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THEMATIC ISSUE

Morphological indications of hypogene speleogenesis in caves of the Urals (Russia)

O. I. Kadebskaya[1] · V. N. Kataev[2] · N. G. Maksimovich[3] · A. S. Kazantseva[1]

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Abstract

Approximately all types of surface and underground karst elements are represented in the Urals. Rock formations are elongated in the longitudinal direction, which allows for a comparative analysis of the processes in karst landscapes in different latitudinal geographic areas. During the long geological history of the Urals, karst development occurred in conditions of extensive occurrence of soluble rocks in the territory and in the geological section in cratons, folded zones and depressions. The most intense karstification occurs in Paleozoic sediments. Sulfate rocks (gypsum and anhydrite) located on the eastern margins of the East European Craton and adjacent parts of the Ural Foredeep are the most karstified. These deposits are also intercalated with thin layers of limestone and dolomite of the Irenskaya Suite, and to a lesser extent—limestones and dolomites of the Filippovsky Unit of the Kungurian Stage and limestones of the Artinskian Stage of Lower Permian. Salt-bearing and sulfate deposits are mainly found in the Ural Foredeep. Karst development in the Devonian, Carboniferous, and Permian carbonate strata with a total thickness of more than 2000 m is typical for the folded zone of the West Ural and Central Ural uplifts. The western slope of the South Urals is the most intensely karstified. Hypogenic karst cavities occur from the Polar to the Southern Urals on the western and eastern slopes. The article presents the most interesting examples of hypogenic speleogenesis in the Ural.

Keywords Urals · Hypogene speleogenesis · Karst · Cave

Introduction

Indications of hypogenic karst can often be found in the caves of the Urals. Their short review is provided in this chapter. The Urals occupy an immense territory, located in four climatic zones and having a complex geological structure. In Fig. 1, the eastern and western boundaries of the Urals are defined according to Chibilev (2011) and Shakirov (2011). In the Ural region, nine geographic areas are distinguished, these are located in Fig. 1. The division into different regions (Chibilev 2011) is based on geological, geomorphological, structural and tectonic features.

In the Urals, there are almost all types of surface and underground karst features. Rock formations are elongated in the longitudinal direction, which contributes to the comparative analysis of the processes in karst landscapes in different latitudinal geographic zones. The wide distribution of soluble rocks through the territory and in the geological section in cratons, folded zones and valleys predetermined the karst development over the long geological history of the Urals. The most intense karstification occurs

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✉ A. S. Kazantseva
kazanalena@bk.ru

O. I. Kadebskaya
icecave@mi-perm.ru

V. N. Kataev
geoldek@psu.ru

N. G. Maksimovich
nmax54@gmail.com

[1] Mining Institute of the Ural Branch of the RAS, Perm, Russia

[2] Perm State National Research University, Perm, Russia

[3] Natural Sciences Institute, Perm, Russia

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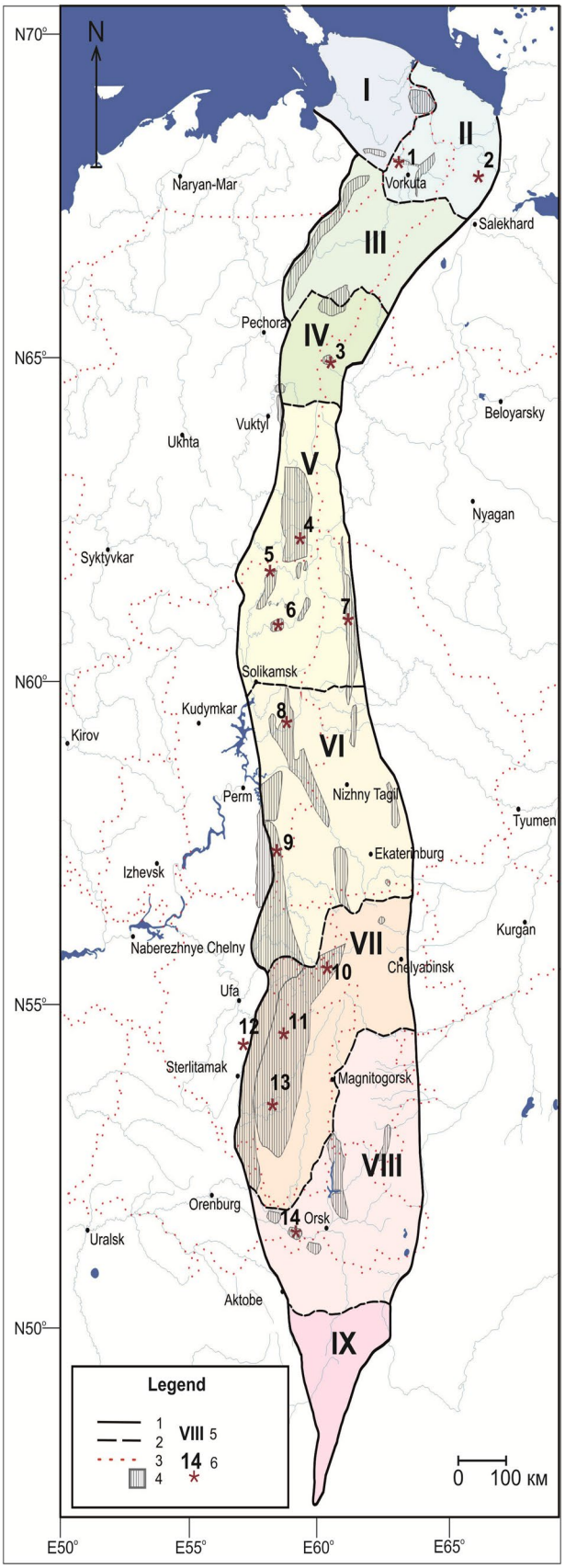

