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Hydrodynamic Model of Formation of Karst Voids

Zurab A. Kereselidze, Davit T. Odilavadze, Marina S. Chkhitunidze

M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University
M. Alexidze 1, 0160, Tbilisi, Georgia
z_kereselidze@yahoo.com; odildavit@gmail.com

ABSTRACT

The physical representation of the dynamic picture of the karst development pursues various objectives, among which, in particular, is to assess the characteristic time scale of their formation. Obviously, this problem is quite complicated because of the many-sidedness of the process of karsting, proceeding with both: general characteristics and local features. In particular, karst voids can have a variety of forms, some of which have some regularity due to similarity with a certain geometric figure. For example, for karst, a funnel-shaped form with a base on the earth's surface is quite common. The effectiveness of the leaching factor is directly dependent on the geological quality of the medium and the duration of the action of the water. It seems that to confirm the uniformity of the mechanism, the action of which leads to the elution of the solid rock, one can turn to the approximation of the hydrodynamic boundary layer arising when flowing over a solid surface. The rate of washing out of solid rock from the karstic cavity depends on the flow of water, which can vary depending on the flow regime. However, we can talk about some average characteristic, if we assume, for example, that the water movement is laminar. it should be noted that the value of the rate of karst leaching used for numerical evaluation is very approximate. it nevertheless seems that with the help of the model we have used, it is possible to obtain more accurate quantitative estimates.

Key words: hydrodynamic, karst voids.

Introduction

Investigation of natural causes leading to the formation of karst voids, formed both on the surface and in the depth of the Earth, is a common problem of geophysics and hydrogeology. The physical representation of the dynamic picture of the karst development pursues various objectives, among which, in particular, is to assess the characteristic time scale of their formation.

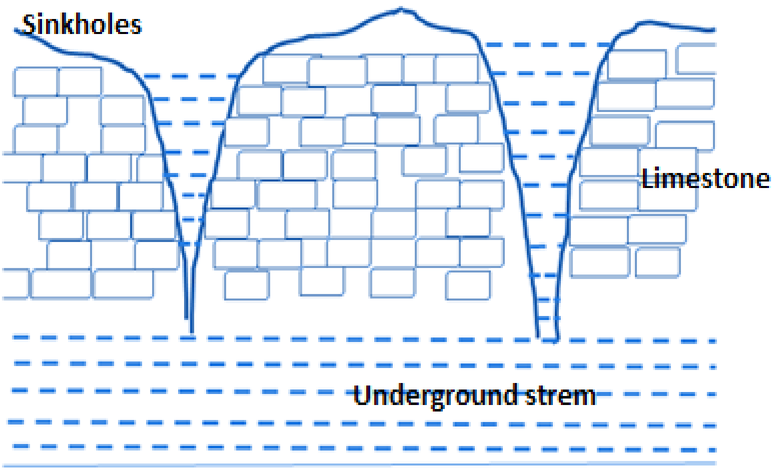

Fig.1

Obviously, this problem is quite complicated because of the many-sidedness of the process of karsting, proceeding with both general characteristics and local features [1]. Specificity is mainly determined by local geology and climate, however, not only these factors [2]. For example, there is a variety in the form of karst voids, noted in spatially separated places, but almost identical in terms of the action of natural factors [3-5]. In particular, karst voids can have a variety of forms, some of which have some regularity due to similarity with a certain geometric figure. For example, for karst, a funnel-shaped form with a base on the earth's surface is quite common (Fig. 1).

The nose of the funnel can join with the channel of the underground river or a reservoir of groundwater or with a cave. However, despite the wide variety of forms of karst voids, for everyone there are common factors that give rise to their formation. First of all, it concerns the universality of the mechanism of washing out of solid rock, which leads to the appearance of voids. The effectiveness of the leaching factor is directly dependent on the geological quality of the medium and the duration of the action of the water. Undoubtedly, under the same hydrological conditions, the process of elution of the rock in limestone or in sandstone should be more intense than, for example, in basalts. Although porosity, i.e. the moisture capacity of basalts is higher than that of sandstones and limestones, basalts are also higher in resistance to shear due to their hardness. It is also obvious that the formation of voids in a solid rock directly depends on the intensity of atmospheric precipitation, which, in addition to the surface, also has a deep effect, feeding groundwater. Simultaneously with climatic factors, the process of karst formation is also affected by the orography of the area, which determines the topology of surface runoff. Moreover, in direct dependence on orography, there is also a typology of deep water bearing channels (filtration capillaries) supplying underground reservoirs [3].

