BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Journal of Geological Research
https://ojs.bilpublishing.com/index.php/jgr-a

ARTICLE

Analysing the Influencing Factors of a Postgenetic Subsidence Doline's Development Using Model Experiments

Szilárd Vetési-Foith*

Faculty of Sciences, University of Pécs, 7624, Hungary

ARTICLE INFO

Article history
Received: 16 June 2020
Accepted: 26 June 2020
Published Online: 30 June 2020

Keywords:
Model experiment
Subsidence doline
Influencing factors
Connection between the parameters
Estimating other parameters

ABSTRACT

The subsidence dolines are the most common surface forms of the concealed karsts. One type of these dolines is the suffosion doline. In this model experiment the influential role of these kind of dolines' development factors were analyzed. The aim of the study was to determine the significance of the parameters (cover thickness, secondary porosity of the bedrock, chimney diameter, grain size) that influence the development of a suffosion doline. To study the influencing factors numerous (162) experiments were made with different parameters, in a manner that during the experiments we changed only one parameter, so the effects of it would be detectable from the final solution. These measurements were made with the use of a special tool, designed and built for this purpose. According to the data we gained from the model experiments, the development of a suffosion doline is influenced by many parameters. If these parameters are in an optimal connection to each other, a suffosion doline may appear on the surface. Knowing these parameters of the covered karstic depressions lets us estimate other parameters that may influence the development of the subsidence dolines.

1. Introduction

The objective of our study was to laboratically determine the parameters (size and diameter of the chimney, cover's thickness, grain size and the secondary porosity of the cover) which affect the development of the suffosion dolines and how these factors influence the simulations made by us. Numerous experiments were made with different parameters, in a manner that during the measurements we changed only one parameter at a time, so their impact to the final solution would be detectable. According to the data we gained from the model experiment we estimated some other parameters that influence the development of covered karstic depressions.

As of the middle 60's the use of model experiments gained popularity in karstic researches as well. We can find data in numerous papers which describe studying karstfields and karstsystems with model experiments [1,2,3]. In these researches plaster were used by the researchers instead of limestone. The reason of this was that the dissolution and the morphogenesis happens faster on plaster than on limestone. Before the millenium these kinds of experiments were concentrated mostly on the microforms (karren) of the coverless surface. The development of the rillenkarren was examined by Glew and Ford [4], the development of the wall karren was researched by Dzulinsky et al. [5]. The morphogenesis of the karrforms was examined by Veress et al. [6] using physical analogue model expe-

**Corresponding Author:*
Szilárd Vetési-Foith,
Faculty of Sciences, University of Pécs, Pécs Ifjúság str. 6, 7624, Hungary;
Email: szilard.vetesi@gmail.com

  DOI: https://doi.org/10.30564/jgr.v2i1.1988

riments, built on plaster as well. The dissolution, flow, sedimentation and subsidence processes under laboratory conditions on bare and covered karsts were examined by Veress and Péntek [7] and Deák et al. [8,9,10].

The model experiment discussed below is an upgrade of a method featured in two previous studies. In a model experiment presented by Veress et al. [11] the researchers put a covering layer with different grain sizes on individual plaster blocks and they studied the phenomenon developed on the cover by changing the place where the water was added. They stated that the size of the feature which formed on the cover's surface was specified by the nature of the water's movement as well as the size of the material loss in the bedrock. Vetési-Foith [12] analysed if porosity change in the cover induces the development of covered karstic depressions.

A similar process was analyzed by Arevalo and Zuriguel [13] in case of grain silos. The size of the lowering caused by gravitation, the size of the outlet, and the grain size were compared, and they measuered that, how the connection between these parameters cause clogging of the outlet. They stated, in the clogging of the outlet, the size of the outlet and the grain size has the biggest influential role. Nevertheless the size of the lowering caused by gravitation does not play a significant role in the process.

Depressions develop in natural conditions if the superficial deposit loses its stability [14]. Subsidence dolines can form by suffosion (suffosion doline), collapse (dropout doline), dissolution (solution doline) and compaction (compaction doline) [15,16,17,18]. Although these processes often work together.

On covered karst (concealed karst) subsidence dolines are the most characteristic landforms [19,20,16]. The subsidence dolines form during the rearrangement and material loss of the superficial deposit where the bedrock has a high or increased secondary porosity. This causes, that a part of the superficial deposit transports locally to the bedrock. The matter reciever forms can be the depressions of the bedrock, the branches of the the epikarst and the phreatic zone, and the cavities or branches of the superficial deposit as well [16,18,21].

If the superficial deposit is non-cohesive the matter of the cover transports into these dissolving forms of the bedrock either by suffosion or by shedding gradually. If the superficial deposit is cohesive it collapses into them if it loses its stability. The stability of the superficial deposit depends on its thickness, its clay content, the size of the cavities in it, the groundwater flow rate, the pressure of the pore water [14], the water abstraction, but it is affected by construction, vehicle traffic [16], point-increased load [22] as well. The material loss in the superficial deposit will cause a closed depression on it's surface.

A prerequisite for the processes above is that the bedrock must have material-absorbing capacity, i.e. secondary porosity. This is possible if, during its karstification, caves, shafts, chimneys, branches, karren, or other cavities form [15,23,24,25,20,16,18].

