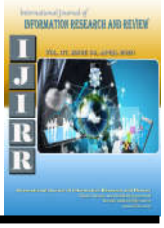

IJIRR
International Journal of Information Research and Review
Vol. 07, Issue, 03, pp.6865-6870, April, 2020

RESEARCH ARTICLE

OPPORTUNITIES OF ANALOGUE PHYSICAL MODELING IN KARSTRESEARCH

[*]Szilárd Vetési-Foith

University of Pécs, Faculty of Sciences, Hungary, 7624, Pécs Ifjúság str. 6. Hungary, 8400, Ajka, Kórház str. 5. 8/51

ARTICLE INFO

Article History:

Received 15th January, 2020
Received in revised form
29th February, 2020
Accepted 07th March, 2020
Published online 30th April, 2020

Keywords:

Model, Model Experiment, Laboratory Conditions, Karst, Karstic Processes, Analogy.

ABSTRACT

Using analogue physical models for research in natural science is generally widespread. In karst research, modeling was first used to study the dissolutional denudation of gypsumkarst in the 60's. Later, the study of physical analogue models in karst researches were expanded to the form development of dissolutional, flow, and depositional phenomena that can be observed on karsts. This study presents those theoretical and practical problems our workgroup(of which the author of this study was also a member) has solved by designing, building and operating physical analogue models, and by evaluating the results as well. Using model experiments in karstresearch, mainly in the field of morphological researches has become effective because the analogue correlation was applied between the natural object and the model built in the laboratory. With the appropriate use of the analogy, the form developed in nature can be replicated, thus the factors that influenced its formation can be studied.

INTRODUCTION

Model based approximation is an important element in scientific research and cognition. There are three kinds of model which we can encounter in karstic researches, these are the following:

- Karstic models are created to interpret karstic processes and phenomena in a way that using the known data and observations, explanatory theoriesare made.
- By creating theoretical models, we generalize an existing theory and operate the model by entering certain data.
- In case of an experimental model, we create a closed or as closed as possible system in the laboratory, and by operating it we can observe changes, andmeasure data. The analogue model is a variant of the experimental model.

The aim of our study is to present the generalization of our experiences by the laboratoryexperiments, emphasizing the interoperability between nature and laboratory, and the difficulties of it.Karstic processes were modeled with our experiments. We examined the dissolution, flow, sedimentation and subsidence processes under laboratory conditions on bare and covered karsts (1), (2), (3), (4), (5), (6), (7), (8).We tried to build up the self-made material physical models in the laboratory in such a way, that they would resemble the processes occurring in natural circumstances as much as possible. So we considered the relation between the plaster board and the karstic bedrock, the slope of the plaster board and the slope of the bedrock, the manner of water dosage and the water supply of the karstan analogue relation (fig. 1). The sedimentation basin is the copy of that doline, where the process of sedimentation took place (fig. 2). If the phenomena taking place in the laboratory can be linked together with the processes and the results of the processes taking place in nature, then we can call our material physical models analogue physical models.Analogue physical models can be used to study e.g. dissolution and flow processes, and other factors that cause the development of karstic forms. The effect of these parameters appear together on the field, and they explicate their effect together.Under laboratory conditions, parameters can be isolated and varied individually. By examining the effect of the parameters separately, the factor whose effect influences the examined phenomenon (dissolution, flow, development of a depression) can be determined. A detailed examination can reveal the mode and extent of the effect and its limitation. The karstic experiments in our laboratory were preceded by numerous others (9), (10), (11), (12), (13), (14). The corrosional erosion of plaster was examined by Reinboth (15), Völker (16), Dzulynski et al. (17), Slabe (18), (19), (20), (21), butthe research method of the phenomenon under laboratory conditions was also used by Glew and Ford (22). In the latter work, water, i.e. the solvent, was applied to the plaster surface using a rainfall simulator. However, simulating the rainfall from a height of 2.6 m, in addition to the dissolving effect, also had a considerable mechanical effect.The formation of scallops was studied by Rudnicki (23), Goodchild and Ford (24), and

---

***Corresponding author:* Szilárd Vetési-Foith,**
University of Pécs, Faculty of Sciences, Hungary, 7624, Pécs Ifjúság str. 6. Hungary, 8400, Ajka, Kórház str. 5. 8/51.