Fig. 1 Location of the main karst areas and hypogene features within the Urals (Chibilev 2011). See Table 1 for specification of areas. 1–3—Boundaries: 1—the Urals physiographic land; 2—regions; 3—administrative; 4—the main areas underlain by soluble formation distribution (karst areas); 5—physiographic region; 6—object with indications of hypogene origin and their numbers: 1—The Pymva-Shor springs; 2—Yanganape and Nyavape ridges; 3—Puyvin cave; 4—The Pechora and Unya rivers valley karst landscape; 5—Larevskie springs; 6—Eranka and Divya caves; 7—karst landscape in the Sosva and Vighai rivers valleys; 8—Mariinskaya, Kizelovskaya (Viasherskaya), Rossiyskaya, and Usvinskaya-1 caves; 9—Ordinskaya Cave and Kungur Ice Cave; 10—Schumiha, Nadezhda and Kurgazak caves; 11—The Zilim river valley karst landscape; 12—Aurgazinsk karst landscape and Vertolyotnaya cave; 13—Shulgan-Tash cave; 14—Kzyladyrsk karst landscape

in Paleozoic sediments. On the eastern margins of the East European Craton and the adjacent parts of the Ural Foredeep, karst is found in sulfate rocks (gypsum and anhydrite) intercalated into thin limestone and dolomite layers of the Irenskaya Suite, and to a lesser extent limestones and dolomite of the Filippovsky Unit of the Kungurian Stage and limestones of the Artinskian Stage of Lower Permian. Salt and sulfate deposits are found mainly in the Urals (Kostarev 1990; Maksimovich and Kostarev 1973).

In the folded zone of the West Ural and Central Ural uplifts, karst development is characteristic in the Devonian, Carboniferous, and Permian carbonate strata of a total thickness of more than 2000 m. The western slope of the Southern Urals is most intensely karstified.

To date, more than 3200 caves with a total length of about 244 km have been registered in the Urals. Morphological indications of hypogenic origin are observed in cavities formed in closed aquifer systems as a result of increased groundwater flow through layers of soluble rocks and in caves associated with zones of tectonic disruptions (Lobanov 1974; Pescheri Povoljya, Urala i Priuralya statisticheskii spravochnik 2010).

In the areas of development of the hypogenic karst, large springs and outputs of deep saline waters are documented, associated with the margins of the major hydrological basins of the Northern and Southern Urals.

Hypogenic hydrothermal cavities that are not associated with surface karst and local surface recharge are also common in the Urals.

Zoning of the Urals and distribution of karst areas and caves are presented in Table 1.

Overview of karst regions

As a result of the research, 14 areas of hypogenic karst manifestation were identified, which are described below.

Table 1 Lithologic types of karst in the physiographic regions and subregions of the Urals with indications of hypogene origin

No.	Physiographic region	Lithology and level of karst study	Key study objects
I	Pay-Khoy Range (Jugorskaya)	Carbonate karst; poorly studied	No objects
II	Transpolar Urals (Zapolyarno-Uralskaya)	Carbonate karst; poorly studied	Pymva-Shor karst springs, Yanganape and Nyavape ridges
III	Polar Urals (Polyarnouralskaya)	Carbonate karst; poorly studied	No objects
IV	Cis Polar Urals (Pripolyarnouralskaya)	Poorly studied	Puyvin cave
V	North Urals (Severouralskaya)	Carbonate karst, well studied	The Pechora and Unya rivers valley karst landscape, Divya, Eranka caves and Larevskiye springs, Karst landscape in the Sosva and Vighai rivers valleys
VI	Mid-Urals (Sredneuralskaya)	Carbonate and sulfate karst; well studied	Kizelovskaya, Mariinskaya, Rossiyskaya, Usvinskaya-1 caves, Ordinskaya and Kungur ice caves
VII	South Urals (Yuzhnouralskaya)	Carbonate and sulfate karst, well studied	Shulgan-Tash, Kinderlinskaya, Khlebodarovskaya, Schumiha caves, Krasny Klyuch spring and Assinskiye springs
VIII	South Urals region (Priyuzhnouralskaya)	Carbonate, sulfate and salt karst; poorly studied	Springs on the Boevaja gora
IX	Mughodzhary Hills and the Mughodzhary region (Mughodzhary)	Carbonate and sulfate karst; poorly studied	Headwaters of the Emba river

The Pymva-Shor springs (1)

On the western slope of the Transpolar Urals, the most northern karst area is Adzva river.