The essence of the problem

It seems that to confirm the uniformity of the mechanism, the action of which leads to the elution of the solid rock, one can turn to the approximation of the hydrodynamic boundary layer arising when flowing over a solid surface. The general condition necessary for its occurrence in the process of washing out solid rock with water is certainly present. Because Water is a real liquid, when it moves in karst cavities of any shape, viscous effects must necessarily occur.

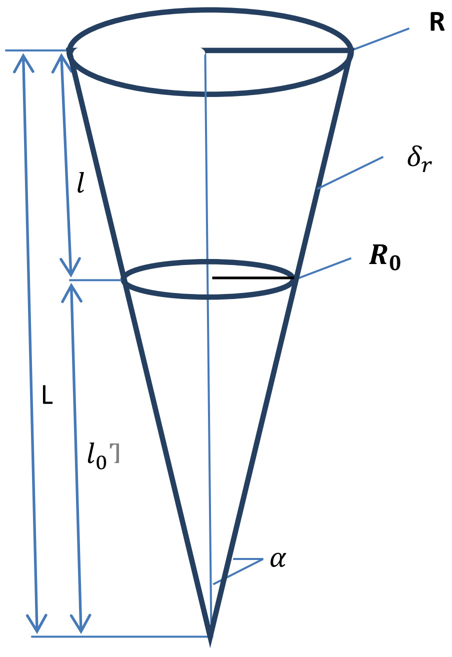

Fig. 2

For a qualitative representation of the karst cavity, it is convenient to use its geometric analogy, for which one can use a figure whose cross-sectional area decreases with increasing of height. Obviously, in the case of radial symmetry, such a figure can be a cylinder, which in the limit passes into a cone (Fig. 2).

Obviously, for the completeness of the geometric similarity of the karst funnel and cone, the latter must be truncated. It is for the funnel of such a form that a mathematically rigorous analytical solution is known that determines the thickness of the laminar boundary layer on the inner surface of the funnel [6]

$$\delta_r \approx 1.5(M^3 - M^{16})^{\frac{1}{2}} \cdot \left[\frac{\nu \cdot l^3 \cdot (\sin \alpha)^2}{R_0^2 \cdot \left(\frac{2\bar{P}}{\rho}\right)^{\frac{1}{2}}}\right]^{\frac{1}{2}}, \qquad (1)$$

In this expression there are parameters of the cone and the flow of water. In particular: $\delta_r$is the thickness of the laminar boundary layer, l_0 is the distance from the top of the funnel to its arbitrary cross section of radius R_0, inclusive of the funnel neck, L is the funnel length, $l = L - l_0$, α is the half-angle of the approximate cone solution, $M = \frac{l_0}{L} < 1$ is a dimensionless parameter present in the mathematical scheme for solving the problem. The flow velocity through the cone funnel in expression (1) is present through the pressure drop between the vertex and the funnel base $\bar{P}$, and ν is the coefficient of the kinematic viscosity of the water.

It follows from expression (1) that in the case of constancy of the parameters of the approximation cone and the kinetic viscosity of water viscosity, the velocity of flow through the funnel will be the only parameter that controls the thickness of the boundary layer. Consequently, the radius of the truncated top of the cone can be identified with the radius of the neck of the funnel. For a significant number of karst craters, this analogy is quite plausible, although in the case of a conventional economic funnel of a classical shape, the cone-shaped part ends in a fairly long cylindrical leg. The karst cavities may not have such an end, although they are no less than a conical funnel, similar in shape to a truncated cone.