Allen (25) on a model made of plaster. Szunyogh (26) and Péntek (27) determined the lower ingrate of karstic surface using mathematical models. With the continuous development of technology, new possibilities have opened up for modeling karst processes using computer programs (28), (29), (30), (31), (32). In our paper we do not want to deal with the models of individual phenomena (dissolution, flow, sedimentation, depression's development). In the method chapter of the various publications (4), (5), (6), (1), (2), (3), (7), (8), the structure and operation of the model were presented in detail. Our karst research team has published numerous studies. In this paper,those works were emphasized what we considered the most important of them. The aim of our study is to summarize and present the experiences that our group earned in the field of karst research using physical analogue models.

A short presentation of our laboratory experiments: The experiments described below are based on the work of Veress et al. (1). The aim was to represent the natural processes (form development on covered karst) in the laboratory, so we tried to create the conditions accordingly. We examined the form development on plaster boards covered with different grain sized sediment (experiment No. 1). We created a 1 or 5 cm thick cover on the 45 cm x 30 cm x 3 cm plaster boards. The grain used to build the cover was fractioned to groups by size using a sieve machine. The slope of the plaster board was 5°, the quantity of distilled water which was dosed by dripping was 5 dm^3 daily and 100 dm^3 altogether. Dosing was paused on Saturdays and Sundays, and was continuous on the other days of the week. The distilled water was dosed on the cover or directly on the plaster board. We examined the forms developed on the covers and on the plaster boards as well. Their size and frequency was recorded (2), (33).

Experiences we get during measuring necessitated the study of the grain fractions of the cover (Experiment 2), i.e. knowing their physical parameters (6), (33). By determining the void volume's water lifting ability and water permeability we followed the guidance of Stefanovits (34). We studied the sedimentation taking place in flood lakes that developed in dolines (experiment No. 3) and the sedimentation forms using the special tool on figure 2 (5). Our goal in this case was modeling the natural processes under laboratory conditions as well. Therefore, we built our model in a way that we can control the rate of water level drop with the help of a tap connected to the sedimentation basin.We abated the suspension of known volume, composition and concentration by varied water level sinking speeds.Sometimes we inserted quiescent periods. In addition to the developed sediment forms, it has become known as well that not only the size but also the composition of the suspension's solid particles determine the settling rate of the suspended matter (6).Therefore we determined the settling rate in suspensions with different grain size and varying composition by gravimetric method under laboratory conditions (6), (3). Knowing the rate of water level sinking and the rate of sedimentation allowed us to study the relationship between these two parameters in the sedimentation basin. Thus, we were able to show how the rate of sinking regulates the sedimentation and thus the conditions under which sediments are forming from the lakes of karstic depressions and under what conditions are they filling up (6), (3). On one type of the carbonate karst's karren (rinnenkarren) we examined (4) the flows and the mixing of fluids flowing in the main- and secondary channels (experiment 4) using the tool on the figure 4.We tried to study the formation and characteristics of the turbulent flow occurring in the nature by changing the joining angle between the main and secondary channels and by changing the inclination of the surface. The different colored fluids were started in the main- and secondary channels in a way that they would meet at the confluence points. The turbulent flow was recorded visually. In the following the experiments of Deák et al. (35) (experiment 5), and Deák et al. (36) (experiment 6) are described. Deák and his co-workers (35) modeled the debris zone formed during karstification using physical analogue model experiments. Their aim was to put the data of an earlier theory into practice (37), (38) and thus to provide data for the development of karstic surfaces by laboratory measurements. Their model was built on the basis of the original theory (37): they separated three zones, zone I, which corresponds to the soil, zone II, which corresponds to the amount of limestone debris formed via dissolution and zone III, which corresponds to the karstic bedrock. Due to faster dissolution and easier workability plaster was used in the model experiment. Plaster cubes of different sizes were made and the karstic debris zone was built up from them in different thicknesses. Distilled water was used as a solvent. It was passed through the aforementioned debris zone and the saturation rate of it, the factors influencing the saturation and the depth of the saturation level were examined.

In the following the experiments of Vetési-Foith (7), (8) are described. Our goal was to establisha suffosion-like (grain shedding) process which creates suffosion dolines with the use of a special tool (experiment 7). We examined the parameters (cover thickness, chimney diameter, grain size, void space beneath the chimney) influencing the phenomenon under laboratory conditions. During the measurements we changed only one parameter, so its effects to the final solution would be detectable. From the data we gained in this way we were able to estimate those parameters of a natural subsidence doline which can only be calculated inaccurately or can be specified at a significant cost (e.g. determining the superficial deposit's thickness using VES measurements).

