Long Lujuan Li, Yan Meng, Yuanbing Wu, Zhongyuan Pan, Renchao Yin 2018. Responses of cover-collapse sinkholes to groundwater changes: a case study of early warning of soil cave and sinkhole activity on Datansha Island in Guangzhou, China. Environ Earth Sci 77, 488 https://doi.org/10.1007/s12665-018-7603-3

[40] Yuan D 1987. Environmental and engineering problems of karst geology in China: In: Beck BF, Wilson WL (eds.) Karst Hydrogeology: Engineering and Environmental Applications, Balkema: Rotterdam, pp. 1-11.

[41] Chen J, Beck BF 1989. Qualitative modelling of the cover-collapse process. In: Beck BF (ed.), Engineering and Environmental Impacts of Sinkholes and Karst, Balkema: Rotterdam, pp. 98-95.

[42] He K, Liu C, Wang S 2003. Karst collapse related to over-pumping and a criterion for its stability. Environmental Geology, 43: 720-724.

[43] Pessoa P. 2020. Karst Hydrogeology of the Lagoa Santa Area, in Lagoa Santa Karst Brazil's Iconic Karst Region pp. 135-188. Springer, Cham DOI: 10.1007/978-3-030-35940-9.

[44] Crawford NC (2001) Environmental problems associated with urban development upon karst, Bowling Green, Kentucky. In: Beck BF, Herring JG (eds) Geotechnical and environmental applications of karst geology and hydrology. Balkema, Lisse, pp 397–424.

[45] Klimchouk A, Andrejchuk V (2002) Karst breakdown mechanisms from observations in the gypsum caves of the western Ukraine: implications for subsidence hazard assessment. Int J Speleol 31 (1/4) 55–88.

[46] Ford DC, Williams PW 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester, 561 p.

[47] Lovász Gy. 1971. Adatok az Abaligeti-karszt geomorfológiai és hidrológiai jellemzéséhez (Data for the geomorphological and hydrological description of Abaliget Karst) Földrajzi Értesítő XX (3) pp. 283-296 (in Hungarian).

[48] Lovász Gy. 1977. Geomorfológiai körzetek (Geomorphological districts) – In: Lovász Gy. (ed.): Baranya-megyek természeti földrajza, Baranya megyei Levéltár, Pécs pp. 62-68. (in Hunagrain).

[49] Hevesi A. 2001. A Nyugat-Mecsek felszíni karsztosodásának kérdései (Questions of the surface karstification of Western Mecsek) – Karsztfejlődés VI. pp. 103-111. (in Hungarian).

[50] Veress M. 2011. Adatok a Mecsek-hegység fedett karsztosodásához a Cigány földi mintaterületről vett példák felhasználásával (Some data for the covered karstification of the Mecsek Mountains using examples taken from the Cigány föld research area) – Karszt és Barlang 2010 évf. I-II. pp. 9-30 (in Hungarian).

[51] Lippmann L., Kiss K., Móga J. 2008. Az Abaliget-Orfűi karszt karsztos felszínformáinak vizsgálata térinformatikai módszerekkel (Investigation of the karstic phenomenon near Orfű and Abaliget by GIS methods) – Karsztfejlődés XIII pp. 151-160 (in Hungarian).

[52] Hoyk E. 2002. A Nyugat-Mecsek karszt dolináinak morfometriai vizsgálata (A morphometric investigation of the karst dolines of Western Mecsek) – Karsztfejlődés VII. pp. 161-171. (in Hungarian).

[53] Waltham, T. 2008. Fengcong, fenglin, cone karst and tower karst. Cave and Karst Science 35 (3) pp. 77-88.

[54] Esteban M., Klappa C. F. 1983. Subaerial exposure environments – In: P. A. Scholle, B. G. Bebout, C. H. Moore (eds.): Carbonate depositional environments – AAPG Memoir no 33 pp. 1-54.

[55] Korpás L., Juhász E. 1990. Paleokarszt földtani modellek (Paleokarst geological models) – Karszt és Barlang 1990 (II) pp. 105-116. (in Hungarian).