# Factors influencing solution in karren and on covered karst

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## Abstract

The effect of the following factors on karstification were investigated: the presence of *Pinus mugo*, slope length, and slope angle (Totes Gebirge, Austria), the wind action (Diego de Almagro Island, Chile), the thickness and quality of covering sedimentary rock (Bakony Mountains, Mecsek Mountains, Hungary) and the role of karst water (tsingies, Madagascar). The methods were as follows. The specific cross-sectional area of rinnenkarren and their specific shape-parameter in Totes Gebirge were calculated. Morphological maps of several karren forms at Diego de Almagro Island were prepared and specific width of these karren features was also computed. Topographic cross-sections were created and height measurements of Madagascar tsingy areas carried out as well. Vertical electrical sounding (VES) method was applied in the Bakony Mountains and in the Mecsek Mountains. The following conclusions could be established: dissolution is more intense on slopes with *Pinus mugo* than on bare slopes. Rinnenkarren (channels) may develop under rivulets, but they can be created by seepage, too. The wind moves the water on Diego de Almagro Island, therefore it controls the dissolution process. On the windward side of landforms both the number and the size of karren forms are increased and as a result, the amount of total dissolution is also higher due to the wind effect. Tsingies represent the initial phase of karstification. They develop when the karst water table sinks temporarily to a lower level after reaching the surface. The covered karst forms of the Bakony Mountains developed at places where the covering sedimentary rocks are thinner, whereas the covered karst features in the Mecsek Mountains developed where the clay beds of the covering sedimentary strata end.

**Keywords:** karren, covered karst, factors effecting karstification, plants, dip angle, length of slope, wind, karst water table, thickness of covering sedimentary rock

## Introduction

Karstification is influenced by many factors. These are e.g. the characteristics of the limestone (its contamination, fabric, structure, bedding and thickness, the characteristics of the karst movement, the climate and of the soil). The role of these factors were investigated by many authors and the results may be found in standard works on karstification (Sweeting, M.M. 1972; Jennings,

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J.N. 1985; Trudgill, S.T. 1985; Jakucs, L. 1977; Ford, D.C. and Willams, P.W. 1989, 2007).

In this study a few findings from various sample areas will be presented. These phenomena are the following: the presence of *Pinus mugo*, the slope angle and slope length, the wind action, the position of karst water table (as to the development of surface karst forms), the quality and thickness of the covering sedimentary rock.

## Sample areas

The scope of research included the following areas: Totes Gebirge (Eastern Alps, Austria), Island of Diego de Almagro (Chile), Ankarana tsingy and Bemaraha tsingy (Madagascar), Bakony Mountains and Mecsek Mountains (Hungary).

The Totes Gebirge is the remnant of the overthrust fold of Upper Eastern Alps. The mountains are built of Dachsteinkalk. Karren formation in Totes Gebirge mainly takes place on the cuesta surfaces of glacier valleys. Wallkarren are found on the steep slopes of the heads of the cuestas, while rinnenkarren dominate the gentler slopes of the cuestas with bedding planes *(Photo 1)*. The investigations were carried out in the *Pinus mugo* belt. They addressed the development of channels (runnels), furthermore the relationship


*Photo 1.* A bare slope with small dip angle from Totes Gebirge. – 1 = type A channel; 2 = type B channel


*Photo 2.* Shadow dune karren. – 1 = direction of wind

between the development of channels in the presence and absence of *Pinus mugo*, and the dependence on the length of the slope and the slope angle.

Diego de Almagro Island is situated in the Patagonian group of islands. The rocks of the island became metamorphosed during the Upper Carbonic tectogenesis (Maire, R. *et al.* 1999). Three marble stripes edged into the non-karstic metamorphic rocks, which were of lamprophyres and basalt origin (Maire, R. *et al.* 1999). Upon the marble surface extensive karren forms developed. The most frequent of them are dissolutional basins (kamenitzas), rinnenkarren, meanderkarren, wandkarren, ripple karren and remnant forms (e.g. shadow dune karren inselberg, whaleback dune karren inselberg, *Photo 2).* These were described by Jaillet, S. and Hoblea, F. 2000. (2000) and Veress, M. *et al.* (2006).

According to Maire, R. *et al.* (1999) the amount of the rainfall can reach 8000 mm/year. The duration of rainfall can be several hours a day. The wind has played an important role in the development of the karren features of the island. According to Zamora, E. and Santana, A. (1979) the average velocity of the wind can be 60–80 km/h, but sometimes it reaches 150–200 km/h. The influence of the wind on the formation of karren was investigated with a special reference to the dissolution on Diego de Almagro Island.