The oritical experiences: The point of the physical analogue model has already been presented in the introduction. The design and construction of the model to be made in the laboratory is inconceivable without field knowledge and experience. It is not possible to formulate the problem to be examined without observations and measurements made in the field.The parameters that need to be built into the physical model are from the data obtained from the field. The model does not always have to behave in an analogous way in its form, but in its function and operation. For example, the sedimentation basin we have built (6) is only slightly similar to a natural doline with a moderately slopy side (experiment 3), but the characteristics of the "lake" formed in it correspond to the characteristics of a periodic flooding lake formed in a doline (figure 2). The operation of the created lake reflects the change of the water level (decrease), the different speed of the decreases, and the breaks of the decreases of the flooding lakes indolines. The tool used in the work of Vetési-Foith (7), (8) is only theoretically similar to a natural covered karst area (Experiment No. 7), but with its help they were able to model a suffosion-like process and that was sufficient to achieve the goal of the study.

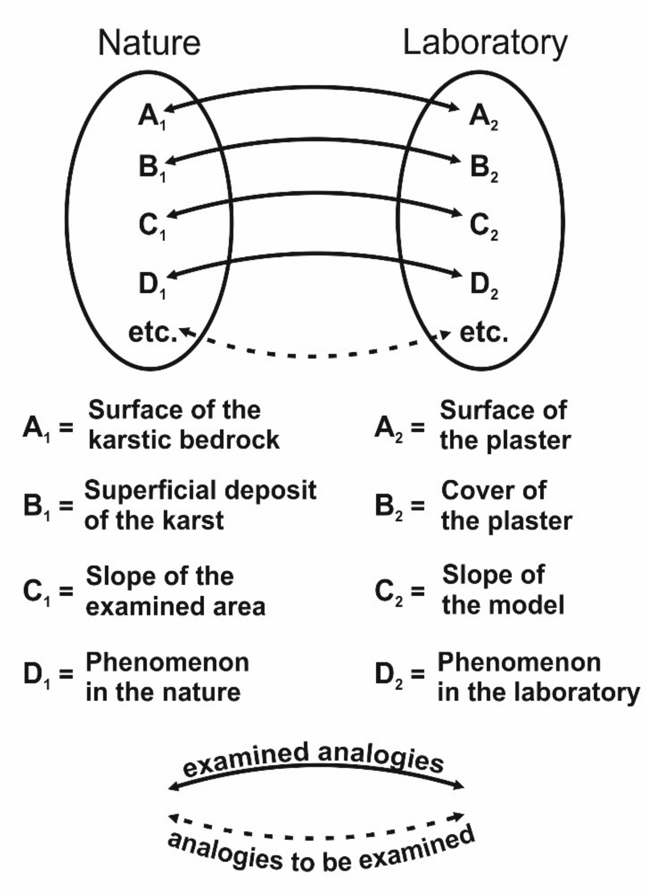

Figure 1. The interpretation of the analogue between the nature and the laboratory

Figure 2: The model of the sedimentation basin [5]

The shape of the form developed during the dissolution experiments (Experiment 1) (2), (33) is the same as the shape of the natural form, but the two forms differ in material quality. The plaster boards replicate the surface of the carbonate karst, however they differ in material, which only matches with the material of the bedrock of the gypsum karst. The solubility of gypsum is 183 times higher than limestone's (39), so it dissolves faster. This difference allows its application. Therefore, the form development is also faster and thus the process and its result can be studied. With accurate measurements performed by using physical analogue models, exact connections can be established.

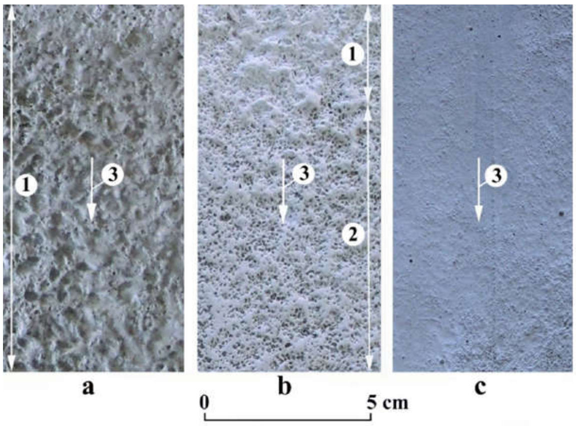

Figure 3. The solution forms developed on plaster boards under covers made up by different grain sizes[2] Legend: 1. finger pads, 2. chimneys, 3. angle direction of the surface, a. grain size: 2,5-5 mm, b. grain size: 0,25-0,5 mm, c. grain size: <0,063 mm

