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HYDROGEOLOGICAL CONDITIONS OF KARST DEVELOPMENT IN CARBONATE ROCKS WITHIN THE SVIATOHIRSK BRAHIANTICLINAL

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In the process of filtration, groundwater dissolves the mineral substance of carbonate rocks or leaches from them individual components. The geodynamic consequence of such chemical activity of groundwater in carbonate rocks is karst, which causes the destruction of rocks. Groundwater plays an exceptional role in the chemical transformation of carbonate rocks. Geochemical work of groundwater consists of leaching and dissolution and removal of mineral matter from them. Under natural conditions, the parameters of «rock – water» system, within which karst formation processes take place, are quasi-stable, and the dissolution of mineral matter in groundwater is determined mainly by the concentration gradient between the liquid phase and the saturated solution layer formed at its contact with carbonate matter of rocks. The main factor in the process of karst formation in carbonate rocks is carbon dioxide, which is present in water in free and soluble forms. Infiltration water and groundwater contained in karst reservoirs constantly dissolve and transfer the substance of carbonate rocks. This leads to a constant increase in the size of karst cavities, which, in turn, is a significant factor in increasing the intensity of hydrogeodynamic processes in the underground hydrosphere. Technogenic karst is formed under conditions of anthropogenic impact on the geological environment. The most common reason for this is pollution of surface water and groundwater.

The establishment of hydrogeological factors of karst formation in carbonate rocks in this article is considered in view of the solution of such a significant problem as the buildings protection of Sviatohirsk monastery from destruction, which is currently intensive. This religious complex is located within the Sviatohirsk brachyanticlinal. The presented approach can also be used for built-up areas with similar ecological-hydrogeological and technogenic conditions. *Key words:* groundwater, change of chemical composition, discharging of deep waters, heat and mass transfer, karst, carbonate rocks, dissolution, tectonic faults.

Гідрогеологічні умови розвитку карсту у карбонатних породах у межах Святогірської брахіантикліналі. Сухов В.

В процесі фільтрації підземні води розчиняють мінеральну речовину карбонатних гірських порід або вилуговують з них окремі компоненти. Геодинамічним наслідком такої хімічної діяльності підземних вод у карбонатних породах є карст, що спричиняє руйнування порід. Підземні води відіграють виняткову роль у хімічному перетворенні карбонатних порід. Геохімічна робота підземних вод складається з вилуговування і розчинення та виносу з них мінеральної речовини. У природних умовах параметри системи «порода – вода», в межах якої відбуваються процеси карстоутворення, мають квазістабільний характер, а розчинення мінеральної речовини у підземних водах визначається, головним чином, величиною градієнта концентрації між рідинною фазою та шаром насиченого розчину, що утворюється на її контакті з карбонатною речовиною порід. Головним чинником процесу карстоутворення у карбонатних породах є двооксид вуглецю, що присутній у воді у вільній та розчинній формах. Інфільтраційні та підземні води, що вміщуються у карстових колекторах, постійно розчинюють та переносять речовину карбонатних порід. Це призводить до постійного збільшення розмірів карстових порожнин, що, у свою чергу, є суттєвим фактором збільшення інтенсивності гідрогеодинамічних процесів у підземній гідросфері. Техногенний карст формується в умовах антропогенного впливу на геологічне середовище. Найчастіше причиною цього є забруднення поверхневих та підземних вод.

Встановлення гідрогеологічних чинників карстоутворення у карбонатних породах у даній статті розглядається з огляду на вирішення такої значної проблеми, як захист споруд Святогірського монастиря від руйнації, який наразі має інтенсивний характер. Даний релігійний комплекс знаходиться у межах Святогірської брахіантикліналі. Також представлений підхід можна використовувати для забудованих територій із подібними еколого-гідрогеологічними та техногенними умовами. *Ключові слова:* підземні води, зміна хімічного складу, розвантаження глибинних вод, тепломасоперенесення, карст, карбонатні породи, розчинення, тектонічні порушення.