Thus, the flow of liquid through the funnel is largely determined by the viscous boundary layer arising on its inner surface. However, the thickness of the boundary layer, in addition to the viscosity of water, is also dependent on the water velocity. Therefore, the structure of the flow in the funnel should be quite complicated. In particular, at a distance from the boundary layer, the viscosity effect should decrease and the likelihood of a laminar flow change to turbulent flow increase. Consequently, based on the degree of loading (the level of filling the karst cavity) funnel with liquid, it is physically possible to assume the possibility of realizing various types of motion that can correspond to the following typologically different patterns:

1. Laminar flow, which can occur only in the case of a weak funnel load in the event that the flow of water through the funnel is constant. The movement of water in the direction of the neck of the tapering funnel occurs in the field of gravity. Therefore, laminar flow can theoretically be resistant to small perturbations only when the pressure gradient is constant between the base of the funnel and its neck. Otherwise, the layer structure of the flow will be violated, i.e. there will be the possibility of water turbulence. Such a transformation of the flow structure does not at all mean that the boundary layer on the inner surface of the funnel must completely disappear. For example, the boundary layer can simply detach from the surface. However, in this case, you should expect a decrease in water flow in the funnel, which can change the degree of its load.

2. Mixed forward-rotational motion, which occurs when the load of the funnel increases. Such a movement primarily means an increase in the transverse pressure gradients in the funnel. Along with the increase in the volume of water entering the funnel, the violation of the laminar flow structure may be caused to some extent by the roughness of the surface of the funnel. In the case of a karstic cavity, as an impulse giving rise to a disturbance of the flow, it may be, for example, a mechanical collapse or the ingress of large stones that are carried by the flow of water into the cavity. However, the most probable reason for the appearance of rotational motion in a karstic funnel is the detachment of the viscous boundary layer from its internal surface. Theoretically, this phenomenon can be considered the beginning of the emergence of turbulent water movement, when large-scale eddies begin to appear in it. In the karst funnel, the characteristic dimensions of these vortices must be commensurate with the geometric parameters of the cavity. In the process of

intensification of turbulent motion in the funnel, one cannot exclude the decrease of the longitudinal pressure gradient, and, consequently, the flow of water.
3. Fully developed rotational movement, periodically occurs in the funnel at its maximum load, which is physically real only for a small volume funnel. In this case, it cannot be said that for some time the longitudinal flow, which determines the flow of water, can be weakened or even completely stopped in the funnel. However, this hydrodynamic effect does not mean that pressure gradients can completely disappear, because rotational movement in the funnel will continue. A similar phenomenon sometimes occurs in the economic funnel, which is tightly seated in the neck of the bottle with an incompletely filled liquid. The effect of "locking" the funnel is facilitated by the leveling of the longitudinal pressure arising in the field of gravity due to the increased pressure of compressed air from the side of the bottle (the so-called air cork). In this case, to continue the process of filling the bottle, it is necessary to raise the funnel, i.e. eliminate the air plug. Obviously, "locking" the karst cavity can be an extremely rare short-term phenomenon, probably arising in a funnel connected to an underground water reservoir.

A qualitative picture of washing out the karst cavity

Reducing the flow of water in the karst funnel, up to its "locking", can contribute to those factors that are able to level the longitudinal pressure gradient. The effect of these factors causes the turbulence of water, as a result of which large-scale eddies appear, which, over time, are fractured into smaller-scale vortices. If the fragmentation of the vortices is slower than their generation, the intensity of the large-scale rotational motion in the funnel increases for a time, which can contribute to an increase in the thickness of the viscous boundary layer on the inner surface of the funnel. At the same time, it cannot be said that the boundary layer can completely fill some part of the funnel in the direction of its narrowing and, thus, so slow down the flow in order to substantially reduce the water flow. Obviously, the probability of such an effect can be quite high in only a karstic cavity of a small volume. In this case, an unstable flow can arise, which can be typologically represented as an alternation of the states of "opening" and "locking" the funnel. As mentioned above, this situation can arise only if the karst cavity is connected to an underground water reservoir.