Subsidence dolines can be syngenetic and postgenetic [18]. The developed form on the superficial deposit and the form of the bedrock which receives the cover's material are coevals in case of syngenetic dolines, the receiver form of the bedrock is older by postgenetic dolines. The development of postgenetic depressions were modeled in our experiments.

The relationship between the thickness of the superficial deposit and the size of the subsidence dolines formed on it has been studied by several researchers. According to Waltham et al. [16] when the superficial deposit is thicker the dolines form on it are smaller. Hyatt et al. [26] suggest that doline size does not depend on the thickness of the superficial deposit or its water permeability, but rather on the type and age of it. In the following study, we did not simulate the formation of depressions, but examined the relationship between the thickness of the superficial deposit and the absorption capacity of the bedrock. The formation of subsidence dolinas is influenced by several processes, but the depressions of the present model experiment were developed exclusively by grain shedding and the role of the studied parameters was studied on this basis. Although the dolines measured in this study are characteristic landforms of clayey superficial deposit, its use was omitted because the cohesiveness of the clay would have prevented the process of grain shedding.

During the experiments (covered karstic environment in a laboratory and simulated processes) we are looking for answers to the following questions:

(1) Is the volume of the material loss in the superficial deposit (henceforward cover) equal to the volume of the depression on the cover's surface?

(2) If not, what causes the difference?

(3) How are the parameters of the depression on the cover's surface influenced by the cover's thickness, the diameter of the chimney, volume of the void space below the chimney and the grain size of the cover?

(4) How can we define the so-called active zone (see below) participating in the depression's formation, and what kind of parameters influence it's size?

(5) How can we describe the process of the depression's formation?

(6) Is there any relation between the grain size of the cover and the shape (diameter/depth) of the depression?

(7) Is the involved but not known parameter playing a

role in the development of natural dolines estimable if the parameters of the depression developed during the model experiment are known?

2. Methods

The Grain-shedder Tool

The experimental tool is a rectangular prism restricted by metal plates (henceforward the grain-shedder tool) into which cover material was piled up. At the bottom side of this tool can the blocks representing the bedrock - made of an easily fabricable material (plaster) - be found. Into these blocks boreholes were made with different diameters (henceforward chimney). Onto these blocks air dried and fractionated cover was put with varied parameters (thickness and grain size) in a manner that the two solid parts (the drilled plaster block and the cover) could be separated from each other. To achieve this a metal plate was slipped into the experimental tool from the side. When the metal plate was suddenly removed it allowed the cover to reach the chimney, thus creating a grain-flowing process which, although not a suffosion, is similar to it (Figure 1). It is not suffosion because it was not the water moving the grain, but a similar effect because the grain flows through the chimney to the space below the plaster block. Therefore this system is called the grain-shedder tool. The tool was built in a manner that it should be approximately a hundred times smaller than the natural dimensions.

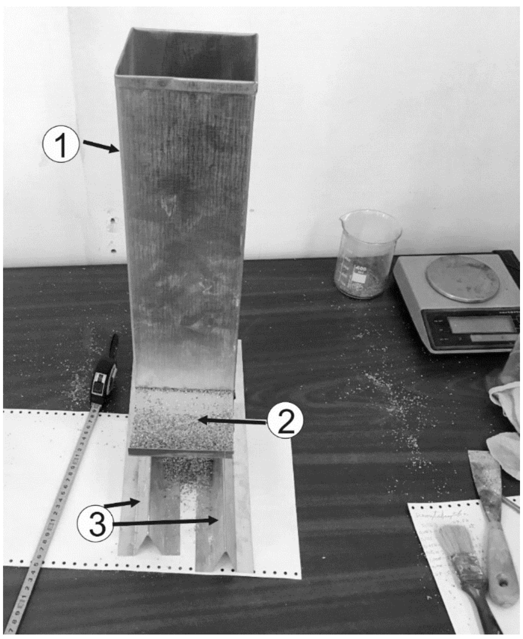

Figure 1. The experimental tool and it's parts, 1. the metal prism, 2. the metal plate what separates the drilled plaster block and the cover, 3. metal rails which create the void space below the tool

The experiments were made with the use of the grain-shedder tool using the following parameters:

(1) Diameter of the chimney: 0.5 cm, 1 cm, 1.5 cm.

(2) Cover thickness: 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm.

(3) Grain size of the cover: 0.250-0.500 mm, 0.500-1.000 mm, 1.000-2.000 mm.

(4) Without lifting the grain-shedder tool (0 cm), and with (2.5 cm and 5 cm) lifting the tool.

The space below the grain-shedder tool was necessary because there are many chimneys in natural karstic rocks below which there are horizontal cave systems (Figure 2).