Formulation of the problem. Groundwater is an active factor in geodynamic processes, the result of which is, among other things, such a process as karst of carbonate rocks. The waters involved in these phenomena are predominantly infiltrative, although, under certain conditions, in areas of ruptured fluid-conducting tectonic faults, they may have deep formation and include deep fluids. These waters are both pressureless and pressure. They are characterized by anomalous parameters of chemical composition, mineralization, as well as other physical-chemical parameters. The process of karst, which poses significant threats to buildings and constructions, occurs mainly under the action of free water exchange, the horizons and complexes of which are in the near-surface, disturbed by weathering, part of lithosphere. These waters have high filtration rates and have a direct connection with the day surface. Infiltration waters of free water exchange zone include “top water”, groundwater of Quaternary sediments, as well as water circulating in the most weathered

upper part of the marl-chalk layer of Upper Cretaceous to depths of 5–10 to 100–150 m, and sometimes more [10, 16]. Other natural factors (tectonic, lithological, geomorphological) also influence these geodynamic processes to a large extent. Groundwater is characterized by two main types of geological activity – physical (mechanical) and chemical (soluble), which, respectively, determines the development of such a geodynamic process in carbonate rocks as karst. Very often, both mechanical and chemical activities of groundwater occur simultaneously. Therefore, determining the role of each of these processes in the destruction of carbonate rocks requires field observations, laboratory studies and theoretical justifications [15].

The relevance of research. Karst is one of the two most important hydrogeodynamic processes in carbonate rocks, associated with the processes of their leaching and dissolution by groundwater. Karst processes not only cause chemical and physical destruction of rocks, but also determine the intensity of migration and concentration of chemical elements and compounds in aqueous solutions and significantly affect the formation of the chemical composition of groundwater. Solving the problem of carbonate karst allows to solve theoretical and practical problems: calculation based on chemical thermodynamics of karst formation energy; determining the direction and intensity of karst development; the influence of carbonate karst on the relief with the formation of its specific "karst forms"; calculation of natural geological risks associated with karst processes for buildings and constructions. Solving these problems determines the relevance of this paper [13].

Sviatohirsk brachyanticline is located on the northern side of Bakhmut depression in the eastern part of Dnieper-Donetsk depression. Marl-chalk sediments north of Sviatohirsk are exposed on the right bank of Siversk Donets river in the form of a rock up to 100 m high with the historical and architectural complex of Sviatohirsk Monastery located on it. Based on the actual material of studies of geodynamic processes involving groundwater and their effects in the Upper Cretaceous rocks on the Sviatohirsk brachyanticline, we considered the hydrogeological features of karst in carbonate sediments to solve problems of protection of buildings from destruction, which is very relevant today [17].

Analysis of recent research and publications. A modern scheme of deep faults in the study region was proposed by V. I. Skarzhinsky (1973). Subsequently, in 1975, this scheme was somewhat improved [7]. The tectonic activation of region, which took place at the Mesozoic stage of geological development, was analyzed in detail by V. Konashov (1983). In 1986, a map of modern tectonic movements of the earth's crust was compiled, which allowed to determine the absolute indicators of geodynamic landslides of various geological structures, including Sviatohirsk brachyanticline [21].

The papers of V. G. Bilokon are devoted to neotectonic movements in the region, deep sources of geodynamic energy, as well as substantiation of point of view that the Siversk Donets river basin is a geodynamic system that reflects processes of great depths [1, 2, 3]. The fluid regime of existing in the region fault zones was also considered in [7, 8, 9], in which the theoretical basis for the study of geodynamic processes in the system "carbonate rocks – groundwater" was constructed.

The results of special studies of karst in the marl-chalk layer of Upper Cretaceous were published by V. V. Sukhov and V. G. Suyarko (2012, 2015, 2017, 2018). In particular, a conceptual synergetic geological and hydrogeological model of suffusion and karst development in carbonate rocks and the territory of Sviatohirsk monastery was proposed, which takes into account both exogenous and endogenous factors of geodynamic processes development [17]. This is a serious basis for predicting and studying the development of suffusion-karst phenomena in areas of tectonically activated faults [14].