The pulsating character of motion, in comparison with laminar flow, can significantly enhance the viscous interaction between solid rock and water and, thus, depend on the efficiency of washing out of the inner surface of the karst. To substantiate this assumption, let us consider a qualitative model that can be supported by quantitative estimates. It is known that the cause of the appearance of a viscous boundary layer is the effect of adherence of liquid particles to a solid surface. From a mechanical point of view, this means that the tangential stress between the water layers is insufficient to overcome the surface friction force that appears on the streamlined surface. According to Hooke's law, the shear stress is proportional to the shear strain rate [7,8]

$$\tau = G\gamma. \tag{2}$$

In liquids, the shear stress:$\tau = \mu\left(\frac{\delta u}{\delta y}\right)$, where μ- is the dynamic viscosity coefficient, u - is the longitudinal velocity, y the coordinate is the perpendicular to surface, G is the shear modulus, γ is the coefficient whose value for the liquid can be taken equal to unity .

It is obvious that the magnitude of the tangential stress depends on the steepness of the profile of the velocity distribution of the fluid in the boundary layer. Flourishing (2) determines the stability threshold of static equilibrium in a fluid. Otherwise, if the magnitude of the tangential stress exceeds a certain limit determined by the shear modulus, the laminar flow structure must change. Therefore, water turbulence will begin, as a result of which a viscous boundary layer can come off a solid surface. Consequently, the magnitude of the shear stress is an indicator that determines the moment when the laminar flow regime changes to turbulent. To estimate the magnitude of the tangential stress between the layers of water, one must determine its flow velocity. Strictly speaking, for this it is necessary to solve the boundary layer equation with boundary conditions corresponding to a particular flow problem, which is even an analytically insoluble problem even for a stationary flow. However, in some problems, the physical consequences of which do not require particularly accurate quantitative evidence, one can take advantage of the possibility of rough estimates. However, these estimates must necessarily follow from a qualitatively correct model. For the problem of analyzing the action of the hydrodynamic mechanism contributing to the occurrence of karst voids, in our opinion, this possibility is quite possible. This statement is based on the physical visibility of the model we use. This facilitates the analysis of qualitative conclusions from the model, without which it is impossible to judge the reliability of quantitative estimates. The simplicity of our model is primarily due to the ability to determine the hydrodynamic parameters without a rigorous analytical solution, which is achieved by the way of using the method of physical analogy, which allows using previously known analytical results. In particular, in order to estimate the magnitude of the tangential stress from formula (1), δy can be replaced by a finite linear scale of velocity variation, i.e. Thickness of the boundary layer δ_r . In addition, because the motion in the funnel is due to the action of gravity, at any level of the karst cavity δu can be regarded as the magnitude of the free fall speed. Moreover, for rough estimates, the average values of these parameters can be quite sufficient: $\underline{\delta_r}$ and $\underline{u}$.

Thus, within the framework of our model it is possible to remain within the limits of statics, i.e. there is no need to solve the equation of water motion. For example, knowing the characteristic value of the velocity, it is easy to estimate the magnitude not only of the component of the tangential stress (2), but also other components of the stress tensor. In a cylindrical coordinate system, these components are determined by the expressions [7, 8]

$$\tau_{r\varphi} = \mu\left[r\frac{\partial}{\partial r}\left(\frac{\partial u_\varphi}{\partial r}\right) + \frac{1}{r}\frac{\partial u_r}{\partial \varphi}\right],$$
$$\tau_{\varphi z} = \mu\left[\left(\frac{\partial u_\varphi}{\partial z}\right) + \frac{\partial u_z}{\partial \varphi}\right], \qquad (3)$$
$$\tau_{rz} = \mu\left[\left(\frac{\partial u_r}{\partial z}\right) + \frac{\partial u_\varphi}{\partial r}\right],$$

Where u_r, u_φ and u_z are the velocity components, the coefficient of dynamic viscosity of water.