The Island of Madagascar is built mainly by gneiss. Jurassic and Eocene limestone occur in small expansions. The characteristic karst type of the island is the tsingy (the Ankarana tsingy, the Bemaraha tsingy, the Namoroka tsingy and the Bemarivo tsingy). Collapse dolinas occur in many karst areas of the island and different kinds of them were distinguished (Rossi, G. 1986). Solution dolinas however occur on the higher karst plateaus exclusively, e.g. on Kelify Plateau (Rossi, G. 1986) and in the higher part of the Bemaraha tsingy (Balázs, D. 1980). The amount of the rainfall decreases from north to south. It is 2200 mm/year on the Ankarana tsingy, and drops down to 1100–1500 mm/year on the Bemaraha tsingy. Also there is a southward decrease in the duration of rainfall events. The maximum altitude of the surface of the Ankarana tsingy is higher than that of the Bemaraha tsingy (it is 295 m on the Ankarana Little tsingy, 318 m on the Ankarana Great tsingy, 75 m on the Bemaraha Little tsingy and 190 m on the Bemaraha Great tsingy). The karst water table may occur on the bottom of the grikes of the Bemaraha Little tsingy. Its depth compared to the surface is about 25 metres on the Bemaraha Little tsingy, while it is about 140 metres on the Bemaraha Great tsingy (Veress, M. *et al.* 2008a, 2008b). Since the tsingies can be found close to the sea, the sea-level fluctuations caused a rapid change in the karst water table level, with high intensity and in the immediate vicinity of the tsingies. The reason for it was that the rivers which are the local erosional bases of the tsingies did not exist at the time of the rise of the sea level. Thus the River Manambolo which is the erosional base of the tsingies with an altitude of 50 m, occurred under the sea level when the rise of the sea level exceeded 50 metres. The effect of the karst water table on karstification of the surface was analysed on Madagascar.

The tsingy karst is built by assemblages of large-sized grikes (*Photo 3*, Veress, M. *et al.* 2008a, 2008b). The depth of the grikes is between 0.5–7 metres on the Ankarana tsingy, while they can reach a depth between 10–120 metres on the Bemaraha tsingy. Clints of various dimension and pinnacle with diverse shape and size are among grikes (Rossi, G. 1986; Veress, M. *et al.* 2008a, 2008b). Rillenkarren, kamenitzas, pits, rinnenkarren occur in great density on the clints and pinnacles of the tsingies (Veress, M. *et al.* 2008a, 2008b).

*Photo 3.* Grike systems from the Bemaraha tsingy (Delaty, J.N. *et al.* 2006)

The Bakony Mountains in Hungary are a type of faulted mountains built of Mesozoic and Eocene calcareous rocks. The surface of the 300–500 m high blocks is covered with loess and partly with various types of loess loam. These are the covered karst surfaces of the mountains. The calcareous floor is dissected under the covering sedimentary rocks, because karstification already happened previously on the surface of these rocks (Végh, S.-né 1976). The covered karst forms are limited in size and they have a low density in the Bakony Mountains (Veress, M. 2008, 2009).

The Mecsek Mountains are faulted-folded structures. The northernmost margin of the West Mecsek built of Triassic limestone is affected by karstification. Limestone is superimposed by loess and sandy-clayey cover sediment.

Two generations of dolines were distinguished by Szabó, P.Z. (1968) on this covered karst surface. The older generation of dolines are the larger landforms of those developed on the limestone floor, therefore they are solution dolines, being lined or filled with sediments completely. The latter (buried dolines) do not have depressions on their surface. The younger and smaller dolines have developed in the sedimentary rock cover. These dolines are covered karst features. There is a high density of the dolines (solution dolines and covered karst dolines alike) in the Mecsek Mountains. Their values can even reach 137 pieces/km$^2$ and 164 pieces/km$^2$, respectively (Hevesi, A. 2001; Lippmann, L. *et al.* 2008).

The thickness and quality of the covering sedimentary rock were investigated to establish the relationship between the overlying sedimentary rock and covered karstification.

## Methods

– The width and the depth of karren forms along profiles were measured on bare slopes of the Island of Diego de Almagro. Similar measurements were carried out both on bare slopes and slopes with *Pinus mugo* in Totes Gebirge where they are located closely to each other. Several profiles were erected here in three-metre distance from each other in areas with minor dip angle and bare slopes. The depth and width of the channels were also measured along these profiles.

– The specific width *(c)* and the density *(ρ)* of the karren forms on the Island of Diego de Almagro were computed. The values of *(c)* and *(ρ)* of the forms as well as the specific cross-section areas of the channels (*A)* and shape-parameters of the channels *(f)* were also calculated for the study area in Totes Gebirge (Veress, M. *et al.* 2008c, 2010). The above parameters can be calculated as follows:

$$c = \frac{\Sigma W_k}{l}$$

$$A = \frac{\Sigma A_0}{l}$$

$$f = \frac{\Sigma f_0}{l}$$

Where $W_k$ is the width of a channel along the profile (if the calculation of specific width is to be meant for the channel, its width is concerned),

$A_0$ the cross-section area of a channel along the profile,

$f_0$ the shape of a channel along the profile,

l the length of the profile,

$$A_0 = a \cdot b$$
$$f_0 = \frac{w}{d}$$

where w is the width of the channel,

*d* the depth of the channel.

The average cross-section area of the channel *(A)* and the average channel shape *(f)* were calculated as well. To calculate *(A)* and (l) the overall cross-section areas and the overall shapes of the channel were divided with the number of the channels.

– Function relationships were searched between D (the distance between the upper margin of the slope and the site of the profile), *A* and *f*.

– The karren features of the leeward slopes and windward slopes were compared on Diego de Almagro Island.

– Karren forms were mapped on Diego de Almagro Island.

– The thickness and the quality of different beds and that of the covering sedimentary rock were measured with vertical electrical sounding (VES). Geoelectrical-geological cross sections were constructed. The morphology of the limestone floor, the thickness and the structure of the covering sedimentary rock and its beds may be determinant along these geoelectrical-geological cross sections (Veress, M. 2008).