Description of the study. Karst formation, which occurs due to the soluble action of water, is one of the main landscape-forming phenomena [9, 11]. But within the marl-chalk stratum, this process is not the main factor in the formation of relief, although it plays an important role in the development of cracks and cavities of marl-chalk layer. Karst is associated with the formation of surface depressions, grottoes and other geomorphological forms that arose in this carbonate Upper Cretaceous massif due to chemical reactions in the system "rock – water" [6].

It should be noted that the question of existence within the marl-chalk layer of carbonate karst until recently was open, because previous studies have found only active solid runoff associated with suffusion phenomena (Storchova A. M., Molodan V. O., 1982, et al). In the process of field observations, we have established the facts that indicate the development of carbonate karst here, due to the chemical interaction in the system "rock – water". The most important factors in the karst development are the dynamics and temperature of groundwater, their chemical and gas composition, which provide the intensity of chemical reactions with the dissolution of carbonate rocks [11, 23].

According to our observations, water exchange systems, which were formed in the Upper Cretaceous sediments, led to the formation of two types of karst here – hypergenic (epicarst) and hypogenic (endocarst) [12, 17]. If the development of karst first type is associated mainly with infiltration waters, the second type of karst is due to the discharge of water from deep horizons and deep fluids and, in particular, carbon dioxide [5, 22]. The peculiarity of karst development is the constant acceleration of this process intensity in time and the increase in the volume of karst rocks in space. This trend is mainly provided by the constant expansion of groundwater filtration channels (due to the dissolu-

tion of rocks) and, accordingly, the acceleration of their movement in the fracture-cavity space [6].

The interaction of infiltration and pressure water of different chemical composition with carbonate sediments leads to the appearance of cavities of different sizes and shapes, the parameters of which depend on the permeability of rocks, their fracturing, filtration rate and aggressiveness of water and gases, and existence time of system "groundwater – carbonate rocks". At the same time, metasomatosis processes can be observed, which are manifested in the recrystallization of carbonate rocks – hemolitogenesis with the formation of amorphous and sometimes crystalline carbonate [17]. Among the karst landforms associated with the epicarst, the most common are funnels with a depth of several centimeters to 0.5-1.0 m, which are often found on terraces (chalk ledges) and relatively inclined slopes. Curry cracks filled with "chalk powder" are also installed here. Similar forms, but with crusts of amorphous and sometimes cryptocrystalline calcite (aragonite) are confined to the tectonic cracks that cut through the outcrops of this stratum. The latter are manifestations of endo- or hypokarst. The consequences of ancient epicarst include, in particular, the grottoes, which are associated with both modern and ancient water levels in the Siversk Donets river [13].

In the marl-chalk stratum of Upper Cretaceous within the Sviatohirsk monastery, groundwater is confined to its upper fractured zone, the roof of which is quite uneven [4]. In the areas of near-surface occurrence of zone, the modern relief repeats its outlines. The formation of fractured zone in the Upper Cretaceous rocks is associated with both ancient and modern processes of geological weathering, in which infiltration waters played an important role. The thickness of weathered fractured zone up to 5–10 m, as well as its overlap with Quaternary sandy-clay sediments and soils created the preconditions for the formation of aquifer within the chalk ledge. The filtration coefficients of groundwater within it vary from 0.01 to 15.0 m/day, and the flow rates of wells – from 5.0–10.0 to 30.0–40.0 dm^3/s. In areas of tectonic fracture (sometimes tens of centimeters wide), vertical discharge of Paleozoic groundwater is often observed along wells. It should be noted that the waters of Cretaceous sediments are characterized by neutral or close reaction (pH 6.8–7.2), mineralization in the range of 3–5 g/dm^3 and sodium bicarbonate composition. Instead, Paleozoic groundwater has a more alkaline reaction (pH 7.6–8.0), higher (up to 10 g/dm^3) mineralization and other chemical composition – from sulfate-chloride mixed cationic composition to sodium bicarbonate, and in some cases even sodium chloride. An important geochemical feature of such waters is the anomalous amounts of both free and soluble carbon dioxide [16]. All this creates favorable conditions for the karst processes development within the marl-chalk stratum, on which are the ancient monastery buildings.

