Conditions and factors for karst development in the Southern Urals and Cis-Urals

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Abstract. *The conditions and types of karst are given, three main groups of factors of its development are identified: geological-geomorphological, climatic-hydrogeological and technogenic. The main regularities of distribution and modern activity of karst are established depending on the factors of its development.*
Keywords: *sulfate karst, carbonate karst, a group of karst development factors, geological-geomorphological, climatic-hydrogeological, technogenic.*

Introduction

Numerous existing definitions of karst reflect three approaches to this process [19]. Geographers and geomorphologists consider karst as a phenomenon, studying its surface and underground manifestations; geologists see in it a polygenetic process of changing the properties of rocks; hydrogeologists and geological engineers understand karst as a unity and totality of a process and phenomenon. The author, like a number of other researchers (Anikeev, Gvozdetsky, Maksimovich, Sokolov, Stupishin, etc.), understands karst as the totality of the process and the phenomena caused by it. Namely, karst is an exogenous geological process caused by the dissolving and eroding activity of natural and man-made waters circulating in relatively readily soluble rocks, as a result of which underground and surface karst forms (karst manifestations) are formed.

If the conditions for the development of karst are interpreted quite unambiguously by most researchers, then, as Timofeev D.A., Dublyansky V.N., Kiknadze T.Z. [19], a unified approach to determining the factors of its development does not currently exist. Researchers have identified more than 100 factors of karst development, which are combined into groups of constantly acting, slowly and rapidly changing [21] factors: geological, hydrodynamic, hydrochemical, geomorphological, climatic [1, 3, 18, 20, etc.].

Despite more than two centuries of studying the karst of the Southern Urals and the Cis-Urals, scientific publications contain various interpretations of the conditions and factors of its development, and special systemic works on studying the factors of karst development in the region, in addition to considering its individual aspects [6, 7, 8, 18 and etc.], have not been conducted before.

Purpose of the study – systematization of the main conditions and factors of the development of karst in the region under consideration and analysis of their influence on the intensity and activity of its development at the present stage.

Initial data and research methods

The initial materials for the research were the information collected by the author about the karst of the Southern Urals and the Cis-Urals, the analysis of the intensity of distribution and the activity of its development, contained in the reports of OJSC "Bashkirgeologiya", CJSC "ZapUralTISIZ" and OJSC "Archstroyizvskaniya", as well as the author's own research, individual aspects karst region, published in 2014-2021. [9-16].

Results and discussion

Terms accepted in the article and their current definitions.

The intensity of the distribution of manifestations of karst – the magnitude of the change in the geological environment as a result of the development of the karst process over a certain period of time (for the region under consideration from the Pliocene to the present day). Most often it is expressed through the karst content coefficient (the number of karst sinkholes per unit area within the karst fields) and the karst occurrence of the territory (the ratio of the number or area of karst forms per unit area of karst areas within which they are developed).

Karst development activity – the magnitude of the change in the geological environment (a measure of its variability in time) as a result of its development [21]. Usually expressed in terms of karst denudation (mm); the ratio of the number and (or) volume of newly formed karst forms to a unit of area and time (pcs./km^2*year or units*m^3/km^2*year); the average annual increase in their volumes (m^3/km^2*year) [19].

Karst development factors – natural conditions and technogenic circumstances that determine the scale of the development of the karst process: the intensity of the distribution of karst forms and the activity of its new manifestations.

Conditions for the development of karst. Currently, it is generally accepted that for the development of karst [according to 18, p. 126], a simultaneous combination is necessary: the presence of soluble rocks and their permeability, the presence of moving waters and their aggressiveness to water-bearing rocks. The absence of one of these four conditions makes the development of karst impossible. In this regard, karst can be characterized as a process of activity with dissolving capacity, circulating in readily soluble rocks of natural and man-made waters. That is, karst develops with the interaction of two natural environments - rock and water.

Karst development factors. Based on the basic conditions for the development of karst, all (more than 100) known factors can be divided into two main groups - geological-geomorphological and climatic-hydrogeological. At the present stage, they are joined by a group of technogenic factors. The first two groups are determined by the geological structure and natural conditions of the territory, and the third - by the degree of anthropogenic load on the geological environment.