## Results

### *The impact of plants, dip angle and the length of slope on karren formation*

Based on the measurements it can be stated that the specific cross section areas of channels are more extensive on slopes with *Pinus mugo* than on bare slopes (9.12 $dm^2/m$ vs 3.65 $dm^2/m$, respectively). According to the measurements by Mariko, S. *et al.* (1994) the cause of it is that the snow which covers vegetation in high mountains has a high $CO_2$ content. *Pinus mugo* cannot photosynthesize under the snow but it is able to dissimilate. Therefore the dissolution capacity of the meltwater originating from the *Pinus mugo* patch is higher.

Channels develop under rivulets (Trudgill, S.T. 1985; Ford, D.C and Williams, P.W. 1989). According to Veress, M. *et al.* (2008c) the channels may develop in two ways: due to percolation or due to rivulets. After filling of the channel the meltwater seeps between the snow and the limestone during the development generated by percolation. The current of this water is laminar and it dissolves the side and the bottom of the channel. Rivulet generated development can change into percolation generated development at the same channel, and vice versa. The specific cross section area of the channel and the specific shape of the channel also depend on the dip angle of the slope with *Pinus mugo* (Veress, M. *et al.* 2008c; Veress, M. 2010). The velocity of the flow is higher on a steeper slope. The greater velocity induces turbulent flow which in turn increases the rate of dissolution. Therefore dissolution is also more intense on slopes of greater dip angles covered with *Pinus mugo*. The flow velocity may change only if the water flows on the slope but it cannot change in case of seepage. During the percolating generated development the incision of the channel does not depend on the dip angle. Therefore development due to rivulet can dominate on slopes with *Pinus mugo*.

Type A and type B channels were distinguished on bare slopes with small dip angles *(Photo 1).* Type A channels have small sizes, V cross sections, small catchment areas, small specific cross section areas and great shapes. Due to the latter one, the specific cross section area of type A channels which can be found along a profile is small and their specific shape-parameter is great *(Table 1).* Type A channels do not have tributary channels. Type B channels have U cross sections, extensive catchment areas, great cross section areas, and small shapes. Due to the latter one, the specific cross section area of type B channels which can be found along a profile is great and their specific channel shape-parameter is small *(Table 1).* Type B channels have tributary channels of type A. Type A channels dominate bare slopes with great dip angles. There is a dense network of channels on such steep slopes.

There is a functional relationship among d and the specific cross section areas of type B channels and the specific shape-parameter of type B channels on bare slopes of small dip angles (Veress, M. 2010). The specific cross section areas of these type B channels can be greater while the specific shape-

*Table 1. Parameter values of type A and type B channel of some bare slopes from Totes Gebirge*

| | Type A channel | | | | | | Type B channel | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mark of the slope | n | P | T | t | f | l | n | ϱ | T | t | f | l |
| slope marked I/9/1 | 11.8 | 1.3 | 100.7 | 67.1 | 3.2 | 1.9 | 3.3 | 0.4 | 183.0 | 278.5 | 0.3 | 0.6 |
| slope marked I/9/2 | 24.6 | 1.6 | 153.7 | 107.2 | 3.1 | 1.9 | 5.7 | 0.3 | 305.4 | 699.2 | 0.4 | 0.8 |
| slope marked I/9/3 | 9.8 | 1.1 | 94.0 | 89.6 | 2.4 | 2.3 | 3.6 | 0.4 | 172.6 | 420.4 | 0.4 | 1.1 |

parameter of the channels can decrease in the function of d *(Figure 1).* It is only possible if an increasing amount of water flows across the lower and lower parts of the channels for even longer time. The cross section area of the channel will increase due to the growing amount of water. The channel will incise due to the growing existing rivulet as dissolution at the bottom of the channel will take more time. Hence type B channels increase due to rivulets. Such functional connection cannot be established in case of type A channels. Therefore type A channels develop due to percolation.

## The influence of the wind on solution and karren formation

The rate of dissolution of marble is 0.06 mm/year on Diego de Almagro Island (Hoblea, F. *et al.* 2001). The rate of dissolution of limestone is 0.015 mm/year in the Alps (Bögli, A. 1961). The speed of dissolution is as many times higher on the island as the rainfall is more abundant than in the Alps. At the same time the karren forms of the island sometimes can be tenfold or fifty times larger in size than the karren forms of the Alps. The cause of the development of the greater sizes is that the wind moves the surface water into a narrow stripe. Therefore dissolution is concentrated only in limited place. Dissolution does not take place in leeward for example behind boulders. Thus shallow dune karren inselbergs develop at these places *(Figure 2, Photo 2).* The following facts prove the effect of wind action:

– The residual forms (karren inselberg) have W–E trend.
– The windward sides are steep, the leeward sides are gentle.
– The remnant forms have a streamlined shape *(Photo 2).*