Without a special assumption, we can assume that the magnitude of any component of the flow velocity outside the boundary layer depends on the rate of free fall. At the same time, proceeding from the very essence of the definition of the boundary layer, its thickness should be much smaller than the radius of the funnel section, at least at a certain distance from its base. However, such an assertion may turn out to be incorrect due to the narrowing of the funnel near its nose, where the boundary layer can completely occupy its cross section. In addition, it is obvious that the dependence of the velocity on the azimuth angle φ can be significant only in the case of an inhomogeneous vorticity, the intensity of which must increase in proportion to the decrease in the cross-sectional area of the funnel. In this case, it is quite right to assume that the value of the component τ_{rz} is significantly higher than the values of the other components of the stress tensor. Therefore, their influence on the process of washing out solid rock in the boundary layer can be considered unimportant. This means that the viscous interaction is mainly due to the rotational motion of the liquid in the plane of the cross-section of the funnel. In the general case, this rotation will be unstable because of its non-uniform nature. Consequently, the non-stationary picture of the movement of water through the funnel is represented as a sequence of decaying from large to small vortices. It can be obtained by means of the kinematic velocity model, used, for example, in the work to simulate the inhomogeneous rotational motion of an ionospheric plasma in an incompressible approximation [9]

$$u_\varphi = u\frac{R_0 - r}{R_0}(\cos\varphi - \sin\varphi),$$
$$u_r = u\frac{R - r}{2R_0}(\cos\varphi + \sin\varphi), \qquad (4)$$
$$u_z = u,$$

Where $0 \le r \le R$ is the radius of the cross-section of the approximation cone, and u is the characteristic velocity.

If the vertical velocity is assumed constant, then it is obvious that the remaining components (4) satisfy the plane equation of continuity

$$\frac{1}{r}\frac{\partial(rV_{r})}{\partial r}+\frac{1}{r}\frac{\partial V_{\varphi}}{\partial\varphi}=0, \qquad (5)$$

which is one of the conditions for the dynamic possibility of motion along the model (4). Such a case will correspond to a qualitative typological picture, the evolution of which should lead to the formation of a chain of vortices whose linear scale will gradually decrease during the movement of water in the karst funnel (Fig. 3)