Group of geological and geomorphological factors

Factor of the composition of karst rocks and the frequency of their composition. The distribution of karst in terms of the composition of karst rocks and conditions of occurrence is correct in Figure 1, from which it can be seen that mainly sulfate, carbonate and sulfate-carbonate karst is developed in the Southern Urals and in the Cis-Urals. It developed most intensively in karst rocks devoid of insoluble impurities. Klastokarst [16] and locally sulfide karst [14] are also developed in the region to a limited extent.

Water permeability factor of karst rocks is manifested by the greater karst formation of areas with increased water permeability, due to more intense fracturing in the zones of disjunctive faults and tectonic faults with a general tendency to decrease with depth [4].

Thickness factor of sediments overlying karst rocks in the region it is most clearly manifested in the areas of development of sulfate karst in the karst country of the East European Plain. As the karst gypsum of the Kungurian stage sinks in the western direction under the non-karst sediments covering them, the karst content of the territory gradually decreases, and where the gypsum roof is at a depth of more than 100 m, it is practically absent [13], which is the basis for mapping the western boundary of the distribution of sulfate karst.

The factor of the composition of the sediments covering the karst rocks, defining genesis, strength properties and their water permeability is the basis for distinguishing the types of karst in the region under consideration by the nature of the overlap of karst rocks by non-karst ones: open (bare or Mediterranean), covered (sub-eluvial-deluvial or Central European) covered (sublimnic), overlapped (sub-alluvial or Kama) closed (Russian) [4, 15].

Relief formation history factor is predetermined by the history of the geological development of the territory and is due to neotectonics. At the present stage, in the Southern Urals and in the Cis-Urals, karst develops inherited from the course of relief formation in the Neogene-Quaternary. In the Early Pliocene, during the inception and the beginning of the formation of deeply incised (up to 200 m) Late Pliocene paleovalleys of rivers [22], there was a sharp activation of the development of karst, which weakened in the Pleistocene, interrupted by periods of activation during the formation of pradolines of rivers in the early Neopleistocene [4].