Figure 4. The hydrophilized rinnenkarren system built up to measure the flow of water. [4] Legend: α. joining angle of the secondary channel, l. the length of the secondary channel

Thus, in the sedimentation experiment (Experiment 3), function connection can be established between the measured data, such as time, in minutes (min) and density (g/cm^3). The function created this way expresses the change in sedimentation rate (6). Thus, with the help of material physical analogue models, a theoretical model can be formed. By the series of dissolution experiments (2), (33) (Experiment 1), it was important, that only one parameter can be changed from the selected parameters (e.g. inclination, grain size, etc.), all other parameters (e.g. amount of dosed water, etc.) must remain unchanged and be known. Thus, the effect of the changed parameter (inclination, grain size) to the examined phenomenon is demonstrable. For example, how the sizes of the dissolution forms (finger pads) on the plaster board change under different grain sized cover, with the same inclination, using the same amount of solvent (2), (33) (Figure 3).

Or for an another example (7), (8) how the size of the developed depression changes if the cover thickness is continuously reduced while the other parameters (chimney diameter, void volume of the space beneath the chimney, grain size) remain unchanged in experiment 7. From a theoretical point of view, it is very important to choose the size of the physical analogue model right. A model that is too small requires less material, the operation takes less time to perform, but makes the evaluation uncertain, because the measurable or visible changes themselves will be significantly smaller and thus cannot be detected or measured. The material (plaster, distilled water, fractioned cover) requirement of a model that is too large is significantly higher, so it is advisable to determine the size of the model in relation to the needs of the experiment to be performed. Even in a larger (and thus not cost-effective) model, it is not certain that the form will be more defined using the usual amount of time and solvent. It is also probable that the size (in our case the small size) has an effect on the nature and intensity of the studied process and thus on the development of the form(s). We can distinguish the phenomena we studied based on their time and resource requirements. The solution-form developing phenomenon (experiment 1) studied in the case of covered karsts has the longest time (six weeks) and the biggest equipment (100 dm^3 distilled water per experiment) requirement. To study sedimentation-formation (experiment No. 3), the time required for the experiment was much less (4-5 days). The model experiment investigating the formation of covered karstic depressions (experiment No. 7) required the least time.

In this case,it took longer to build the models than the process of the form developing itself, which was almost immediate. Knowing the time required for the model to build and for the form to develop, it can be concluded how many times the experiment can be repeated in a given time. In cases where the material and time requirements allow it, the measurements should be performed as many times as possible, in an odd number. The final results are given by the averages of the results of these measurements. In the case of material-intensive and time-consuming model experiments, the workgroup has a way to repeat only in case when the process is stuck underway because the experimental tool or model malfunctions. It follows that the result is more inaccurate, since we did not get the result from the average results of several measurements, but only from the data of a single one. We also have experienced that forms that do not exist in the field appeared on the model, especially on the plaster board (experiment No. 1). It can be assumed that this is due to an effect in the physical model that does not work in nature, or does not exist in it. For example the “wall effect”. This “wall effect” is caused by the frame delimiting the model, which impedes the free flow of the solvent (distilled water). The phenomena of the experiments that do not exist in nature should be disregarded when evaluating the results, but the reason for their occurrence should be clarified. It may be a typical problem that a property of a material that builds up the model impedes its operation (e.g., friction).During the operation of the experiment, it may turn out that it does not depict the processes and phenomena taking place in the nature faithfully. Therefore it is often necessary and possible to approach the natural processes in an appropriate extent by subsequent changes (e.g. adding additives). Such a problem was encountered in the study of turbulent flow (4) (experiment No. 4). The main and secondary channels made of plasticine are hydrophobic. By treating the surface of the channels, it was possible to create a hydrophilic surface (figure 4). /In this way, the interaction between plasticine and the water can be established, which in the nature is between the rinnenkarren formed on carbonate karst and the water flowing in it. The results of the experiments can be quantitative or qualitative. The result is quantitative (experiments No. 3, 4, 5, 6, and 7) where the data of the material built into the model are known precisely by its mass, volume, density, etc. (i.e., the parameters that have some effect) (40), (33), (7), (8).Thus for example in the case of experiment No. 4, a functional relationship can be established between the different inclination of the slopes and the beginning and the ending of the whirlpools (4). The description of the result is qualitative if the results of the experiment are recorded according to what form, where, continuously or intermittently or possibly incompletely developed (2), (3), (33).