Within the Polar and Transpolar Urals, some cavities were formed due to discharge of thermal waters. Some of them were subsequently buried and filled with sediments. Karst springs with discharges up to 10 L/s occur in the river valleys. The Pymva-Shor springs are a remarkable example (Mityusheva 2010).

Pymva-Shor karst topography is located 2 km above the springs of the same name discharging into the Adzva river (Fig. 2a). The springs of warm mineral water in this area are the most northern in the Urals. Rock outcrops at the banks of the Pymva-Shor river are comprised by Upper Devonian–Lower Carboniferous bituminous limestones. There are seven springs with flow rates ranging from 0.2 to 10 L/s in this area (Mityusheva et al. 2007). According to recent research, waters in the Pymva-Shor springs are of Na–Cl composition and have elevated concentrations of radium (from 0.2 to 1.1 Bq/L). The summer temperatures of the waters vary from 27 to 32 °C. Permafrost is absent in the karst area, and the microclimate favors vegetation uncharacteristic of tundra (Mityusheva et al. 2007).

Caves on the right bank of the Pymva-Shor river are formed in the zone of discharge of thermal waters on the western slope of the Urals Mountains. This territory is referred to exposed (naked) and covered karst types. In the limestone massif, 17–20 m above modern ascending sources, there are six karstic cavities up to 1.5–2.0 m in size. All cavities have a dome-shaped form and traces of the effect of ascending karst waters. Perhaps there was an uplift of the massif, where the caves are located, during tectonic movement, and the unloading of thermal waters moved to the lower part of the limestone cliff (Fig. 3a). River valley cutting into the karstified massif did not affect thermal waters feeding from the underlying horizons. The isotopic signatures show that spring waters are mainly meteoric. The waters in the springs are the result of mixing of highly mineralized chloride (sulfate chloride) sodium waters rising along deep-seated faults with the infiltration waters of hydrocarbonate calcium or calcium–magnesium composition (Mityusheva 2010).

Yanganape and Nyavape ridges (2)

On the eastern slope, more than 100 km north of the Arctic Circle of the Polar Urals, are Yanganape and Nyavape ridges. The elevations of the peaks of Yanganape and Nyavape ranges reach 250–300 m a.s.l. and stand out well among the flat tundra. The surface of the southern Yamal has an undulating topography and absolute altitudes of the surface 55–80 m a.s.l. Cryogenic forms of relief such as frost mounds and thermokarst depressions with shallow lakes and marshes are widely developed here. In the study area, the thickness of permafrost reaches 100–150 m. Geologically, the crests of the Yanganape ridge are composed of old reefs of the Lower Devonian (Khromykh and Belyayev 2010). In this area, the thickness of the Lower Devonian karstified rocks reaches 170 m. Caves are located in the margins of the reef structures surrounded by deep-sea sediments with pelagic fauna and extrusive rocks at the base (Khromykh