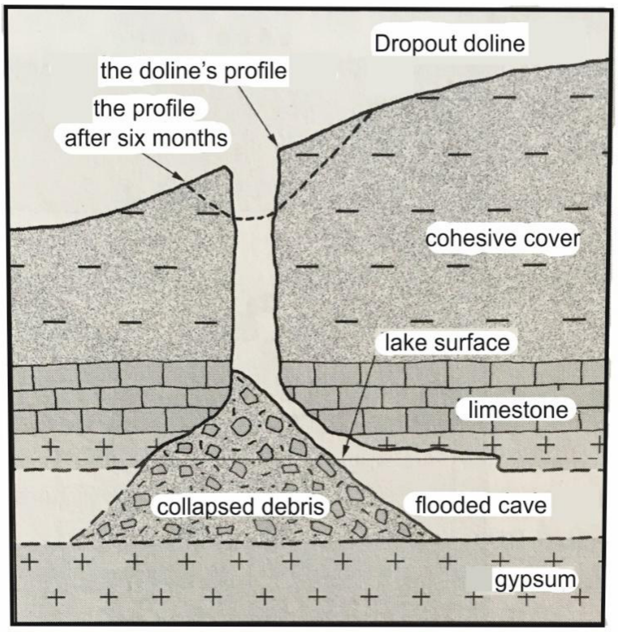

Figure 2. Horizontal cave system under a dropout doline [16]

The grain shedding phenomenon was studied in 162 experiments by combining these four parameters' different values. In each case we measured the lowering of the cover's surface, the diameter and the depth of the depression, as well as the volume of the material passed through the chimney. From these data further parameters were calculated. These are the followings:

(1) Volume of the depression (cm^3)

$$V_d=1/3*\pi*r^2*M_d \tag{1}$$

where V_d the volume of the depression (cm^3), r the radius of the depression (cm), M_d depth of the depression (cm). The established depressions were regarded as circular cones, thus for the calculating of the depression's volume we used the upper formula (Figure 3).

DOI: https://doi.org/10.30564/jgr.v2i1.1988

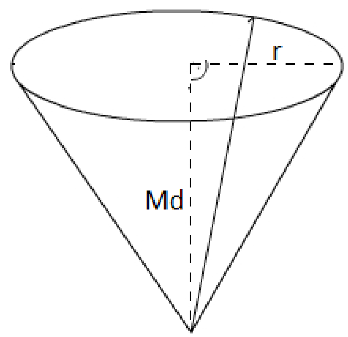

Figure 3. Theoretical figure of the created depression, r. radius of the depression, Md. depth of the depression

(2) The shape of the depression (O):

$$O=2r/M_d \quad (2)$$

where r is the radius of the depression (cm), M_d means the depth of the depression (cm) (Figure 3).

(3) Volume of the active zone that participates in the formation of the depression ($V_{active\ zone}$):

$$V_{active\ zone}=1/3*\pi*r^2*h \quad (3)$$

where r is the radius of the depression (cm), h is the cover's thickness at the end of the experiment (cm) (Figure 4).

During the experiments we stated that during the development of the depression an active- and a passive zone came into being. The active zone is the part of the cover from which the cover's material departs directly into the chimney. The passive zone is the part of the cover from which the cover's material doesn't depart through the chimney directly, but it may depart to the active zone (Figure 4).

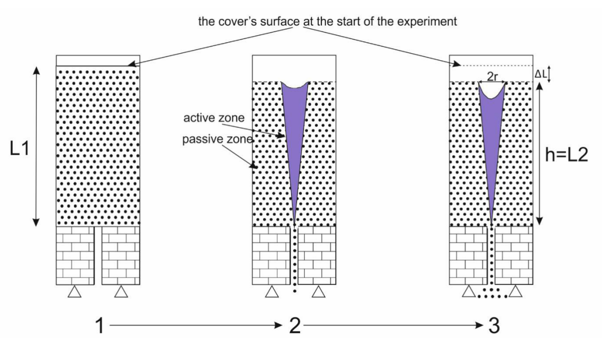

Figure 4. Flowchart of the depression's developing. 1. the start of the experiment, 2. the matter sheds through the chimney, 3. a depression formed on the cover at the end of the experiment, L1. thickness of the cover before the experiment, h=L2. thickness of the cover after the experiment, 2r. diameter of the depression, ΔL subsidence of the cover's surface

(4) The size of the active zone compared to the original volume of the cover ($V_{az}\%$):

$$V_{az}\%=V_{az}/V_1 100 \quad (4)$$

where V_{az} is the volume of the active zone (cm^3), V_1 is the original volume of the cover (cm^3), which we get as we calculated the volume of the cover in the grain-shedder tool.

(5) Estimating other, not known parameters of the covered karstic depressions:

For the estimatings quotients was made as the followings:

(1) The depth of the depression formed during the experiment was divided by the cover's thickness. If we know the quotient, the degree of the reduction and the depth of the natural depression, the cover's thickness involved in the formation is estimable.

(2) The diameter of the depression formed during the experiment was divided by the cover's thickness. If we know the quotient, the degree of the reduction and the diameter of the natural depression we are able to determine the cover's thickness involved in the formation.

3. Results

3.1 Relationship between the Material Loss Made in the Bedrock and the Volume of the Depression Formed on the Cover's Surface

During the grain sheddings two phenomenons were appearing on the cover's surface: the sagging of the whole surface and a depression occuring on a part of it. Based on the measured data we stated, that the volume of the depression formed on the cover's surface and the volume of the matter shedded through the chimney are not equal (table 1, 2 and 3). The volume of the matter shedded through the chimney was always greater than the volume of the depression. With the reduction of the cover's thickness the volume of the depression is getting closer to the volume of the fallen matter, but it never reaches its size. By 20 cm cover thickness and by 0.5 cm chimney diameter, with the use of the smallest grain size the volume of the fallen matter is 42 cm^3, the volume of the depression is 0.1 cm^3. With changing the cover's thickness the data changes as the followings: when the cover is 15 cm thick the volume of the flowed matter is 42 cm^3, the volume of the depression is 3.5 cm^3. When the cover is 10 cm thick the volume of the flowed matter is 43 cm^3 the volume of the depression is 13.1 cm^3. When the cover is 5 cm thick the volume of the shedded matter is 44 cm^3, the volume of the depression is 36.8 cm^3 (table 1).