In the case of dissolution experiments (Experiment No. 1), the effect of the built in material’s properties (thickness, grain size) on the process (form development on the plaster and on the cover) can only be described qualitatively (e.g. what forms appear on the plaster and on the cover). However, if we examine the dimensions of the forms we obtain quantitative results. The data obtained in this way (number of forms, dimensions) are approximates but suitable for comparison. By evaluating the results of the covered karstic model experiments (experiment No. 1), it was necessary to pay attention to which shape appeared on the plaster under the form that developed on the cover. For example, what kind of a form was developed under also py-sided depression that was formed on the cover during the experiment (e.g. kamenitza or chimney).The connection and the interaction between the form of the cover and the bedrock became describable on the basis of these data (2).We also experienced that there were forms on the cover, but there was no solution form on the plaster beneath it. This was mostly typical in that case when the cover was made up of small grains, because in such a case the water movement was horizontal, and thus the dissolving effect took place elsewhere on the plaster, or not at all (2) (33).

Practical issues and problems of modeling: The primary and thus the most important criterion when building a model is that the physical model to be built must fit with the analogy well. Will we presumably be able to answer the questions that arose in us based on our experience in the field after we know the results of the model experiment? Do the connections work in an analogue way?. Therefore, the imagined image of a several times rethought model must be conferred one after the other, even in a debate over whether it is suitable for answering the questions asked. After the documentation of the plan (e.g. based on a drawing), the construction of the model begins. To build and operate the model, always use the same material within a project, preferably purchased from the same place. Model plaster was always used in the experiments it was needed, distilled water was used as a solvent, the cover material was taken from the same place and treated (dried) in the same way and fractioned with the same sieve machine. Trying out the built model and performing the preliminary experiment has several advantages, for example the flaws of the model can be revealed, which can still be corrected and the time required for the experiment can be estimated.

When estimating the duration of the project, the occurrence of a malfunction must be taken into account. It is necessary to know the likeliest hindrances to the process, which was the production of distilled water in the dissolution experiment. This slowed down the experiments. It is recommended to keep a laboratory log from the beginning of the experiment series, i.e. the preliminary experiment. The essence-, the daily activity-, the unexpected and extraordinary events of the activity, the experiences gained during the operation of the model should be recorded in this log. If the laboratory work is contracted in team work, the responsibilities of the persons and its fulfillment should also be recorded. The plan of the model should also be documented. The recorded plan should not only be used for construction, but is recommended for use during publication as well. Based on the plan, the preparation of the model requires a thorough consultation with the expert who builds it. Sometimes the object which he has to make is very special to the constructor(Figure 5). If the constructor is aware of the reason for the special need, misunderstandings can be avoided. We can create the planned model ourselves during the laboratory work. The operation of the model and the related activities do not require special laboratory training. Practical activity develops the skills of the workgroup-member. Ingenuity, interest in the topic, perseverance at work, diligence should be important personality traits of anyone who wants to engage in such activities. Documenting the results requires special precision. The well-documented experimental results are the basis for the evaluation and then publication, also allows the data to be retrieved. Quantitative evaluation, which is based on the results of the measurements, is performed using statistical methods and functional analyzes. It is more difficult to evaluate the qualitative results (dissolution measurements - form development). We recommend creating tables based on the laboratory logs, where indicators with a legend can be grouped based on a variable parameter (e.g. grain size).

Summary

The close relationship between field and laboratory work should be emphasized, in which the leading role is always belongs to the field experience. The laboratory results must always be compared to the observed phenomenon in the field, and mapping experience as well. The result is valid only if it is consistent with the data obtained from the nature. The experiment performed alone can be completed very slowly, over a long period of time. Physical analogue model experiments can take several weeks, but it is even possible that the process to be studied takes less time to perform than building the model. An important part of planning is to estimate the duration of the examination correctly. The organization and management of the teamwork, the cohesion of the group requires regular consultation. Such research requires attention and tolerance from the members of the workgroup. Success can be achieved through sustained, lengthy work, but the result is always significant.