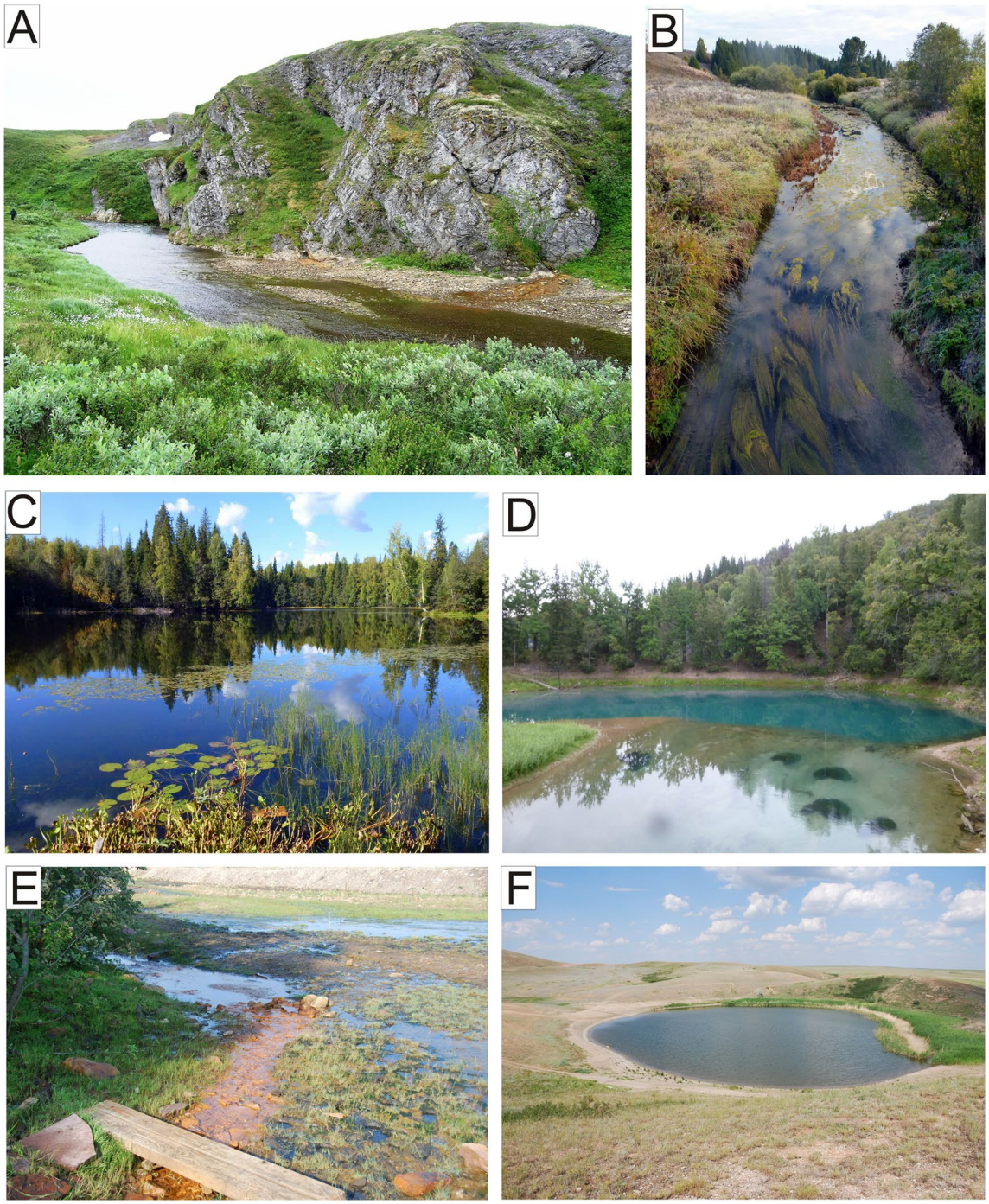

Fig. 2 **a** Pymva-Shor second group of springs in the discharge zone (photo by Mityusheva); **b**, **c** discharge of karst waters in the Durnyatskaya depression; **d** high-discharge spring Krasny Kluch; **e** Assinskiye mineral springs; **f** rising spring on top of a saline dome of Boyevaya Mount

and Belyayev 2010). Reefs are varied in shape and size and are mainly circular or oval in plan and conical in section. A reef's base diameter ranges from 0.5 to 1 km. On the territory of the study, there are six caves with lengths of not more than 35 m. On top of Mount Yanganape, there is a lake with an unusual for permafrost formations depth of 36 m (Fig. 3c).

The development of karst in the area of the Yanganape ridge (the western slope of the Urals) occurred in two stages. Initially, hypogenic cavities were formed soon after the construction of the reef. They were filled with limestone debris, calcite and various volcanic rocks cemented with calcite, hydromica and chlorite materials. Silicon and framboidal pyrite are abundant. Debris of rutile, apatite, pyrite (pyritic