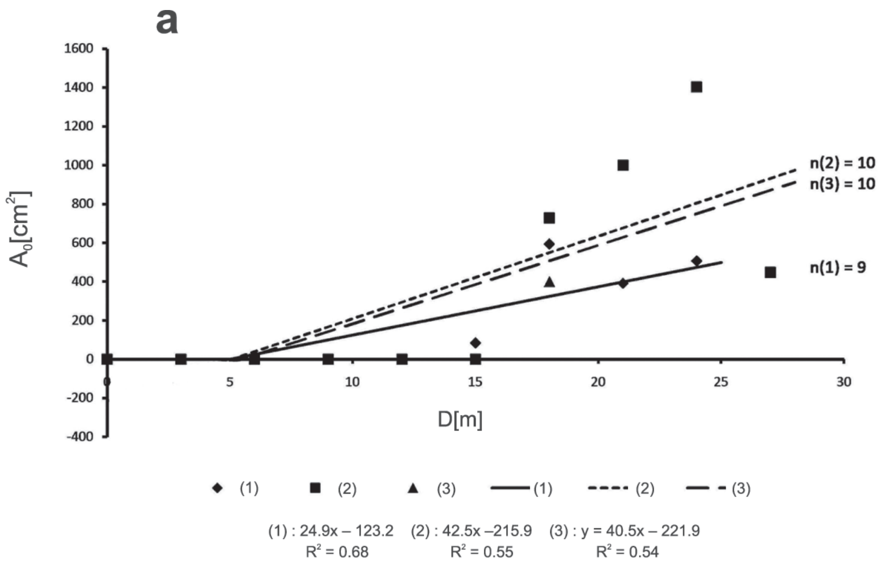
The wind controls the process of dissolution in the following manner:

– The wind moves the water from west to east.
– The wind separates the sheet water into rivulets as observed on numerous occasions.

Wind action could increase the rate of dissolution; also dissolution of higher intensity contributes to the development of larger karren forms. It might happen in the following way:

– More rainwater falls on the windward slope than on the leeward slope (per time unit). The wind makes the raindrops move therefore the dissolution is stronger on the windward slope than on the leeward one. According to calculations of Szunyogh, G. (2004, 2005) the rate of denudation is four times higher if the angle of the slope is 70° and the velocity of the wind is 10 m/s than in calm conditions with the direction of the wind being perpendicular to the slope.

– High wind velocity increases the speed of the flow, which causes turbulence. The intense collision of raindrops and snowflakes produces a similar effect.



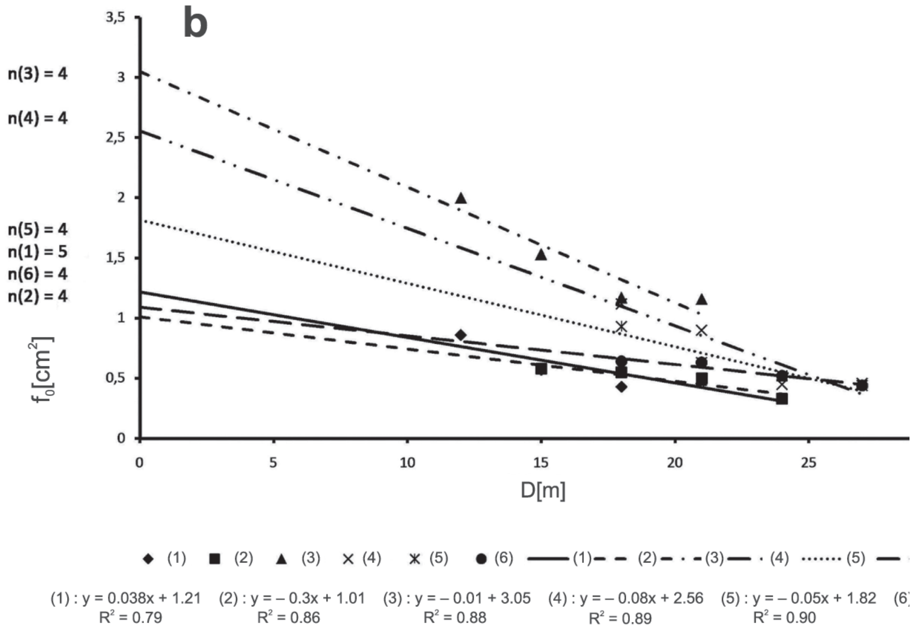




*Fig. 1.* Functional relationship between the various parameters of the type B channels on a bare slope of Totes Gebirge. – a = $f_0$-D functions of the channels; b = $f_0$-d functions of the channels, $F_0$ cross section area of the channel, $f_0$ the cross section shape of the channel, d. distance between the upper margin of the slope and profile site (similar signs are calculated $F_0$ and $f_0$ values of the same channel at various profile sites)

– The wind increases pressure, therefore atmospheric $CO_2$ penetrates into the water. According to Veress, M. *et al.* (2006), as a result the dimension of the dissolution is increased by 0.18 mg/l in case of laminar water current if the velocity of the wind is 100 km/h. The collision of the raindrops and snowflakes also increases pressure. According to our calculations the pressure will increase up to 130% in the water if the velocity of the wind is 50 km/h, therefore solubility will increase 1.3 times at laminar flow (Veress, M. *et al.* 2006).