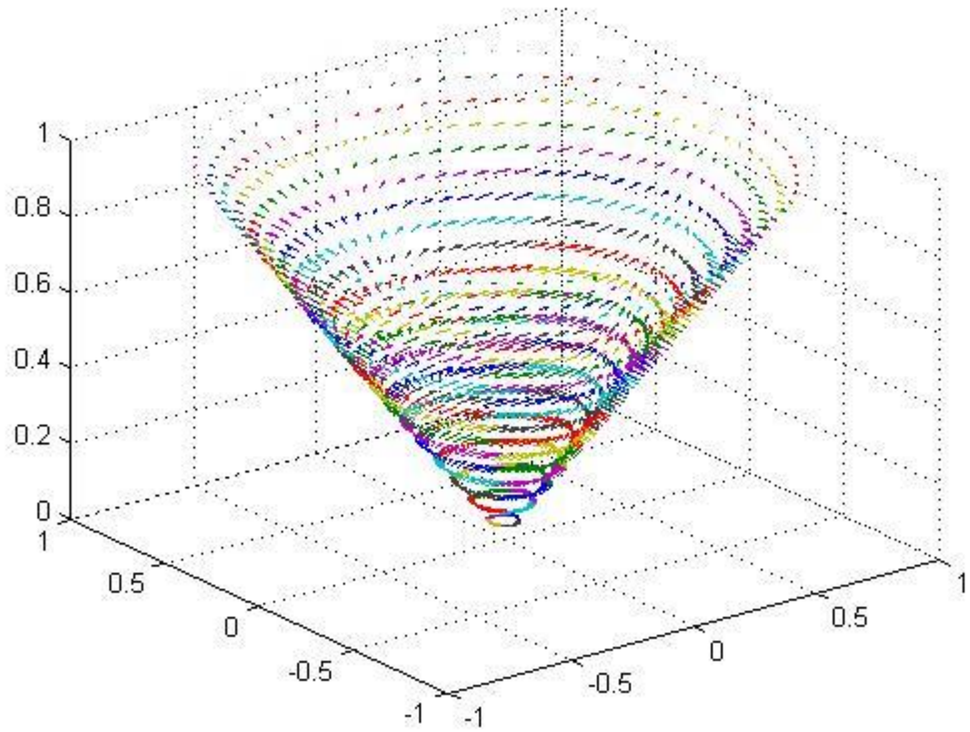

Fig. 3

To quantify the intensity of the leaching process in a karst funnel, as the main linear scale of the inhomogeneity, one can use the characteristic thickness of the viscous boundary layer in the middle of the funnel. To estimate it numerically by expression (1), we use the model cone with the following parameters: $L = 10m$, $R = 1m$ (radius of cone base), $sin\alpha \approx 0.1$, $M \approx 0.5$, $R_0 \approx 0.5$. The coefficient of kinematic viscosity of water: $\nu \approx 1.3\times10^{-6}m^2s^{-1}$. The free-fall speed at the selected cross-section level, which is related to the pressure drop:

$$u = \left(\frac{2\,\bar{P}}{\rho}\right)^{\frac{1}{2}} = 10\ ms^{-1}.$$

We shall regard this quantity as the average characteristic for the entire cone. As a result of substituting formula (1) for all the numerical parameters, we get that the characteristic thickness of the viscous boundary layer is $\delta_r \approx 10^{-3}m$. It should be noted that this quantity is of the same order of magnitude, for example, for the thickness of the boundary layer at Horizontal flat plate. The validity of such a statement is obvious and the principle of hydrodynamic similarity operates.

To observe it, we must determine the dimensionless Reynolds number corresponding to our model cone: $Re\approx \frac{uR}{\nu} \approx 8\times10^6$. It is known that in the case of a flow past a flat plate, the thickness of the boundary layer depends on the square root of the Reynolds number in accordance with the inverse proportionality law [7,8]. Consequently, for $\underline{Re \approx 8\times10^6}$, the boundary layer on a flat plate, like the thickness on the inner surface of the model cone, will have a characteristic thickness commensurate with $10^{-3}m$.

Thus, if we take into account some structural monotony of karst craters, which arise only because of the washing out of different hard rocks, it can be assumed that the characteristic value of the thickness of the viscous boundary layer on the inner surface of almost any karstic funnel should be within one millimeter. The model we used also quite clearly represents the mechanical result of the tangential stress effect between a solid rock and water. Obviously, to effectively wash out the shear stress on the inner surface of the karst cavity must repeatedly exceed the magnitude of the water shear modulus, which serves as a criterion for static equilibrium between layers of a laminar viscous fluid. Within the framework of our model, when the parameters are: $\mu = 10^{-3} kg\, m^{-1} s^{-1}$, $u = 10 ms^{-1}$ and $\delta_r \approx 10^{-3}$, the characteristic value of the tangential stress: $\tau = 10\ Nm^{-2}$. Obviously, in comparison with the given value, the water shear modulus is negligibly small: $G = 1{,}3{\times}10^{-5} Nm^{-2}$ [10]. Hence it obviously follows that the boundary layer must be detached from the inner surface of the karst cavity. Also, there is no doubt that the movement of water in the karst cavity with its significant load, i.e. in the case of a sufficiently intense runoff, cannot be laminar.

Therefore, it is the effect of the separation of the boundary layer, which is the cornerstone of our model. Its main goal is to determine the characteristic time scale of the change in the volume of the karst cavity due to the washout effect, i.e. in the assessment of the rate of removal of solid rock from the karstic cavity. It is known that the washout effect usually occurs in a very thin layer, the thickness of which is commensurable or slightly larger than the molecular size ($\sim 10^{-6} m$). The elution coefficient for most of the terrestrial rocks varies in a characteristic range: $/10^{-5} - 10^{-3}/\ \ kg\, liter^{-1}$ [4,5]. According to our assumption, the process of elution must occur in the volume of the hydrodynamic boundary layer. The washout intensity can increase many-fold due to the rotational motion of the liquid and due to the separation of the boundary layer. The time scales of the elution time depend on the specific conditions. However, using the expression for the volume of the boundary layer

$$V_{\delta_r} \approx \pi R L \delta_r, \qquad (6)$$

we can approximately estimate the characteristic value of the rate of washout of solid rock from the karstic cavity.