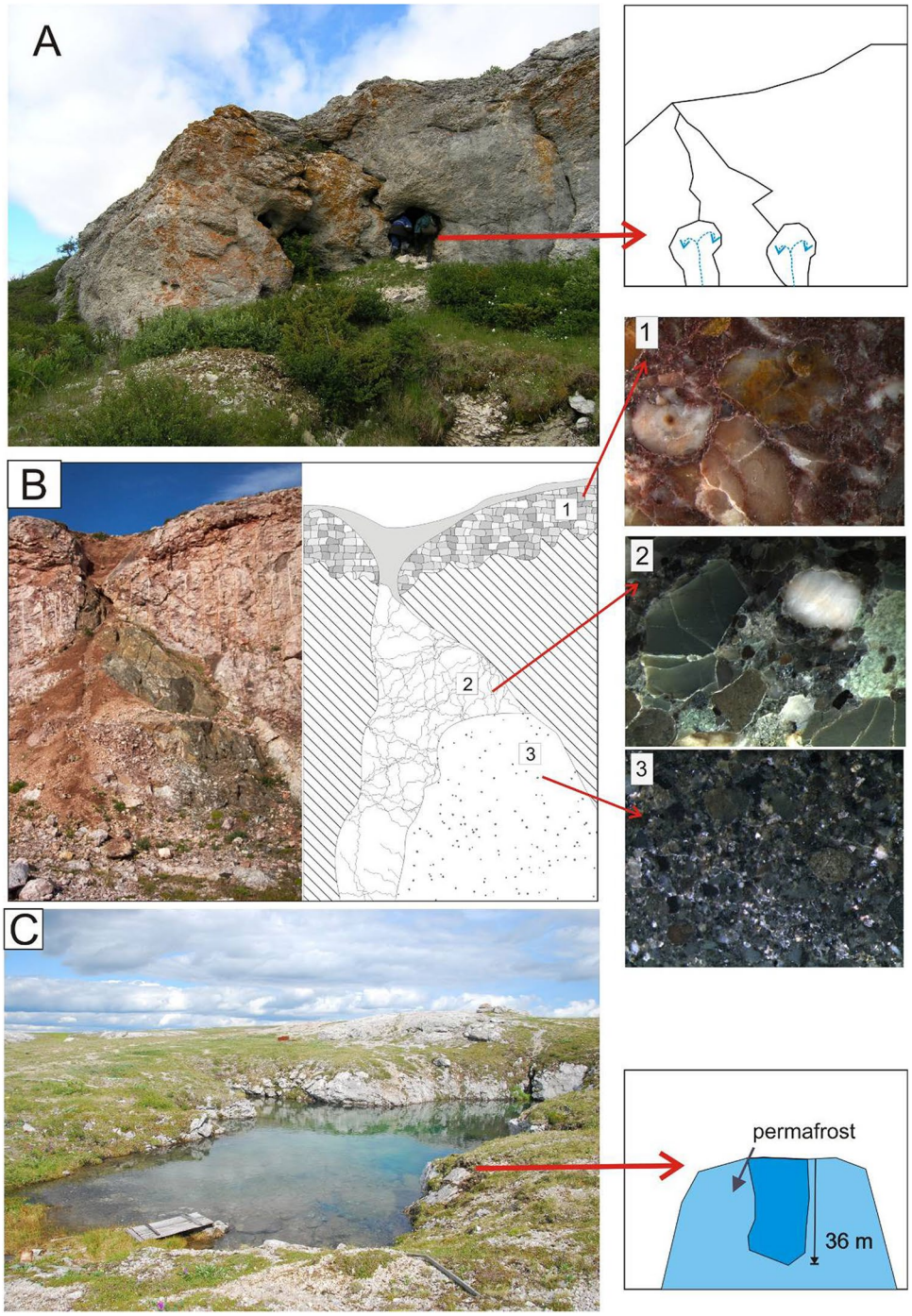

Fig. 3 **a** Caves on the right bank of the Pymva-Shor river formed by rising flow along tectonic fractures (photo by Mityusheva); **b** quarry face in Mount Yanganape, showing the limestone surface overlapped with breccia (1), a karst cavity filled with lithified conglo-breccias (2) and sandstone (3); **c** a 36-m-deep lake on the top of an isolated Yanganape Mountain

ores) are also present (Fig. 3b). Pieces of clay sediments rich in radiolarian skeletons are sometimes encountered. All this signifies deepwater environment and proximity to volcanic sources. Lithification process occurred in the reducing environment in conditions close to greenschist facies of metamorphism (> 100 °C). Newly formed pyrite and probably albite were formed in the process of lithification. Sphen change (leucoxenization) occurred. A 36-m-deep pothole on top of the reef may also signify the ascending discharge of the deep waters during land elevation (Fig. 3c). In modern conditions of permafrost and frost weathering occurred the second stage of karstification.

Puyvin cave (3)

Within ***the Subpolar Urals*** at the Rutilovo upland in the interfluve of the Kobyla-Yu and the Puyva rivers, 100-m-long Puyvin quartz-bearing hydrothermokarst cave occurs in the

Ordovician marbles of the Schugor Suite (Andreychouk and Lavrov 1992; Lavrov and Andreychouk 1993).

On the surface of the plateau, light gray marbles subvertically emerge, to which metamorphic rocks—mica–carbonate–quartz and quartzite shales—are adjacent on both sides. The thickness of the rocks is frequently broken by the diabases, granodiorites, granite porphyries and quartz veins. The veins are elongated-lenticular bodies, extending up to the first hundreds of meters. In the veins and at the contact with the host rocks reveal hydrothermal cavities containing hundreds of tons of rock crystal. The size of the cavities can reach up to 40 m. The host rocks around the quartz veins and cavities are hydrothermally altered. According to Bukanov (1974), the absolute age of the crystalline cavities of the region is 270 million years. The entrances to the cave are wells with a depth of 5 and 6 m with inclined steep walls. The slope of the walls corresponds to the subvertical bedding of the strata. The bottom of the wells represents an extensive, but low (up to 1–1.5 m) the cavity of which through two wells with a height of 5 m can be accessed in the same underlying cavity with a small branches and domes on the arches. In the lower cavity can be observed direct contact vertically bedded marble with quartz residential, as well as crystal-containing cavity therein. The authors in the survey of the cave found that part of the cave's cavities at the contact of marble and quartz veins was formed hydrothermally and syngenetically with cavities of quartz veins. And the vertical wells were formed in later times through the cracks of the subvertical bedding planes of the overlying marbles (Andreychouk and Lavrov 1992; Lavrov and Andreychouk 1993).