 DOI: https://doi.org/10.30564/jgr.v2i1.1988

Table 1. A part of the data set, made by the data of the experiments 1

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Accomplished?	Volume of the depression cm^3
2.5	0.5	0.250-0.500	5	0.4	44	7.5	2.5	yes	36.8
			10	0.8	43	5	2	yes	13.1
			15	1	42	3	1.5	yes	3.5
			20	1	42	1	0.5	yes	0.1
			25	1.2	43	N/A	N/A	yes	0
			30	1.3	44	N/A	N/A	yes	0
		0.500-1.000	5	0.4	14	1	0.5	yes	0.1
			10	0.3	10	N/A	N/A	no	0
			15	0.4	11	N/A	N/A	no	0
			20	0.3	11	N/A	N/A	no	0
			25	0.2	10	N/A	N/A	no	0
			30	0.2	10	N/A	N/A	no	0
		1.000-2.000	5	0	0	N/A	N/A	no	0
			10	0	0	N/A	N/A	no	0
			15	0	0	N/A	N/A	no	0
			20	0	0	N/A	N/A	no	0
			25	0	0	N/A	N/A	no	0
			30	0	0	N/A	N/A	no	0

Note: Dk. diameter of the chimney, Dsz. soil fractions, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the volume of the fallen matter, Md. depth of the depression

Table 2: A part of the data set, made by the data of the experiments 2

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Accomplished?	Volume of the depression cm^3
2.5	1	0.250-0.500	5	0.4	61	9	2.8	yes	59.3
			10	0.5	63	8	2.2	yes	36.8
			15	0.5	63	7	2	yes	25.6
			20	0.9	55	2.5	1	yes	1.6
			25	1	55	1	0.5	yes	0.1
			30	1.2	62	N/A	N/A	yes	0
		0.500-1.000	5	0.8	54	5	2.5	yes	16.3
			10	1	56	2	1.5	yes	1.5
			15	1.3	54	N/A	N/A	yes	0
			20	1.2	55	N/A	N/A	yes	0
			25	1.2	55	N/A	N/A	yes	0
			30	1	55	N/A	N/A	yes	0
		1.000-2.000	5	0.5	8	1	0.5	no	0.1
			10	0.3	4	N/A	N/A	no	0
			15	0.1	2	N/A	N/A	no	0
			20	0.2	4	N/A	N/A	no	0
			25	0.1	2	N/A	N/A	no	0
			30	0.1	2	N/A	N/A	no	0

Note: Dk. diameter of the chimney, Dsz. soil fractions, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the amount of the fallen matter, Md. depth of the depression.

DOI: https://doi.org/10.30564/jgr.v2i1.1988

Table 3: A part of the data set, made by the data of the experiments 3

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Accomplished?	Volume of the depression cm^3
2.5	1.5	0.250-0.500	5	0.2	84	9.5	2.8	yes	66.1
			10	0.4	83	8	3	yes	50.2
			15	0.4	84	8	2.5	yes	41.8
			20	0.6	88	7	3	yes	38.4
			25	0.8	85	4.5	2.8	yes	14.8
			30	0.9	86	3	1.5	yes	3.5
		0.500-1.000	5	0.6	78	7	2.8	yes	35.9
			10	0.8	78	6	2.5	yes	23.5
			15	0.8	77	4	2.2	yes	9.2
			20	0.9	78	3.8	0.5	yes	1.8
			25	1.1	78	N/A	N/A	yes	0
			30	1	78	N/A	N/A	yes	0
		1.000-2.000	5	0.4	68	7	3	yes	38.4
			10	0.6	67	2.5	2	yes	3.2
			15	1.3	67	N/A	N/A	yes	0
			20	1.2	68	N/A	N/A	yes	0
			25	1	68	N/A	N/A	yes	0
			30	0.8	68	N/A	N/A	yes	0

Note: Dk. diameter of the chimney, Dsz. soil fractions, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the amount of the fallen matter, Md. depth of the depression

3.2 The Effects of the Various Parameters' Values to the Development of the Depression

When the chimney's diameter is 0.5 cm the shedding took place only when we used the smallest grain size to build the cover. At 1 cm chimney diameter this process happens even with the use of the medium sized grains. When we built our model with the biggest chimney diameter (1.5 cm) we stated that the process of shedding takes place even with the use of the biggest grain size. Therefore the growth of the chimney's diameter allows material shedding even by a cover consisting of bigger grain, thus the formation of the depression as well. By some measurements we experienced that both the cover's thickness and the chimney's diameter impacts the shedding. Namely when we built our model with the use of 0.5 cm chimney diameter and with 5 cm thick cover, the process of shedding took place, however when the cover's thickness is 10 cm or bigger than that the grains are not able to get through the chimney. Accordingly by same sized chimney diameter and by thinner cover the process of shedding took place, on the other hand when the cover is thicker the shedding either doesn't start or the chimney is clogged during the shedding (table 1).