Conclusion

The volume of the model cone used above approximates the karst cavity: $V \approx \frac{1}{3}\pi R^2 L \approx 10\mathrm{m}^3$. The volume of the boundary layer on the inner surface of the model cone is $V_{\delta_r} \approx 0.03\ m^3$. Consequently, the mass of the solid rock washed from the boundary layer in the case of the full cone load in the case of zero water flow can be $m_0 \approx 3/10^{-4} - 10^{-2}/$ kg. The rate of removal of solid rock from the karstic cavity depends on the flow of water, which can vary depending on the flow regime. However, we can talk about some average characteristic, if we assume, for example, that the water movement is laminar (minimum washout mode) and the water flow rate is $Q \approx 3\ liter/s$. In this case, through the neck of the cone-shaped funnel within an hour, it can pass $\nu = 10 m^3$ volume of water, which corresponds to: $m \approx /10^{-1} - 10/$ kg mass of solid rock. If this process continues, for example, 100 days, then the maximum mass of washed solid rock can be 24 tons. Consequently, the volume of the cone approximating the karst cavity can increase by $V_0 \approx 10 - 12 m^3$, i.e. approximately twice. However, it should be noted that the value of the rate of karst leaching used for numerical evaluation is very approximate. It was obtained in the linear approximation. Despite such a shortcoming, which is a consequence of a rather crude physical analogy, it nevertheless seems that with the help of the model we have used, it is possible to obtain more accurate quantitative estimates. In particular, in order to increase the reliability of the results, it is necessary to use integral relations, in which the effect of nonlinear increase in the washout rate, which varies with the growth of the volume of the karst cavity, should be reflected.

References

[1] Gvozdetskiy N.A. Karstovyye Landshafty. Moskva, iz-vo MGU, ISBN 3-211-00128-1, 1988, 112 s. Vakhrushev B.A.
[2] Karst geomorphology and the notion of karst relief. Speleology and karstology, vol.1, Simpheropol, 2008, pp. 47-53.
[3] Kirtener D.A., Uskov I.B. Klimaticheskiye faktory i teplovoy rezhim v otkrytom i zashchishchennom grunte. Leningrad, Gidrometizdat, 1982, 228 s.
[4] Timofeyev D.A., Dublyanskiy V.N., Kiknadze T.Z. Terminologiya karsta. Moskva, Nauka, 1991, 260 s.
[5] Koronovskiy V.N., Yakushova A.F. Osnovy geologii. Moskva, Vysshaya shkola, 1991, 416 s.
[6] X. Binnie A.M. Harris. D.P. The application of Bonndary-Layer Theory to Swirling Liquid Flow Through a Nozzle. Quart. J. Mech. and Applied,Math.. v.3, 1950, pp. 89-106.
[7] Shlikhting G. Teoriya pogranichnogo sloya. Moskva, Nauka, 1974, 711 s.
[8] Loytsyanskiy L.G. Mekhanika zhidkosti i gaza. Moskva, Nauka, 1973, 847 s.
[9] Kirtskhalia V., Kereselidze Z., Dzhondzholadze N., Chkitunidze M. An Analytical Model of an Asymmetrical Temperature Field in the Polar and Auroral Ionosphere. Georgian Int. J. of Sci. and Tech., №4, 2012, pp.381-90.
[10] Korenchenko A.Ye., Beskachko V.P. Opredeleniye skorosti sdviga vody v eksperimentakh s plavayushchim diskom. Prikladnaya mekhanika i tekhnicheskaya fizika, t.49, №1, 2008, s.100-103.