The Pechora and Unya river valley karst landscape (4)

In ***the North Urals*** the covered type of karst prevails. Karstified carbonates (limestones, dolomites, dolomite limestones) aged from the Middle Devonian up to the Lower Permian, and sometimes older ones (the Silurian and the Ordovician), occur within the West-Urals folded zone, with a total thickness of 2000 m. This territory had been covered by glaciers several times, which resulted in filling of some of superficial and underground features with glacial deposits.

More than 45 caves have been discovered, the largest of which are Medvezhya, Tufovaya, Ledyanaya, Scheghimskaya, Uniynskaya and Kaninskaya, in the valleys of the Pechora, the Unya, the Ilycha, the Podcheryoma and the Schugora rivers (Geologicheskoe nasledie Respubliki Komi (Rossia) 2008).

The most representative object of hypogene origin of this area is the cave Scheghimskaya. It is located in the area between of the rivers Pechora and Large Scheghim, 1.5 km to the North of the village Scheghim. The entrance to the cave is located on a gentle slope of the limestone massif, which is almost devoid in this place covering deposits at the height of 32 m above the level of the Pechora. The cave is developed in large-layered limestones of upper Devonian age at a clear fracture of the strata stretch 330°, falling in the northeast at an angle of 75°. The modern entrance is also tied to this crack, whose length is 1.5 m and width is 0.7 m. The inner wells are led by an almost vertical well, which quickly expands to the spacious, high hall. The total depth of the well and hall is 20 m. The floor of the hall is covered with a scree of limestone blocks. On the vaults of the hall, the domes were preserved, and on the surface of the walls, there are traces of working with water from below. Therefore, the cavity was formed by the water outlet on the tectonic rift that was later revealed to be the failed well.

Larevskie springs (5)

Larevskie Springs occur in the discharge zone of fissure-karst waters of a gypsum-saline strata. They are situated on the left bank in the lower course of the Nizhnyaya Elovka River, Tcherdynsk Region, Perm Krai (Shestov 2009). Sources of rising saline deep waters have been known since the end of the nineteenth century. Waters of these sources are of chloride sodium composition and have high-salinity, considerable strontium (5.2 mg/L), boron and lithium contents (Shestov 2009).

The Verkhnekamskoe deposit of potassium and magnesium salts is related to the salt formations of the depression. Salt rock formations stretch from north to south for 200 km as a belt of 50 km in width, with total area of 6.5 thousand km^2. In the marginal part of the Verkhnekamskoe salt deposit, groundwater discharge zones are formed. Due to the dissolution of the underlying interlayers of salts, the surface dips, from which the sources flow, have large sizes and a glass-like shape. Salt and gypsum/salt karst widely occur in the region, resulting in the formation of large subsidence and collapse features.

Eranka and Divya caves (6)

In the region, there are 98 caves known in the carbonates of the Devonian, the Carboniferous and the Permian. Cave entrances are located on the slopes of the valleys as well as in sinkholes. The largest caves are Divya (10.1 km), Eranka (500 m), Yazvinskaya (300 m), and Chyornaya (250 m). They are believed to represent output channels of underground streams (Dublyansky et al. 2001). However, Divya and Eranka caves contain the most representative objects with morphological elements of hypogene speleogenesis.

Divya Cave is located on the steep right bank of the Kolva River, 10 km north of Nyrob settlement, Perm region. The entrance is situated at an elevation of 90 m above the river.

It is the longest cave of the Urals. The cave is a maze system of chambers and passages extending from west to east. The cave is developed in the Lower Permian layered silicified limestones of the Sakmar and Artinskian Stages, flat-dipping to north. To the southwest of the entrance, a contact zone of the karstified and non-karstified rocks is exposed in a ravine. Karst waters discharge via numerous springs with rising flow located at the foot of the rocks outcrops. No active flows were documented in the cave. The modern water table is significantly below the level of the cave passages. In the ceilings of some chambers and passages, cupolas and domes are observed.

Within the West-Urals folded zone of the North and Mid-Urals, numerous anticline and syncline structures of nearly north–south strike and local disruptions occur in karstified formations, which favor intense vertical water exchange between aquifers. Areas between ridges are mainly built up of carbonate sediments and are basis of erosion and discharge of artesian waters. Dome-shaped ceilings and rising vertical channels are documented in many caves in this area. We have found spherical solution domes in Eranka Cave in the North Urals (Fig. 4a, b). Eranka Cave is developed in the Asselian and the Sakmarian strata of the Lower Permian. The entrance is located at a height of 20 m on the slope of the southeastern exposition, in 350 m from the mouth of the Eranka river which is a left-bank tributary of the Beryozovaya river. The total length of the cave is 500 m. It is the longest cave in the Beryozovaya river valley. A narrow inclined 20-m-long passage leads from the ice part of the cave to a spherical chamber, where the ceiling height reaches 18–20 m.