The aquifer of marl-chalk layer within the region is widespread in both the Bakhmut and Kalmius-Toretsk depressions. Its greatest thickness and water capacity is observed in syncline (interdome) deflections, and the aquifer hydraulic connection is fixed not only with alluvial and groundwater, but also the waters of Siversk Donets river in its valley. Groundwater flows here reach 69–83.3 dm^3/s at water level reductions up to 2–5 m [4]. In the watersheds, the Upper Cretaceous marl-chalk stratum is practically anhydrous. Some researchers attribute this to the absence of fracture zone [4]. However, this is probably due to the increased fracture of Upper Cretaceous rocks and the increase in thickness of free water exchange zone in these areas, and, consequently, the change in the regime of groundwater from pressure to non-pressure. In this case, pressureless or low-pressure (with a pressure of up to 10–20 m) water simply can not reach the watershed structures, which are sometimes at much higher (up to 100–150 m) hypsometric marks [4].

Studies of the groundwater chemical composition in the region of different genesis, selected from both the Upper Cretaceous aquifer and from the fractured zones allowed to determine their average composition and characteristics. These are mainly hydrocarbonate calcium (magnesium) waters with low (0.7–1.2 g/dm^3) mineralization and neutral reaction (pH 6.8–7.2). The CO_2 content in them on average ranges from 17–30 mg/dm^3, and the concentrations of trace elements do not exceed the background values [16]. The generalized Kurlov's equation for marl-chalk layer waters according to calculations of author can have such look:

M1,0 $\frac{HCO_3^- 60\ SO_4^{2-} 25\ Cl^- 15}{Ca^{2+} 55\ Mg^{2+} 30\ Na^+ + K^+ 15}$ pH 7,0; CO_2 17-30

However, against the background of hydrocarbonate and hydrocarbonate-sulfate calcium, magnesium waters with low mineralization, neutral pH and low content of trace elements and gases, there are often waters with other geochemical characteristics. Thus, a strong hydrogeochemical inversion associated with the upward discharge of chloride and chloride-sulphate waters is observed in the area of Petrivsk-Kreminsk fault. This indicates that the supply of such waters involves waters of deep aquifers, discharged within the Sviatohirsk structure [18, 19].

Main conclusions. 1. Karst is a geodynamic consequence of groundwater geological activity, which is manifested in the dissolution and leaching of rocks with the formation of liquid runoff. The following basic conditions are necessary for the karst development: a) physical – a significant thickness of carbonate rocks and low groundwater levels; b) chemical – alkalinity of groundwater of hydrocarbonate-sodium composition and the presence of soluble and free carbon dioxide.

2. Hydrogeological features of karst development in the study area are based on the role of fracture-cavity space in the filtration of groundwater of different formation and upward discharge of aggressive to carbonates

waters of deep aquifers and carbon dioxide, as well as adverse physical-chemical dissolution conditions of marl-chalk rocks.

Prospects for the use of research results. After establishing the main hydrogeological conditions of karst development in carbonate rocks on the territory of Sviatohirsk monastery, the next stage will be the establishment of technogenic factors of these processes activation – pollution of surface water and groundwater, intensification of water withdrawal, extension of water intake network.