If the chimney's diameter is 1.5 cm, the cover's thickness is 5 cm then a depression of 66.1 cm^3 volume appears on the cover. With the same chimney diameter but thicker (10 cm) cover the volume of the formed depression is 50.2 cm^3. We stated that in contrast to the former (where the chimney's diameter was 1 cm), by 1.5 cm diameter a depression occured even on the model built with a 30 cm cover thickness (table 3).

The grain size has the following effects to the experiment: By a 1.5 cm chimney and 5 cm thick cover a 38.4 cm^3 depression occurs using the biggest (1.0-2.0 mm) grain. If the cover thickness is 10 cm with the other parameters unchanged, a 3.2 cm^3 depression develops. If the cover thickness is bigger than 10 cm, a depression will not appear in the same case. Using the smallest grain (0.250-0.500 mm) a depression of 3.5 cm^3 developed even on the thickest (30 cm) cover (table 3).

Without lifting the grain-shedder tool depressions occured only when we built the model with the thinnest cover. With lifting the grain-shedder tool space was created so the amount of material able to shed through was increased. Therefore a depression is able to occur not only at the thinnest, but even with the use of the thickest cover (table 3).

If all the parameters are examined together, then e.g. by 1.5 chimney diameter, with the use of the smallest (0.250-0.500 mm) grain size, a 30 cm thick cover, and the grain-shedder tool lifted to 2.5 cm, we experienced a depression with a volume of 3.5 cm^3. However if the chimney's diameter is only 1 cm and the other parameters are unchanged, there will be no depression on the cover's surface. Likewise there will be no depression on the cover's surface if the chimney's diameter is 1.5 cm, but we build the model with the use of the biggest grain size (1.0-2.0 mm) (table 2 and 3).

3.3 The Active Zone and Its Influencing Factors

We can speak about the active zone only in those cases when depression occurs on the cover's surface. In those cases when there is no depression the whole volume of the cover belongs to the passive zone. The volume of the active zone in itself does not give us an accurate view about its growth depending on the growth of the cover's thickness, thus the size of the active zone was compared to the given cover thickness and we have taken its percentage values as a basis.

According to the data the following parameters have influential role to the size of the active zone: the cover's thickness, the diameter of the chimney, the grain size of the cover, and the volume of the space under the chimney. Decreasing the cover's thickness and its grain size have a positive impact to the volume of the active zone, whereas decreasing the chimney's diameter and the volume of the space under the chimney have a negative impact to it.

By a 0.5 cm chimney diameter and the smallest grain size the volume of the active zone grows continously as the cover's thickness is decreasing. By a 1 and 1.5 cm chimney diameter using the same grain size the volume of the active zone grows continously until a certain point, then it starts to decrease. In spite of this decrease, the size of the specific active zone grows continously as the cover is thinning (table 5 and 6).

4. Discussion

4.1 Relation between the Material Loss made in the Bedrock and the Volume of the Depression Formed on the Cover's Surface

Since the volume of the material loss in the bedrock and the volume of the depression are not equal, thus we suppose that there are other processes during the forming of the depression, e.g. the compaction of the cover's material. This may be possible because during the shedding the grains get closer to each other.

The void volume of the cover is increasing at the be-

Table 4. A part of the data set, made by the data of the experiments

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Volume of the active zone (cm^3)	Volume of the depression (cm^3)	Percentage values (%)
2.5	0.5	0.250-0.500	5	0.4	44	7.5	2.5	67.7	36.8	11.1
			10	0.8	43	5	2	60.2	13.1	4.9
			15	1	42	3	1.5	32.9	3.5	1.7
			20	1	42	1	0.5	4.9	0.1	0.2
			25	1.2	43	N/A	N/A	0	0	0
			30	1.3	44	N/A	N/A	0	0	0
		0.500-1.000	5	0.4	14	1	0.5	1.2	0.1	0.1
			10	0.3	10	N/A	N/A	0	0	0
			15	0.4	11	N/A	N/A	0	0	0
			20	0.3	11	N/A	N/A	0	0	0
			25	0.2	10	N/A	N/A	0	0	0
			30	0.2	10	N/A	N/A	0	0	0
		1.000-2.000	5	0	0	N/A	N/A	0	0	0
			10	0	0	N/A	N/A	0	0	0
			15	0	0	N/A	N/A	0	0	0
			20	0	0	N/A	N/A	0	0	0
			25	0	0	N/A	N/A	0	0	0
			30	0	0	N/A	N/A	0	0	0

Note: Dk. the diameter of the chimney, Dsz. soil fractions,, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the amount of fallen matter, 2r the diameter of the depression, Md. depth of the depression, Vd. volume of the depression.