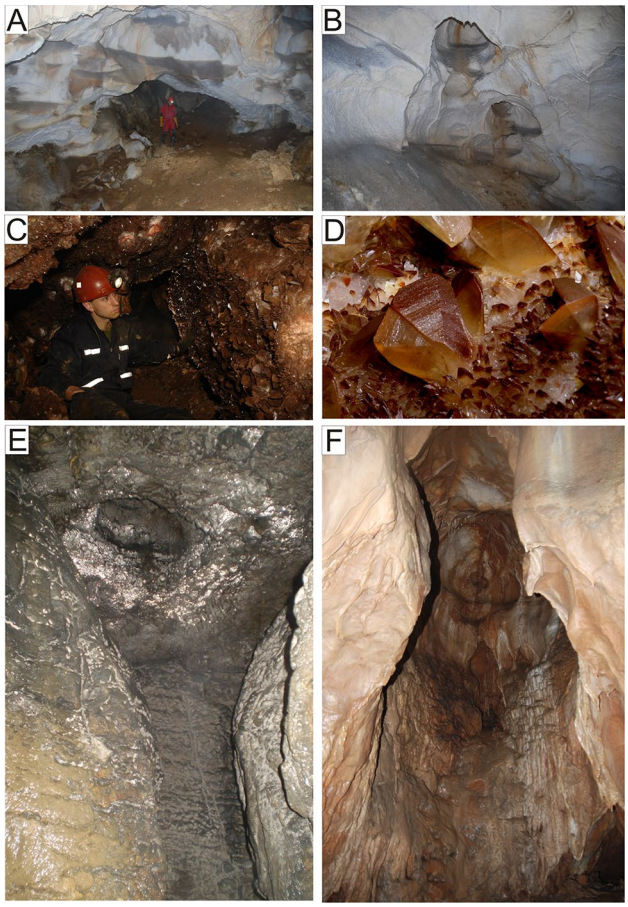

Fig. 4 **a**, **b** Spherical domes and niches in Eranka Cave; **c**, **d** calcite crystals in the karst cavity opened in the Krasnaya Shapochka mine (photo by Tsurikhin); **e** blind chimney in Viasherskaya Cave; **f** blind chimney in Mariinskaya Cave

Karst landscape in the Sosva and Vighai river valleys (7)

On the eastern slope of the Northern Urals in the area of the spreading of rocks, the Vighai River loses some of its runoff in the amount of several cubic meters per second, a significant portion of which is accounted for underflow. Today, more than 70 caves have been studied in the valley of the Vighai River and its tributaries, with a total length of more than 9 km.

Spherical domes have been identified in Tayozhnaya, Saksofon and Lednikovaya caves.

The most remarkable object of hypogenous genesis in the Sosva River valley is the cave of Starateli. The cave is located near the confluence of the tributary of the Sosva River (the Kalya River). The cave length today is more than 600 m (Tsurikhin and Vasil'ev 2013). Despite the small length, the cave is one of the largest (more than 17.5 thousand m^3) caves of the Sverdlovsk region. The lower floors of the caves are canals and are connected to the river. The underground flow of surface and groundwater passes through these channels (Tsurikhin and Vasil'ev 2013).

Mariinskaya, Kizelovskaya (Viasherskaya), Rossiyskaya, and Usvinskaya-1 caves (8)

Within ***the Mid-Urals***, carbonate and sulfate formations are karstified. Karst in the Kizel area is characterized by a rather high activity. Exposed limestones form cliffs up to 100 m high in big river valleys, which occur mostly transversely relative to the folds and faults. The Chusovoy region is the southern extension of the Yayvinsko-Kizelovsky region. The most karstified are dolomites of the Upper Devonian, dolomites and limestones of the Vizean, limestones of the Middle and Upper Carboniferous. Karst features are associated with erosion forms, tectonic disruption zones, contacts of carbonates with non-soluble formations.

Hypogene hydrothermal cavities with volumes of several hundred thousand cubic meters were opened during the development of the Kizel Coal Basin and the Severouralsk

bauxite deposit at depths ranging from 0.2 km to 2.1 km. They are not genetically related to superficial karst topography and surface aquifer. The most remarkable is a karst cavity opened in 1993 in the Krasnaya Shapochka mine at a depth of 700 m (Fig. 4c, d). The cavity is about 60 m long and up to 5 m high, and has a volume of about 1000 m^3. This and other cavities encountered by the mine are lined with calcite crystals up to 7–8 cm in length (Tsyganko et al. 2014).