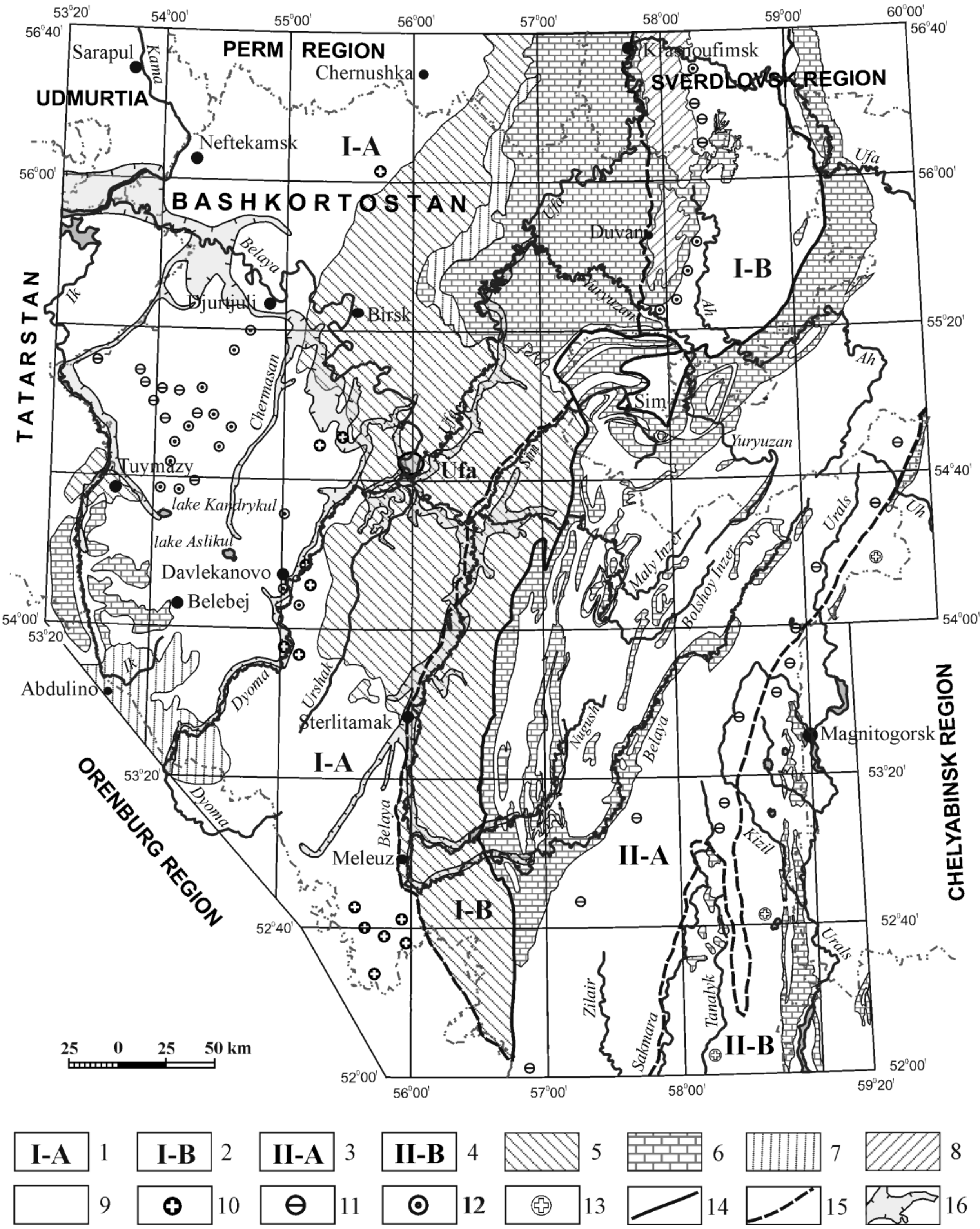

Fig. 1. Types of karst in the Southern Urals and Cis-Urals (Smirnov, 2021 [based on 4, 13, 15, 16])

Karst country of the East European Plain (I): 1 — (I-A) flat karst in horizontally and gently lying rocks of the Cis-Urals; 2 — (I-B) flat and foothill karst of the Cis-Urals in gently sloping and weakly dislocated rocks. Ural karst country (II): 3 — (II-A) mountain and foothill karst in dislocated and highly dislocated formations of the Urals; 4 — (II-B) flat karst in folded-block sediments of the Trans-Urals. Karst types: 5 — sulfate, 6 — carbonate, 7 — sulfate-carbonate, 8 — clastokarst, 9 — areas with no surface manifestations of karst. Local manifestations of karst: 10 —

sulfate, 11 — carbonate, 12 — klastokarst, 13 — sulfide. Boundaries: 14 — karst countries, 15 — types of karst by the nature of the relief and the conditions of bedding of rocks. 16 — contour of paleovalleys of rivers, mapped by N.N. Tolstunova on a scale 1:500 000 (1994) according to the data of the state geological survey of the scale 1:200 000.

Factor of the structure of river valleys and watersheds determines the strengthening of karst from the "cores of watersheds" to the valleys-drains [18, p. 265] and is the basis for the identification of geomorphological types of karst: karst of river valleys and karst of interfluves [4, 5]. Karst of the first type is developed everywhere more intensively.

Group of climatic and hydrogeological factors

Hydrochemical factor predetermines the rate of karst development from the ability to dissolve karst rocks. In the region under consideration, sulfate rocks have the highest solubility in the hypergenesis zone. In distilled water at a temperature of 25°C in 1 liter, it reaches 2.1 g, and in salt waters even 7 g. The solubility of calcium carbonate in distilled water at a temperature of 25°C is low - only 15 mg in 1 liter, but it increases significantly in the presence of in water, carbon dioxide, which enters the rocks along with infiltration water from the atmosphere and soil-vegetation layer. In the presence of free CO_2 - 199.5 mg/dm^3 in 1 liter of water, the solubility of calcite is 455 mg/dm^3, and in its absence - only 11 mg/dm^3. At the same time, an increase in temperature significantly reduces the calcite capacity of carbon dioxide waters. If an increase in the CO_2 content in water leads to an increase in the rate of karst development in carbonate rocks, then in sulfate rocks this does not happen, but on the contrary, it even slightly decreases [3, 8, 18].

Hydrodynamic factor determines the nature of groundwater discharge in river valleys, where there are two main hydrodynamic environments that characterize the development of karst - the hydrodynamic environment of intense and hindered water exchange in fractured karst waters (fig. 2) [10].