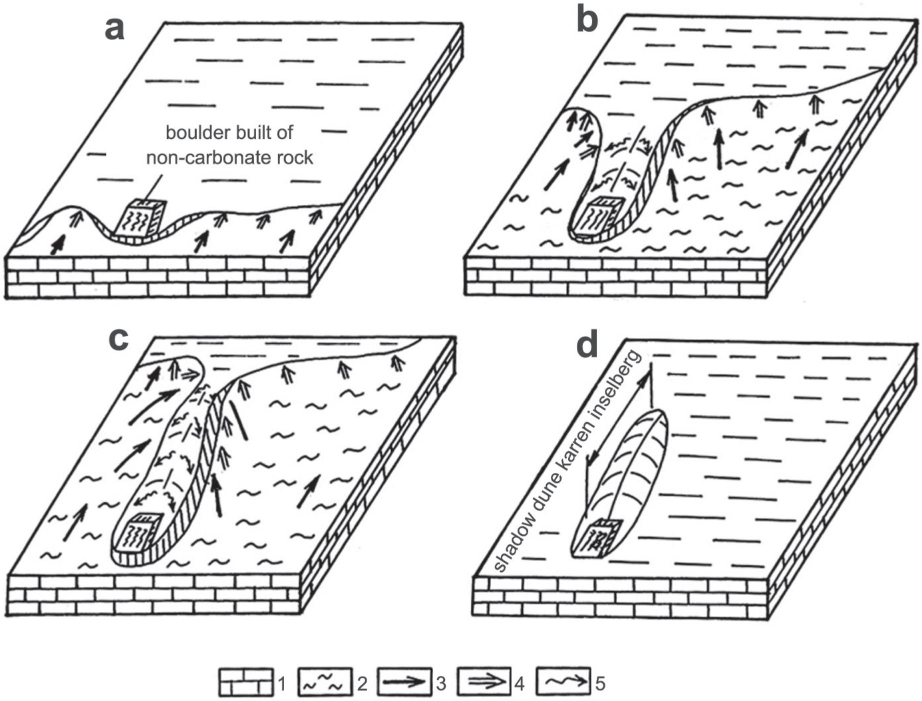



*Fig. 2.* The development of the 'shadow dune karren inselberg' (Veress, M. *et al.* 2006). – a = the water moving to the east dissolutes the surface except the part of the surface which is behind the boulder; b–c = elevation develops at the wind shadow; d = where the wind shadow surface ends the surface dissolutes behind the boulder too, the elevation budds; 1 = marble; 2 = puddle; 3 = wind direction; 4 = dissolution; 5 = dissolution at sheet water

## The effect of karst water on the development of the tsingies

Rainfall percolating along cracks created the Ankarana tsingy by dissolution (Balázs, D. 1980; Rossi, G. 1986; Veress, M. *et al.* 2008b). The great grikes of the Bemaraha tsingy developed when small grikes and caves coalesced into each other. They might have developed due to the collapse of caves. The former caves were created under the karst water table in the phreatic or epiphreatic zone (*Figure 3*, Veress, M. *et al.* 2008a, 2008b).

The sea level had been 60–70 metres higher before the Ice Age compared to nowadays (Mitchum, R.M. *et al.* 1977). Therefore the karst water table was about 60–70 metres higher compared to that of nowadays on the tsingies. (Tectonic uplift was not taken into account because since the beginning of the Ice Age the rise has not been substantial.) Other factors also influence the level of karst water table such as the distance between any parts of the karst and temporary base level and the cavity index of the rock.

The farther is the site of the karst from the contemporary base level the higher is the karst water table. For example it is 200 m higher even at a distance of 25 km from the contemporary base level in the Bakony Mountains, as shown by karst water table maps (Lorberer Á. and Maucha, L. 1982). Its vertical oscillation may even reach 100 metres in dolomite with lower cavity values in the Bakony Mountains, according to the data gained from a karst table observing well in Hárskút, Hungary (Böcker, T. 1972).

The surfaces of the Madagascar tsingies were close to karst water table before Ice Age. (The karst water might create lake or lakes on the deeper parts of the Bemaraha Little tsingy.) Therefore dissolution might happen during arid seasons and low tides or in the glacial stages of the Ice Age on the surface. Therefore in these cases the karst water table sank deeper in the rock. Where the karst water table was higher than the surface of the tsingy (Bemaraha Little tsingy) dissolution took place in the glacial stages of Ice Age, when the karst water table was located lower than recently. Dissolution of short time duration has not stimulated the development of solutional dolina. This landform develops where all of the rock is dissolved over a certain area. This process needs a prolonged dissolution. The cavity level was nearer to the surface on the Bemaraha tsingy than on the Ankarana tsingy. On the one hand it is because the surface of the Ankarana tsingy is higher than that of the Bemaraha tsingy. On the other hand the Manambolo River kept the karst water table 50 m higher above the sea-level during Ice Age on the Bemaraha tsingy. Formation and development of the two tsingies were different from each other as the grikes and the caves could not coalesce to each other on the Ankarana tsingy because of the deeper level of the caves. The coalescing process could happen on the Bemaraha tsingy because the caves were nearer to the surface.