DOI: https://doi.org/10.30564/jgr.v2i1.1988

Table 5. A part of the data set, made by the data of the experiments

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Volume of the active zone (cm^3)	Volume of the depression (cm^3)	Percentage values (%)
2.5	1	0.250-0.500	5	0.4	61	9	2.8	97.5	59.3	15.9
			10	0.5	63	8	2.2	159.1	36.8	13.1
			15	0.5	63	7	2	186	25.6	10.1
			20	0.9	55	2,5	1	31.2	1.6	1.2
			25	1	55	1	0,5	6.2	0.1	0.2
			30	1.2	62	N/A	N/A	0	0	0
		0.500-1.000	5	0.8	54	5	2.5	27.4	16.3	4.4
			10	1	56	2	1.5	9.4	1.5	0.7
			15	1.3	54	N/A	N/A	0	0	0
			20	1.2	55	N/A	N/A	0	0	0
			25	1.2	55	N/A	N/A	0	0	0
			30	1	55	N/A	N/A	0	0	0
		1.000-2.000	5	0.5	8	1	0.5	1.1	0.1	0.1
			10	0.3	4	N/A	N/A	0	0	0
			15	0.1	2	N/A	N/A	0	0	0
			20	0.2	4	N/A	N/A	0	0	0
			25	0.1	2	N/A	N/A	0	0	0
			30	0.1	2	N/A	N/A	0	0	0

Note: Dk. the diameter of the chimney, Dsz. soil fractions,, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the amount of fallen matter, 2r the diameter of the depression, Md. depth of the depression, Vd. volume of the depression.

Table 6. A part of the data set, made by the data of the experiments

Lifting (cm)	Dk (cm)	Dsz (cm)	L1 (cm)	ΔL (cm)	ΔV (cm^3)	2r (cm)	Md (cm)	Volume of the active zone (cm^3)	Volume of the depression (cm^3)	Percentage values (%)
2.5	1.5	0.250-0.500	5	0.2	84	9.5	2.8	113.4	66.1	18.5
			10	0.4	83	8	3	160.8	50.2	13.1
			15	0.4	84	8	2.5	244.6	41.8	13.3
			20	0.6	88	7	3	248.8	38.4	10.1
			25	0.8	85	4.5	2.8	128.2	14.8	4.1
			30	0.9	86	3	1.5	68.5	3.5	1.8
		0.500-1.000	5	0.6	78	7	2.8	56.4	35.9	9.2
			10	0.8	78	6	2.5	86.7	23.5	7.1
			15	0.8	77	4	2.2	59.4	9.2	3.2
			20	0.9	78	3.8	0.5	72.2	1.8	2.9
			25	1.1	78	N/A	N/A	0	0	0
			30	1	78	N/A	N/A	0	0	0
		1.000-2.000	5	0.4	68	7	3	59	38.4	9.6
			10	0.6	67	2.5	2	15.3	3.2	1.2
			15	1.3	67	N/A	N/A	0	0	0
			20	1.2	68	N/A	N/A	0	0	0
			25	1	68	N/A	N/A	0	0	0
			30	0.8	68	N/A	N/A	0	0	0

Note: Dk. the diameter of the chimney, Dsz. soil fractions,, L1. thickness of the cover at the beginning of the experiment, ΔL. the amount of decrease of the cover's thickness, ΔV. the amount of fallen matter, 2r the diameter of the depression, Md. depth of the depression, Vd. volume of the depression.

ginning of the shedding because some matter gets from there to the active zone, followed by a compaction in the cover which is a process that can also cause the difference between the volume of the shedded matter and the volume of the depression (Figure 4). Because of this compaction the grains get closer to each other. This causes the areal sinking of the cover. The rate of the compaction is higher as the grain size is increasing, because in the cover made of bigger grains the grains are located farther from each other than in the cover consisting of small grains. The rate of the compaction is also getting higher with the thickening of the cover, because in the case of a thicker cover it's volume is bigger, thus the space between the grains is also bigger. This is adequately demonstrated: by decreasing the cover's thickness the rate of the areal sinking is decreasing as well. The areal sinking is decreasing because less material isn't able to compact that much.

4.2 The Effect of the Individual Parameters's Size to the Size of the Depression

The size of the depression and the possibility of its forming is affected by the chimney's diameter, the cover's thickness and its grain size, and the size of the space beneath the chimney. The volume of the space below the chimney has the greatest impact to the possibility of the depression's forming. The chimney's diameter is the other determinant of the forming. The bigger this parameter, the bigger the chance of the depression's forming. The grain size of the cover is the third determinant. For the smaller grains it is easier to shed through the chimney and they clog the chimney with a smaller chance, allowing the material to shed through. Considering the chance of the depression's forming the cover's thickness is a significant determinant as well.

The thicker the cover, the lower the chances of forming a depression. These parameters affect the forming of the depression by themselves and in an effect system in relation to each other as well. That's why none of the parameters can be examined in itself. Namely if there is no space underneath the chimney but the chimney's diameter is big, the grain size of the cover is small and all those parameters are coupled with a thin cover a depression can still occur. In this case if the chimney is fully filled with the cover's matter, it generates so big material loss in the cover that's enough for a small depression to develop. Although by increasing the space below the chimney a depression can still form even if the other parameters are less favorable to it's development (table 1, 2 and 3). Namely if the former is small, and the latter is big, then it doesn't matter how big the space below the chimney is the shedding will not start, because the big grains will clog the chimney preventing the matter to shed.