The hydrodynamic environment of the hindered water exchange of fissure-karst waters is characterized by a slow discharge of groundwater due to the development of a loamy-clay cover on gentle slopes and low interfluves. The hydrodynamic environment of intensive water exchange in fissure-karst waters is typical for steep slopes of drainage valleys, where pinching out of impermeable and aquifers and free discharge of groundwater in the form of springs or an invisible overflow from the upper strata to the lower ones along the fissures of the side resistance is observed.

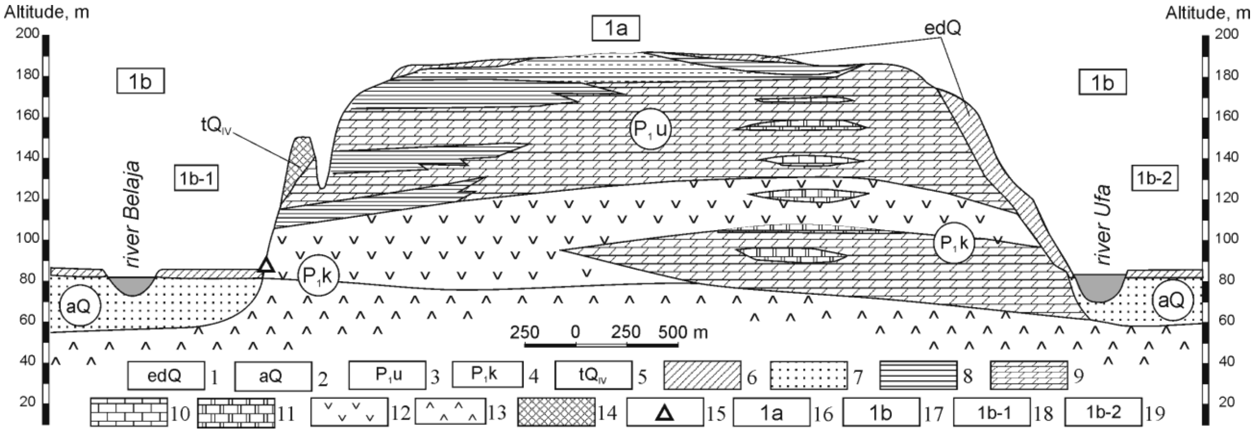

Fig. 2. Schematic geological section along the latitude of the center of Ufa [based on 10]

1− eluvial-deluvial deposits of slopes and watersheds; 2 − deposits of above-floodplain accumulative terraces; 3 − clay-marl-sandy-calcareous red-colored stratum of the Ufa stage; 4 − gypsum-anhydrite stratum of the Kungurian stage; 5 − loam, clay; 6 − sand-gravel-pebble deposits; 7 – mudstone; 8 – limestone; 9 – sandstone; 10 – marl; 11 – dolomite; 12 – gypsum; 13 – anhydrite; 14 – railway track on the Ufa karst slope; 15 – spring karst: 16 – interfluve, 17 – river valleys. 18 – Hydrodynamic environment of intensive water exchange in fissure-karst waters; 19 – Hydrodynamic environment of hindered water exchange in fractured-karst waters,

Climatic (meteorological) factor at the present stage of karst development, it manifests itself in the activity of water exchange in the upper hydrodynamic zones, depending on the amount of precipitation and the regime of karst waters, in particular, the thickness of the zone of seasonal fluctuations in the level of karst waters [18].

Group of technogenic factors

Anthropogenic activity can both promote and hinder the development of karst [5, 7, etc.].

Factors contributing to the development of karst: violation of the waterproof properties of the overburden; the emergence of technogenic sources of formation of aggressive groundwater; mechanical impact of production and technological processes; pollution of atmospheric air and surface waters by aggressive emissions and effluents of industrial enterprises [6]. To these can also be added the pollution of groundwater from the extraction of hydrocarbons; blasting operations and the creation of man-made cavities (wells, mines, adits, drifts, etc.) during the exploration and operation of minerals, the construction of underground storage facilities and subways.

Factors hindering the development of karst: elimination of surface karst manifestations; an increase in the thickness of the water-protective cover over karst rocks; creation of artificial waterproof coatings (asphalting, concreting, etc.); streamlining the flow of atmospheric waters by creating storm collectors; Carrying out targeted engineering anti-karst preventive measures and liquidation plugging of deep forms of karst.