## The influence of the sedimentary rock on covered karstification

Data are available on the thickness and the quality of the covering sedimentary rock, the morphology of the limestone floor of 37 pieces of covered karst forms in the Bakony Mountains, and of 21 pieces of covered karst forms in

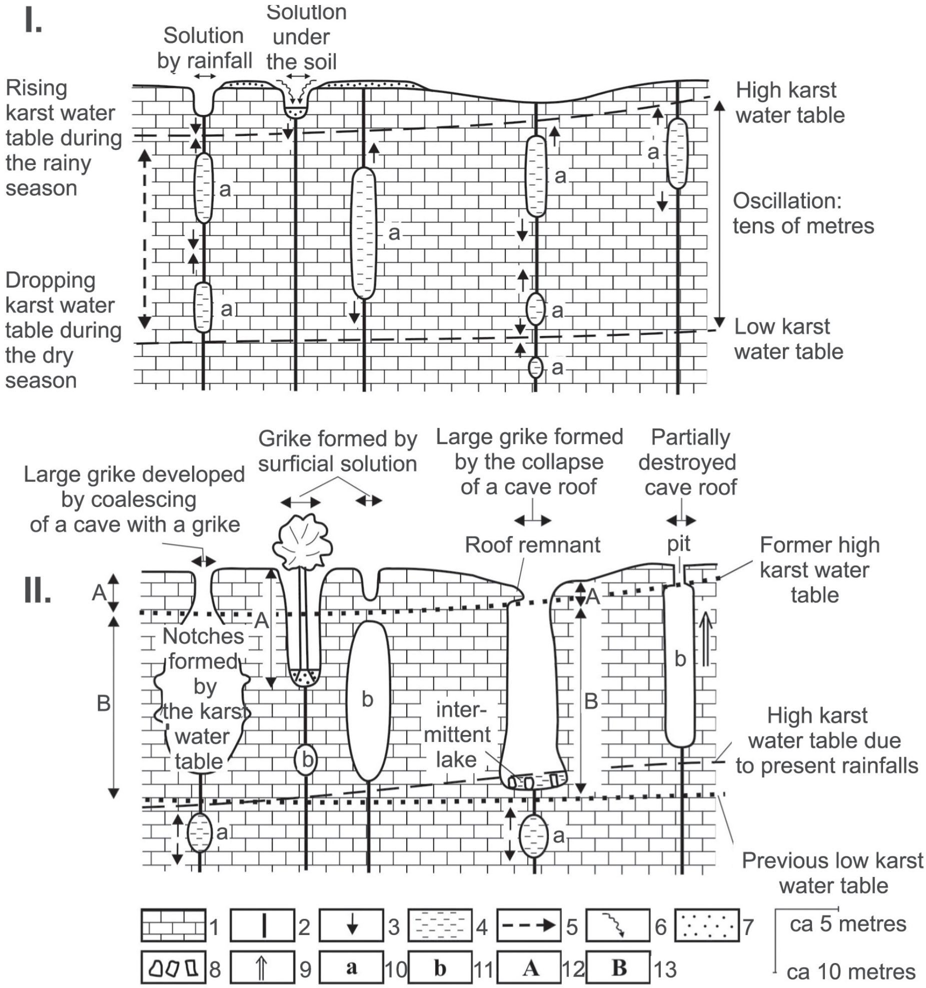



*Fig. 3.* The development of the Bemaraha tsingy. – 1 = limestone; 2 = crack; 3 = direction of dissolution; 4 = karst water; 5 = oscillation of karst water table; 6 = infiltration into the karst; 7 = soil; 8 = collapse; 9 = uplift; 10 = cave filled with karst water; 11 = the cave above karst water table; 12 = grike part which developed above the karst water table; 13 = part of grike developed under the karst water table; I = initial phase; II = present phase

the Mecsek Mountains. (Veress, M. 2004, 2007, 2008, 2009). According to VES measurements 78 per cent of the covered karst forms occur above mounds of the limestone floor in the Bakony Mountains *(Figure 4).* The morphology of the limestone floor is indicative of the development of the covered karst forms because the covering sedimentary rock is thinner above the mounds of the limestone floor, than above its depressions. The thickness of the inner sediment rock of karst forms above the mounds does not reach 6 metres (the thickness is measured below the bottom of the depression). Only 7 covered karst forms have external sedimentary rock cover with a thickness greater than 6 metres (its size may be measured at the margin of the depression). But the thickness of the covering sedimentary rock above the depressions of the limestone floor always exceeds 6 metres and it often reaches 10, or 20 metres depth. Water percolating into the thinner sedimentary rock can reach the limestone floor easier above the mounds. It could also be established that 26 forms occur at the