The size of the depression is definitely determined by the volume of the potential material loss. This depends mostly on the volume of the space below the chimney. The cover's thickness has the biggest influential role to the size of the depression. As the cover is even thinner the size of the forming depressions are increasing linearly. This can be attributed to that a material loss with the same volume at thin cover spreads to a cover with a smaller volume, so the material loss will be relatively bigger, because when the cover is thin less material can get from the passive zone to the active. For this bigger realive material loss the system responds with a bigger void volume growth, what causes relatively bigger compaction and so a higher rate of lowering.

4.3 The Active Zone and Its Influential Parameters

The volume of the active zone is lowering continously with the lowering of the cover's thickness (table 4, 5 and 6). Namely due to the matter-shedding, the void volume of the cover is increasing which is followed by a kind of compaction. The increase of the void volume will be bigger than the volume of the through-shedded matter. The thinner the cover this phenomenon shows up the more, so the increase of the void volume is followed by a bigger relative compaction.

4.4 The Process of the Depression's Forming

The forming of the depression is caused by a sinking on the area of the active zone. The process of the depression's forming is separatable to: widening, and deepening. A general sinking takes place at the beginning of the process, then the material loss will localize to an ever smaller part. First, deepening occurs at this part. The cause of this deepening (sinking) is the material transport and the compaction following the growth of the void volume. The sinking is inhibited by the material which gets from the passive zone to the active. By the deepening of the depression the angle of its slope are getting gradually higher. When the angle of the slopes exceed a certain value, the yet small sized depression starts to widen because the matter from it's edge moves towards the bottom of it. When this happens the deepening of the depression stops, moreover it's depth can even decrease. Every grain size has its own naturally slope angle. Thus the rate of the deepening and the widening is roughly equal in case of the cover is built with the use of the smallest grain. The almost perfect cone-shaped depressions develop in this case. When the cover is made of big grains, they move harder on each

DOI: https://doi.org/10.30564/jgr.v2i1.1988

other, thus such a depression can form which has a bigger depth compared to its width.

This process examined by us can be modified by some parameters, like the amount of water between the grains, the shape and nature of the grain etc. However these parameters were not subject to our research.

4.5 Estimating the Connection between the Size of the Subsidence Dolines and the Influencing Parameters' Sizes of Its Formation

A quotient is calculatable from the sizes (depth and diameter) of the model experiment's depression and the cover's thickness. The sizes of the model experiment's depression are a hundred times smaller than the sizes of the dolines in the nature. From the value of this quotient the cover's thickness by natural dolines is ascertainable (if their sizes are known), knowing that the size values of the natural dolines are exactly the same in meters as the values of the depression in the model experiment in centimeters. We calculated the value of this quotient with the chimney diameter of 1.5 cm so it corresponds with 1.5 m chimney diameter in the nature. The connections we analysed were the followings:

(1) the depth of the depression and the cover's thickness in its surroundings,

(2) the diameter of the depression and the cover's thickness in its surroundings.

The estimated data for the cover's thickness based on the depth of the depression are the followings:

The estimated data for the cover's thickness based on the diameter of the depression are the followings:

The values shown above (table 7 and 8) are only from the model experiment's results we presented above. Thus some influence factors which impact the size of the subsidence dolines and are present in the nature were disregarded. Such are the age of the covered karstic depressions, the area specific amount of precipitation, the character of the bedrock, the amount of CO_2 in the soil air etc. Even so these data could be good guidance in case we want to estimate the cover's thickness without using VES measurements.

5. Conclusion

According to the model experiment the influence factors of the depression's forming are the diameter and the length of the chimney, the cover's thickness, and the grain size of the cover. These parameters influence the depression's forming and the size of the occuring form, not only separately but collectively too. According to our model experiments, forming a depression has a lot of conditions. A depression can form only in that case, when all of these parameters reach a certain threshold value. Thus, from the aspect of the depression to form; small chimney diameter, big grain size, and thick cover can be unfavourable parameters. The depression of the model experiment develops on the area of the active zone by sinking. The sinking is caused by the material loss, and the compaction followed by the associated void volume growing. Knowing that our model has a 1:100 scale and the quotient of the parameters examined in the model experiment, considering the size of natural suffosion dolines', cover thickness and chimney diameter are estimable.

Table 7. Estimating the cover's thickness suggested to the depth of the depression

A depression's depth in the nature (m)	A depression's depth in the model experiment (cm)	The cover's thickness in the model experiment (cm)	The quotient of the cover's thickness and the depth of the depression by the data of the model experiment	Calculated cover thickness by the depressions in case of the declared values (m)
2.5-3	2.5-3	5	1.78	4.5-5.5
2-2.5	2-2.5	10	3.3	6.6-8.3
1.5-2	1.5-2	15	6	9-12
1-1.5	1-1.5	20	10	10-15
lesser than 1	lesser than 1	more than 20	20	more than 20

Table 8. Estimating the cover's thickness suggested to the diameter of the depression

A depression's diameter in the nature (m)	A depression's diameter in the model experiment (cm)	The cover's thickness in the model experiment (cm)	The quotient of the cover's thickness and the diameter of the depression by the data of the model experiment	Calculated cover thickness by the depressions in case of the declared values (m)
7-8	7-8	5	0.5	3.5-4
6-7	6-7	10	1.25	7.25-7.5
5-6	5-6	15	1.9	9.5-11.4
4-5	4-5	20	2.8	11.2-14
lesser than 4	lesser than 4	more than 20	5.5	more than 22

References

[1] Curl, R. L. Scallops and flutes. Transactions Cave Research Group Great Britain, 1966, 7: 121-160.