კარსტული სიცარიელის წარმოქმინის ჰიდროდინამიკური მოდელი

ზ.კერესელიძე, დ. ოდილავაძე, მ.ჩხიტუნიძე

რეზიუმე

კარსტის განვითარების დინამიური სურათის ფიზიკურ მოდელირებას აქვს სხვასადხვა მიზანი, რომელთა შორის არის კერძოდ, მათი ჩამოყალიბების დამახასიათებელი დროის მასშტაბის შეფასება. ცხადია, რომ ეს ამოცანა საკმაოდ რთულია კარსტული პროცესების მრავალფეროვნების გამო, რომელიც ვლინდება თითქმის ყველგან, როგორც საერთო მახასიათებლებით, ასევე ადგილობრივი განსაკუთრებულობებით. კარსტულ სიცარიელეებს შეიძლება ჰქონდეთ საკმაოდ განსხვავებული ფორმები, რომელთა ნაწილს აქვს რეგულარობა გარკვეული გეომეტრიული ფიგურის მსგავსების გამო. მაგალითად, კარსტის საკმაოდ გავრცელებული ფორმა არის ძაბრისებური ფორმა ფუძით დედამიწის ზედაპირზე. გამორეცხვის ფაქტორის მოქმედების ეფექტურობა პირდაპირ არის დამოკიდებული გარემოს გეოლოგიურ თვისებებზე და წყლის მოქმედების ხანგრძლივობაზე. როგორც ჩანს, მექანიზმის ერთგვაროვნების დასადასტურებლად, რომლის მოქმედება იწვევს მკვრივი ნიადაგის გამორეცხვას, შეიძლება მივმართოთ ჰიდროდინამიკური სასაზღვრო ფენის მიახლოებას, რომელიც წარმოიქმნება მკვრივი ზედაპირის გარსდენის დროს.
ნიადაგის გამოტანის სიჩქარე კარსტული ღრუდან დამოკიდებულია წყლის ხარჯზე, რომელიც შეიძლება იცვლებოდეს დინების რეჟიმზე დამოკიდებულად. თუმცა შეიძლება ვისაუბროთ, გარკვეულ საშუალო მახასიათებელზე, თუ დავუშვებთ, რომ წყლის მოძრაობა არის ლამინარული.

უნდა აღინიშნოს, რომ რიცხვითი შეფასებისათვის გამოყენებული კარსტის გამორეცხვის სიჩქარის სიდიდე არის საკმაოდ მიახლოებითი. მიუხედავად ამისა, წარმოგვიდგება რომ, ჩვენს მიერ გამოყენებული მოდელის საშუალებით შეიძლება მივიღოთ უფრო ზუსტი რაოდენობრივი შეფასებები.

Гидродинамическая модель образования карстовых пустот

З.А. Кереселидзе, Д.Т. Одилавадзе, М.С. Чхитунидзе

Резюме

Физическое моделирование динамической картины развития карста преследует различные цели, среди которых, в частности, является оценка характерного временного масштаба их образования. Очевидно, что эта задача является достаточно сложной из-за многобразия процесса карстрирования, протекающего практически повсеместно, как с общими характеристиками, так и местными особенностями. Карстовые пустоты могут иметь самые различные формы, часть которых имеет некоторую регулярность из-за подобия с определенной геометрической фигурой. Например, для карста достаточно распространенной является воронкообразная форма с основой на земной поверхности. Эффективность действия фактора вымывания находится в прямой зависимости от геологических качеств среды и длительности действия воды. Представляется, что для подтверждения однообразия механизма, действие которого приводит к вымыванию твердой породы, можно обратиться к приближению гидродинамического пограничного слоя, возникающего при обтекании твердой поверхности.
Скорость выноса твердой породы из карстовой полости зависит от расхода воды, который может менятся в зависимости от режима течения. Однако, можно говорить о некоторой средней характеристике, если предположить, например, что движение воды является ламинарным.
Необходимо отметить, что использованная для численной оценки величина скорости вымывания карста является весьма приблизительной. Тем не менее представляется, что при помощи использованной нами модели можно получить более точные количественные оценки.