References

1. Белоконь В. Г. Бассейн р. Северский Донец как геодинамическая система, отражающая процессы больших глубин. *Геологический журнал.* 1984. Т. 34. Вып. 5. С. 11–27.
2. Белоконь В. Г. Неотектонические движения в Донбассе и их связь со структурными элементами. *Материалы по геологии Донецкого бассейна:* книга. Москва, 1968. С. 11–15.
3. Белоконь В. Г. О глубинном источнике энергии углеобразования формации Донецкого бассейна. *Геологический журнал.* 1981. Т. 41. № 6. С. 88–99.
4. Гидрогеология СССР: у 6 т. Т. VI, Донбасс. Москва, 1971. 480 с.
5. Климчук А. Б. Гипогенный спелеогенез, его гидрогеологическое значение и роль в эволюции карста. Симферополь: ДИАЙПИ, 2013. 180 с.
6. Климчук А. Б. Эпикарст : гидрогеология, морфогенез и эволюция. Симферополь : Сонат, 2009. 112 с.
7. Лазаренко Е. К., Панов Б. С., Павлишин В. И. Минералогия Донецкого бассейна. Киев : Наукова думка, 1975. Ч. II. 502 с.
8. Лущик А. В., Морозов В. И., Милешин В. П. Подземные воды карстовых платформенных областей юга Украины. Киев : Наук. думка, 1981. 200 с.
9. Основы гидрогеологии. Геологическая деятельность и история воды в земных недрах / Е. В. Пиннекер, Б. И. Писарский, С. Л. Шварцев и др. Новосибирск : Наука, 1982. 239 с.
10. Соколов А. Д. Закономірності тріщинуватості крейдяних порід долини р. Сіверського Донця. *Доповіді АН УССР*, No. 7. 1963. С. 937–940.
11. Соколов Д. С. Основные условия развития карста. М.: Госгеолтехиздат, 1962. 321 с.
12. Сухов В. В., Суярко В. Г., Сердюкова О. О. Гідрогеологічні особливості карбонатного карсту. *ScienceRise.* 2015. No. 7/1(12). С. 23–27.
13. Сухов В. В., Суярко В. Г., Нємець К. А., Матвєєв А. В. Гідрогеодинамічні процеси у карбонатних породах. Частина II. Карст і його вплив на геологічне середовище. *Вісник ХНУ імені В. Н. Каразіна, серія «Геологія.Географія. Екологія».* 2018. Вип. 48. С. 173–184.
14. Сухов В. В., Суярко В. Г., Чуєнко О. В. Про зв'язок сучасних геодинамічних процесів у карбонатних породах з тектонічною активізацією Петрівсько-Кремінського розлому. *Вісник ХНУ імені В. Н. Каразіна, серія «Геологія. Географія. Екологія».* 2017. Вип. 46. С. 56–61.
15. Суярко В. Г., Сухов В. В., Чуєнко О. В. Гідрогеодинамічні процеси у карбонатних породах. Частина I. Суфозія. *Вісник ХНУ імені В. Н. Каразіна, серія «Геологія. Географія. Екологія».* 2017. Вип. 47. С. 64–70.
16. Суярко В. Г. Геохимия подземных вод восточной части Днепровско-Донецкого авлакогена. Харьков : ХНУ имени В. Н. Каразина, 2006. 225 с.
17. Суярко В. Г., Сухов В. В. Концептуальна синергетична геолого-гідрогеологічна модель розвитку суфозії та карсту у карбонатних породах на території Святогірського монастиря. *Вісник ХНУ імені В. Н. Каразіна, серія «Геологія. Географія. Екологія».* 2015. N 1157. С. 63–68.
18. Суярко В. Г. Особенности формирования вертикальной гидрогеохимической зональности в мезозойских структурах Донецкого прогиба. *Геологический журнал*. 1984. Т. 44, No. 1. С. 127–130.
19. Суярко О. В. Про зв'язок зон розвантажування вод глибоких горизонтів палеозою з глибинною тектонікою Донбасу. *ДАН УРСР*. 1970. Сер. Б, No. 5. С. 403–405.
20. Суярко А. В. Роль зон разгрузки глубинных вод в выяснении природы геотермических аномалий и рудной минерализации в Западном Донбассе. *II геол. конференция «Степановскиечтения».* Артемовск, 1968. С. 161–163.
21. Филькин В. А. Опыт составления карты современных движений земной коры по территории Донбасса. *Современные движения земной коры.* К. : Наукова думка, 1986. С. 216–221.
22. Klimchouk A., Ford D., Palmer A., Dreybrodt W. Speleogenesis : Evolution of Karst Aquifere. *Huntsville; Nalt, Speleol. Soc.* 2000. 495 p.
23. White W. B. Karst hydrology: recent developments and open questions. *Eng. Geol.* 2002. 65. P. 85–105.