[2] Quinif, Y. Contribution a l'étude morpholoqique des coupoles. Annales de spéléologie, 1973, 28(4): 565-573.

[3] Fabre, G., Nicod, J. Lapiates, methods and role of corrosion, crypto-karst - Phenomen karst 3, Memoirs and documents of geography, 1982, 3: 115-131. (in French)

[4] Glew, J. R., Ford, D. C. Simulation study of the developement of rillenkarren. Earth Surf. Proc., 1980, 5: 25-36.

[5] Dzulinsky, S., Gil, E., Rudnicki, J. Experiments on kluftkarren and related lapis forms. Z. Geomorphology, 1988, 32 (1): 1-16.

[6] Veress, M., Pidl, K., Mantler, M. The modelling of the karstification of gypsum under laboratory circumstances. Scientific Publications of the Berzsenyi Teacher Training College in Szombathely 11. Natural Sciences, 1998, 6: 147-166. (in Hungarian)

[7] Veress, M., Péntek, K. Theoretical model of surface karstic processes. 30/5000, Journal of Geomorphology, 1996, 40(4): 461-476. (in Hungarian)

[8] Deák, Gy., Szemes, M., Veress, M. Water movements of the plaster cover on physical analogue models. Karst Development, 2015, 20: 215-229. (in Hungarian)
DOI: 10.17701/15.215-229

[9] Deák, Gy., Péntek, K., Füzesi, I., Vetési-Foith, Sz., Veress M. Modeling of the debris zone that developed during karstification. Karst Development, 2017, 22: 61-75. (in Hungarian)
DOI:10.17701/17.61-75

[10] Deák, Gy., Vetési-Foith, Sz., Péntek, K. Examination of the relationship between the depth of saturated water level and the karstic surface development by model experiments. Karst Development, 2018, 23: 31-43. (in Hungarian)
DOI: 10.17701/18.31-43

[11] Veress, M., Gárdonyi, I., Deák, Gy. The study of covered karstification on a gypsum plate with cover. Karst Development, 2014, 19: 159-171. (in Hungarian)

[12] Vetési-Foith, Sz. Examination of the subsidence dolines's with the use of model experiments. Karst Development, 2018, 23: 85-93. (in Hungarian)
DOI: 10.17701/18.85-93

[13] Arevalo, R., Zirugiel, I. Clogging of granular materials in silos: effect of gravity and outlet size. Soft Matter, 2015, 12: 123-130.
DOI: 10.1039/C5SM01599E

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

[15] Sweeting, M. M. Karst Landforms. Columbia University Press, New York, 1973.

[16] Waltham, T., Bell, F., Culshaw, M. Sinkholes and Subsidence. Springer, Berlin-Heidelberg, 2005.

[17] Currens, J. C., Paylor, R. L., Beck, E. G., Davidson, B. A method to determine cover-collapse frequency in the Western Pennyroyal karst of Kentucky. J Cave Karst Stud, 2012, 74(3): 292-299.

[18] Veress, M. Covered karsts. Springer, Berlin-Heidelberg, 2016.

[19] Waltham, A. C., Fookes, P. G. Engineering classification of karst ground conditions. Quarterly Journal Engineering Geology Hydrogeology, 2003, 36: 101-118.

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

[21] Upchurch, S., Scott, T. M., Alfieri, M. C., Fratesi, B., Dobecki, T.L. Epigene and Hypogene Karst. The Karst Systems of Florida Cham, Springer, 2019: 359-441.

[22] Chen, J., Beck, B. F. Qualitative modelling of the cover-collapse process. In: Beck, B. F. (Eds.): Engineering and Environmental Impacts of Sinkholes and Karst, Balkema: Rotterdam, 1989: 98-95.

[23] Benson, R. C., Kaufmann, R. D. Characterization of a highway sinkhole within the gypsum karst of Michigan. In: Beck, B. F., Herring, J. G., (Eds.): Geotechnical and environmental applications of karst geology and hydrology. Balkema, Lisse, 2001: 103-112.

[24] Crawford, N. C. Environmental problems associated with urban development upon karst, Bowling Green, Kentucky. In: Beck, B. F., Herring, J. G. (Eds.): Geotechnical and Environmental Applications of Karst Geology and Hydrology, Balkema: Lisse, 2001: 397-424.

[25] Klimchouk, A., Andrejchuk, V. Karst breakdown mechanisms from observations in the gypsum caves of the Western Ukraine: implications for subsidence hazard assessment. Int. Speleol., 2003, 31(1/4): 55-88.

[26] Hyatt, J. A., Wilson, R., Givens, J. S., Jacobs, P. M. Topographic, geologic and hydrogeologic controls on dimension and locations of sinkholes in thick covered karst, Lowndes Country, Georgia. In: Beck, B. F., Herring, J. G. (Eds.): Geotechnical and Environmental Applications of Karst Geology and Hydrology, Balkema, Lisse, 2001: 37-45.

  DOI: https://doi.org/10.30564/jgr.v2i1.1988