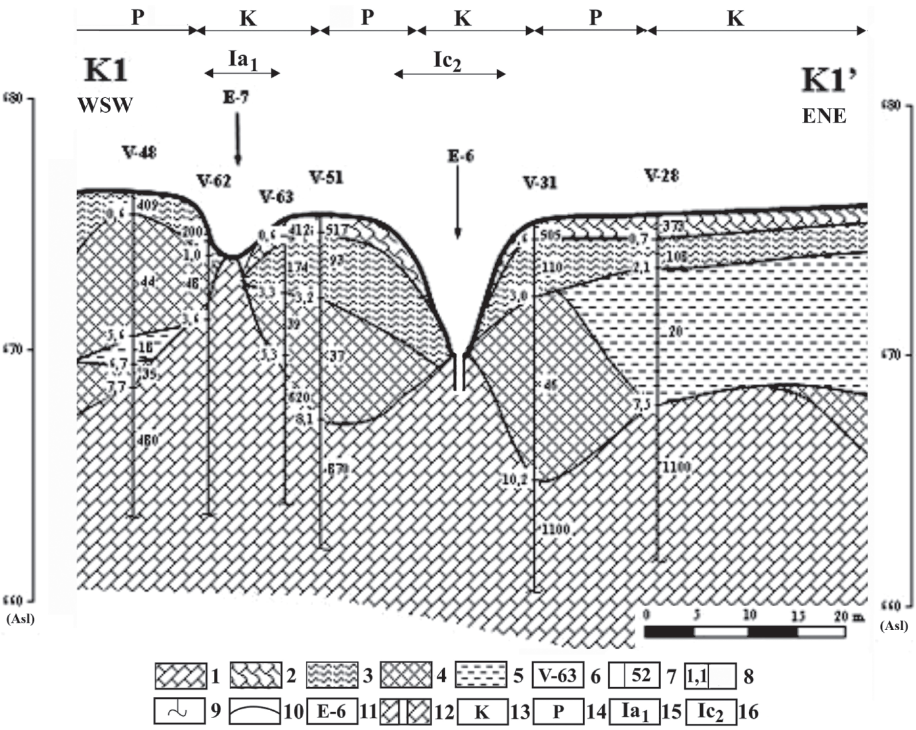



*Fig. 4.* Covered karst dolinas developed above the mounds of the limestone floor (Bakony Mountains, Kőris Mount, Veress, M. 2008). – 1 = limestone; 2 = limestone detritus; 3 = limestone detritus (with clay); 4 = clay (with loess and limestone detritus); 5 = clay; 6 = number and place of VES measuring; 7 = geoelectrical resistance of the beds (Ohm); 8 = depth of the bottom of the geoelectrical beds (m); 9 = penetration of the VES measuring; 10 = border of the geoelectrical beds; 11 = mark of the covered karst form; 12 = pit; 13 = elevation on the limestone floor; 14 = paleokarst depression of the limestone floor; 15 = syngenetical (the karst form and the pit are of the similar age) covered karst form above the elevation of the limestone floor; 16 = postgenetical (the karst form is younger than the pit) covered karst form above the elevation of the limestone floor. Note: the karst forms (marked E-6 and E-7) developed with the sinking of the surface, further with the sinking of the uppermost beds (due to the loss of the matter of the covering sedimentary rock

bottom of the valleys of the covering sedimentary rock. Hence the denudation of the surface adds to that of the covered karst forms. It means that denudation causes the further thinnering of the sedimentary rock cover. Naturally the development of the covered karst depressions rather promotes the increase of the water at the bottom of the valleys than somewhere else.

VES measurements testify about the covered karst forms of the Mecsek Mountains having developed in the areas of the lined or filled solution dolinas. They formed where clay beds or sequences containing clay wedge out

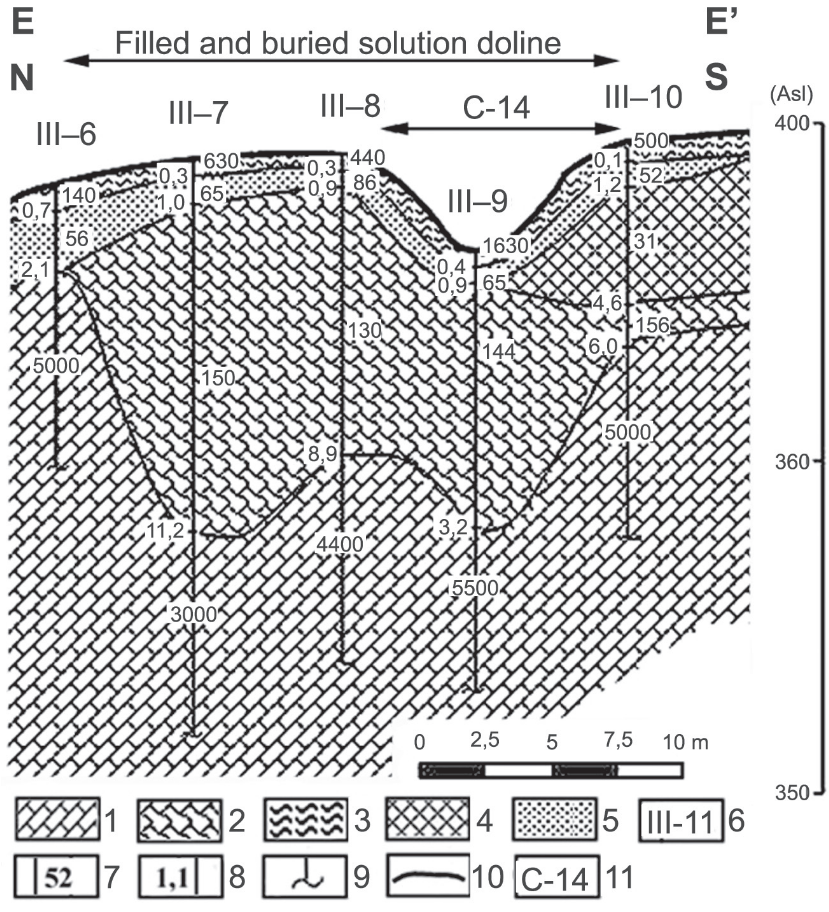



*Fig. 5.* Covered karst doline which developed at wedges out of permeable, filled and buried solution doline (Mecsek Mountains, from the area of Czigány land near Orfü). – 1 = limestone; 2 = limestone detritus (sand?); 3 = soil; sand; silt; 4 = clay (with limestone detritus and sand); 5 = sand, loess (with limestone detritus); 6 = number and place of VES measuring; 7 = geoelectrical resistance of the beds (Ohm); 8 = depth of the bottom of the geoelectrical beds (m); 9 = penetration of the VES measuring; 10 = border of the geoelectrical beds; 11 = mark of the covered karst form

*(Figure 5).* Out of the 21 covered karst formations there are 16 with such attributes. (The cause of this phenomenon is as follows: the water percolates into the karst where clay beds wedge out. The water creates a pit on the limestone floor.) The matter of the covering sedimentary rock can be transported into the pit. A blind burrow develops in the sedimentary rock. A covered karst forms due to the sinking or breakdown of the covering sedimentary rock above the blind burrow (Veress, M. 2008, 2009, *Figure 6*).