REFERENCES

1. Veress M., Pidl K., and Mantler M. 1998. A gipsz karsztosodásának modellezése laboratóriumi körülmények között. (The modelling of the karstification of gypsum under laboratory circumstances) Szombathelyi Berzsenyi Tanárképző Főiskola Tudományos Közleményei, 9. Természettudományok 6: 147-166. (in hungarian)
2. Veress M., Gárdonyi I. and Deák Gy. 2014. Fedett karsztosodás vizsgálata fedővel borított gipsztáblán. (Modelling of the karst development of covered uneven bedrock plaster) Karsztfejlődés, 19: 159-171. (in hungarian)
3. Veress M., Unger Z., Mitre Z., Gárdonyi I. and Deák Gy. 2015. The relationship between suspended sediment settling velocity and water table sinking rates in intermittent lakes in karstic depressions. Elsevier, Proceeding of the Geologists association, 417-425.
4. Deák Gy., Samu Sz., Péntek K., Mitre Z. and Veress M. 2012. Vízáramlási modellkísérletek vályúrendszereken. (Model experiments of water flowing in rinnenkarr systems) Karsztfejlődés, 17: 155-164. (in hungarian)
5. Deák Gy., Samu Sz. and Veress M. Szuszpenziós rendszerek ülepedésének és kiválásnak vizsgálata modellkísérletekkel. (Investigation of veneer development of suspension systems with model experiments) Karsztfejlődés, 2013; 18: 49-69. (in hungarian)
6. Deák Gy., Mitre Z., Szemes M. and Veress M. Ülepedés és vízszintcsökkenésének sebességének viszonya szuszpenziókban. (The relation between the velocities of sedimentation and of water table decrease in suspensions) Karsztfejlődés, 2014; 19: 147-158. (in hungarian)
7. Vetési-Foith Sz. Az utánsüllyedéses dolinák kialakulásának vizsgálata modellkísérlettel. (Examination of the subsidence doline's formation with the use of model experiments) Karsztfejlődés, 2018; 23: 85-93. (in hungarian)
8. Vetési-Foith Sz. Az utánsüllyedéses dolinák képződését befolyásoló paraméterek kapcsolatrendszerének vizsgálata modellkísérlettel. (Analysing the relations of the parameters that influences the subsidence dolines' formation using model experiment) Karsztfejlődés, 2019; 24: 61-79. (in hungarian)
9. Curl RL. Scallops and flutes. Transactions cave research Group Great Britain, 1966; 7: 121-160.
10. Quinif Y.Contribution a l'étude morpholoqique des coupoles. Annales de spéléologie, 1973; 28(4): 565-573.
11. Fabre G. and Nicod J. Lapiés, modalités et rôle de la corrosion, crypto- karstique. Phénomèn karstique III, Mémoires et documents de géographie, 1982; 3: 115–131.
12. Fleurant C., Tucker GE. and Viles HA. A model of cockpit karst landscape, JamaicaModélisation d'un paysage de karst de type cockpit (Jamaïque). Géomorphologie: relief, processus, environnement, 2008; 14(1): 3-14.
13. Fleurant C., Tucker GE. and Viles HA. Modelling cockpit karst landforms. Geological Society, London, Special Publications, 2008; 296(1): 47-62.
14. Lauritzen SE. Simulation of rock pendants – Small scale experiments on plaster models.- In: Beck, B.F. (eds.) Eight international congress of speleology. Georgia Southwestern College, Americus, 1981; 407−409
15. Reinboth F. Beiträge zu Theorie der Gipshöhlenbildung. Die Höhle, 1968; 19(3): 75-83.
16. Völker R. The development of gypsum Caves. 6th. International Congress of Speleology, Olomouc, Abstracts. 1973.