Implementation of the factors of karst development in the region

Due to the higher rate of dissolution of sulfates in comparison with carbonates, the intensity of the spread of karst occurrences in the development areas of the first is up to 5 times higher than that of the second. The incidence of karst landforms associated with the development of sulfate karst reaches 25% (sometimes even higher), while carbonate - does not exceed 5%, and usually is less than 1%. At the same time, the maximum karst content of sulfate karst is observed in areas composed of white sugar-like gypsum without admixtures, and for carbonate karst, everywhere - the most pure organogenic organogenic-detrital limestones in composition [4, 9, 15].

The maximum distribution of surface karst manifestations is observed in areas of open karst. With the same composition of the sediments covering the karst rocks, the infestation by surface karst manifestations is inversely proportional to their thickness. With the same thickness of the overburden, the density of surface manifestations of karst increases from physically strong rocks to weaker ones and from impermeable rocks to water-permeable ones along cracks, with the greatest damage to the overburden deposits, the water permeability of which is due to their porosity. With the same thickness and composition of the overburden, the surface karst content naturally decreases from ancient to young landforms [17] and from positive neotectonic structures [2] to negative ones or to areas with monoclinal gypsum bedding.

The most frequent and diverse forms of sulfate karst on the bedrock slopes of the valleys (karst of river valleys). At the same time, on high slopes in an environment of active water exchange, karst forms are more diverse and numerous than on low and gentle ones, where water exchange is difficult. Steep slopes with gypsum outcrops and adjacent valleys of watersheds with a width (up to 1.5 km) are often affected by karst more than 10%, and gentle slopes are not more than 5%. In addition, in areas where the hydrodynamic environment of intensive water exchange of fractured karst waters is formed, the activity of karst development is always higher than in areas with hindered ones. Thus, long-term (~ 40 years) monitoring observations of karst occurrences on the Ufa slope under conditions of intensive water exchange established the formation of an average of two new sinkholes per year [11], while under conditions of difficult water exchange of fractured-karst waters on the right slope of the valley of the river Ufa (see fig. 2), the formation of karst sinkholes is recorded extremely rarely. In addition, on the Ufa slope, it was found that most often dips are formed in spring, and in the long-term series - in years with an increased amount of atmospheric precipitation [11].

In regional terms, more than half of modern karst sinkholes in the last 20 years have formed in the bottoms of drainage valleys, where the thickness of the deposits covering the karst gypsum is reduced by the erosional activity of rivers. At the same time, the overwhelming part of them is confined to the rear parts of river terraces, the foothills and edges of the modern slopes of river valleys and the slopes of paleovalleys. Along with this, most of the karst sinkholes have arisen in the areas of development of closed and overlapped types of karst in the areas within which they were previously recorded, and in most cases are confined to territories with an increased incidence of surface karst forms in the contours of neotectonic uplifts [15].

Technogenic factors at the present stage are mostly factors that accelerate the development of karst in the cities of Ufa [5-7], Blagoveshchensk, Birsk and in the extraction of minerals, which is manifested in the formation of new karst sinkholes. In 2000-2020, the formation of at least 35 large failures was reliably recorded in the residential areas of the listed cities [12, 15]. Their formation was repeatedly recorded in quarries and their surroundings during the extraction of limestone and gypsum, as well as in the contours of the Tuymazinskoye oil field. The last pitcher-shaped karst sinkhole at the Tuymazinskoye field was formed in May 2012. Its depth was 11.5 m, the diameter from the surface was 2.5, and along the bottom - 9.0.

Conclusions

The conditions for the development of karst are uniquely determined by all karst researchers and are implemented in the Southern Urals and the Cis-Urals as well as in other karst regions.

The factors of karst development are determined by the peculiarities of the geological structure and natural conditions of the region under consideration. The identified groups of factors (geological-geomorphological, climatic-hydrogeological and technogenic) determine the differences in the intensity of distribution and the activity of karst development in its individual parts of the Southern Urals and the Cis-Urals. At the same time, most often they affect the rate of karst development in a complex manner, and often the allocation of only one of them is relatively conditional.

Further studies of karst in the region should be aimed at studying the climatic-hydrogeological and technogenic group of factors, which, in comparison with the geological-geomorphological group of factors, have been studied to a much lesser extent.

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