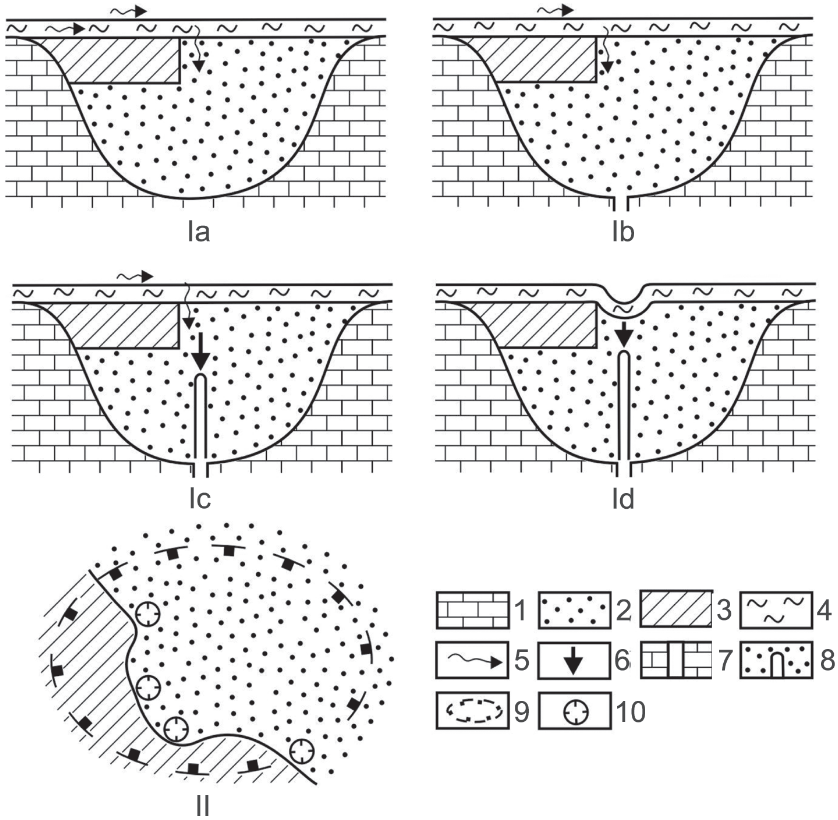



*Fig. 6.* Covered karst form which developed at the margin of the permeable beds wedged out which is above a filled solution doline. – 1 = limestone; 2 = sand-loess (with limestone detritus; 3 = clay (with limestone detritus and sand); 4 = soil, sand, silt; 5 = water flow on the surface, and water infiltration into the covering sedimentary rock; 6 = suffusion; 7 = pit; 8 = blind burrow; 9 = buried solution doline; 10 = covered karst form; I = cross-section; II = view from above; Ia = the flowing water of the surface and that of the permeable beds of the covering sedimentary rock seeping into the limestone at places where the permeable beds wedge out; Ib = pit develops; Ic = a blind burrow develops; Id = a covered karst form develops above the blind burrow by sinking of the covering sedimentary rock (suffusion doline)

## Conclusions

Karren formation is more intense on slopes with *Pinus mugo* than on bare slopes. The channels of the slopes with *Pinus mugo* develop due to rivulets. Channels with small catchment areas on bare slopes are exceptions.

The channels may be formed due to rivulets and by percolation of the water on bare slopes. Channels can develop due to percolating with greater chance if the dip angle is smaller and the slope is shorter.

The wind has an effect on dissolution. Large-size and elongated forms develop on Diego de Almagro Island if the velocity of the wind is high enough and its direction is constant. The rate of the dissolution increases too on the windward side if considerably strong winds blow.

The development of the tsingies of Madagascar is only partially due to the specific climate. In its development the karst water table has played a more important role. Tsingies might develop because karst water was close to their surfaces. There is not a direct connection between the quantity of the rainfall and the development of the tsingy. (E.g. precipitation is less on the Bemaraha tsingy of a larger size.) Therefore the tsingy represents the initial phase of karstification and it has remained in the phase where the karst water table was the most influential factor in its development. The development of the tsingy began already before Ice Age. The distance which is between the karst water table and the surface of the tsingy controlled the size and morphology and the process of tsingy formation.

The covered karst form developed above the mounds of the limestone floor, or in the denudation stripes of the covering sedimentary rock. Primarily they are on those denudation stripes (valley bottoms), where mounds can be found on the limestone floor. It means that the covering sedimentary rock is the thinnest at these places and this is why water can percolate through the covering sedimentary easily.

The clay beds of older dolines make the development of the karst forms possible. Where the clay beds end the water can infiltrate from the surface. The amount of infiltrated water also increases at these places, because the water of the clay surface parts may infiltrate there. This process is helped by older lined dolinas. Namely surface flow of the rain which falls on their areas is not possible.

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