17. Dzulynski S., Gil E. and Rudnicki J. Experiments on klustkarren and related lapis forms. Zeitschrift für Geomorphologie, 1988; 32(1): 1-16.
18. Slabe T. Experimental modelling of cave rocky relief forms in Paris plaster. Atti e Memorie della Commissione Grotte E. Boegan, 1995; 32: 65−83.
19. Slabe T. Two experimental modellings of karst rock relief in plaster: subcutaneous ’rock teeth’ and ’rock peaks’ exposed to rain. Zeitschrift für Geomorphologie, 2005; 49(1): 107-119.
20. Slabe T. Karren simulation with plaster models.- In: Ginés A., Knez M., Slabe T. and Dreybrodt W. (eds.) Karst rock features – karren sculpturing. ZRC Publishing, 2009; 47−54.
21. Slabe T., Hada A., Knez M. Laboratory modeling of karst phenomena and their rock relief on plaster: subsoil karren, rain flutes karren and caves. Acta Carsologica, 2016; 45(2): 187-204.
22. Glew JR. and Ford DC. A simulation study of the development of rillenkarren. Earth Surfaces Processes, 1980. 5(1): 25-36.
23. Rudnicki J. Experimental work on flutes development. Speleologia, 1960; 2(1): 17−30.
24. Goodchild JG. and Ford DC. Analysis of scallop patterns by simulation under controlled condition. The Journal of Geology, 1971; 79(1): 52−62.
25. Allen JRL. The origin of cave flutes and scallops by enlargement of inhomogeneities. Rassegna speleologica Italiana, 1972; 14(1) 3−20.
26. Szunyogh G. A horizontális karsztos lepusztulás folyamatának matematikai modellezése. (Mathematical modeling of the horizontal karstic denudation) A Berzsenyi Dániel Tanárképző Főiskola Tudományos Közleményei, 9. Természettudományok, 1994; 4: 173-201. (in hungarian)
27. Péntek K. Karsztosodó mészkő térszínek lepusztulásának matematikai modellje. (Mathematical model of the limestone surfaces’ karstification) Karsztfejlődés, 2001; 6: 13-25. (in hungarian)
28. Perne M. and Gabrovšek F. The problems of rillen-karren development: a modeling Perspective.- In: Ginés A., Knez M., Slabe T. and Dreybrodt W. (eds.) Karst rock features – karren sculpturing. ZRC Publishing, 2009; 55−61.
29. Kaufmann G. Modelling karst geomorphology on different time scales. Geomorphology, 2009; 106(1-2): 62-77.
30. Mitre Z. Vályúban áramló víz áramlási viszonyainak modellezése számítógépes szimulációval. (Modelling of water flow conditions in channels with computer simulation) Karsztfejlődés, 2016; 21: 75-95. (in hungarian)
31. Mitre Z. Karros fővályúban létrejövő áramlások szimulációs vizsgálata. (Simulated examination of flow in the main channels of karren systems) Karsztfejlődés, 2017; 22: 77-88. (in hungarian)
32. Mitre Z. Digitális vályúmodellen végzett áramlási szimulációk adatainak vizsgálata különböző lejtési és becsatlakozási paraméterek esetén. (Analysis of flow smulation data in digital channel system model in case of different junction and slope angle parameters) Karsztfejlődés, 2018; 23: 5-18. (in hungarian)
33. Gárdonyi I. and Szemes M. Fedett karsztos folyamatok vizsgálata modellezéssel. (Analysin covered karstic processes using model experiments) Országos Tudományos Diákköri Konferencia, Kolozsvár, 2015: 37 p. (in hungarian)
34. Stefanovits P. Talajtan. (Pedology) Mezőgazdasági Kiadó, Budapest. 1981.
35. Deák Gy., Péntek K., Füzesi I., Vetési-Foith Sz. and Veress M. A karsztosodás során kialakult törmelékzóna modellezése. (Modelling of the debris zone that developed during karstification)Karsztfejlődés, 2017; 22: 61-75. (in hungarian)
36. Deák Gy., Vetési-Foith Sz. and Péntek K. A telítődési szint helyzetének és a karsztos felszín kapcsolatának vizsgálata modellkísérlettel. (Examination of the relationship between the depth of saturated level and karstic surface development by model experiments) Karsztfejődés, 2018; 23: 31-43. (in hungarian)
37. Veress M. and Péntek K. Kísérlet a karsztos felszínek denudációjának kvantitatív leírására. (An attempt to describe the kvantitativ denudation of karstic surfaces) Karszt és Barlang, 1990; 1: 19-27. (in hungarian)
38. Veress M. and Péntek K. Theoretical model of surface karstic processes. Zeitschrift für Geomorphologie, 1996; 40(4): 461-476.
39. Jakucs L. Morphogenesis of karst regions: Variants of Karst Evolution. Adam Hilgar, Bristol, 1977.
40. Deák Gy., Szemes M. and Veress M. A gipsz fedőjének vízmozgásai fizikai analóg modelleken. (Water movements of the plaster cover on physical analogue models) Karsztfejlődés, 2015; 20: 215-229. (in hungarian)

****