Kizelovskaya (Viasherskaya) cave is located on the territory of Kizel town on the right bank of the Viashera river, at the foot of a 10-m-high cliff that exposes the Vizean (Lower Carboniferous) limestones. The maze pattern and the presence of rising vertical conduits and cupolas suggest the hypogene origin of the cave. The cave has the length of 7.6 km and depth of 46 m, and consists of more than 90 chambers connected by passages of irregular morphology (Valuysky 2000).

Similar indications of possible hypogene speleogenesis were found in Mariinskaya cave, which is situated in the West-Urals folded zone, 20 km southwest of Kizelovskaya cave. The cave has two entrances that open in an elongated rocky hump composed of the Vizean and Serpukhovian (Lower Carboniferous) massive limestones. The length of passages is about 1 km and depth is 47 m (Valuysky 2000). There are four levels in the cave, connected via smooth conduits and pits, which morphology is indicative of rising flow (Fig. 4f).

Further to the south, in the Chusovskoi region, karst develops in dolomites of the Upper Devonian, dolomites and limestones of the Vizean, and limestones of the Middle and Upper Carboniferous. The region is characterized by disappearing streams and blind valleys, swallow holes, high-discharge springs and caves (Maksimovich 1958). There are 175 caves in the region, the longest of which are Bol'shaya Pashiyskaya (522 m), Tchudesnitsa (512 m). Worthy of noting is Goluboe Ozero (Blue Lake)—a rising spring in which divers explored 240-m-long and 56-m-deep cave.

Ordinskaya Cave and Kungur Ice Cave (9)

The territory of the Yuryuzano-Sylvenskaya depression is unevenly karstified. Karst features are most abundant in the crest and slopes of the depression, where lenses of gypsum and salts among insoluble sediments. An almost continuous strip of karst sinkholes and larger depressions stretches from the Barda River southwards to the Tisa settlement.

Sinkholes are occasionally filled with water and turned into lakes. Saline springs discharge in river valleys (Gorbunova 1979). The Polazninskii-Shalashninskii region is located on the shores of the Kamskoe water reservoir. Karst in this area is mainly developed in gypsums and anhydrites of the Kugurian Stage, and to a lesser extent in the intercalating limestones and dolomites. Landscape of the Durnyatskaya depression is particularly rich in representative karst features, including interconnected lake springs (Beloye, Tchyornoye, Rogolyok, Kamenka) (Fig. 2b, c) that feed various rivers.

The Sylvensko-Serginsky and Irensky regions are situated in the junction area of the Eastern European Craton and the Urals Foredeep. They include the catchment of the lower course of the Sylva River and its tributary the Iren' River. Karst is mainly developed in gypsum and partly in carbonates of the Irenskaya Suite and rarely in the limestones and dolomites of the Solikamskaya Unit. Karst is of open, covered (with eluvium and alluvium) and overlapped (with the Solikamskaya rocks) types. Solution and suffosion sinkholes, trenches, collapse and subsidence sinkholes, depressions, lakes and karst valleys are common landscape features, and karstified fractures, voids and caves occur in the subsurface. Over 100 caves in gypsums and anhydrites are known in the region, among which the largest ones are Kungurskaya Ledyanaya (Kungur Ice Cave) (5.7 km) and Zuyatskaya (1.4 km).

Kungur Ice Cave (Fig. 5) is located at the outskirts of Kungur town, Perm Krai, in the eastern flank of the Russian (Eastern European) Plain, at the junction of two geographical

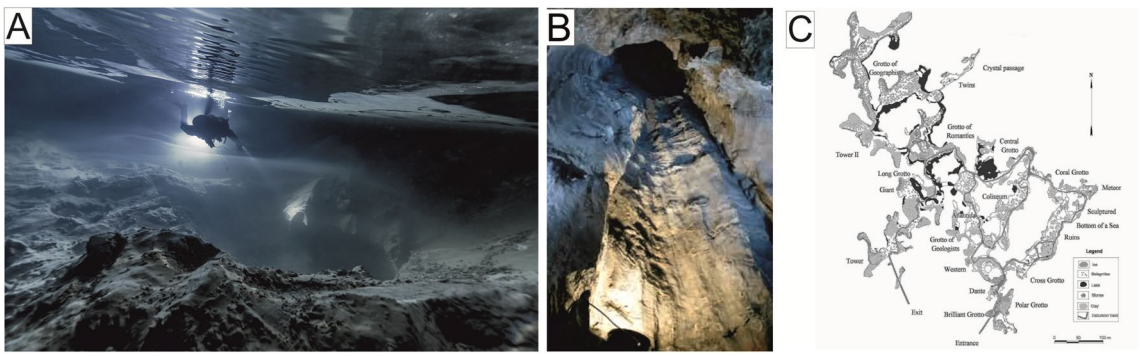

Fig. 5 **a** An isolated cavity in the center is a feeder, still filled with water (photo by Gorbunov); **b** "organ pipe" (22 m high and 3 m in diameter) in the Efirnyi Chamber in the Kungur Ice Cave (photo by Shirinkin); **c** plan of the Kungur Ice Cave

regions, Transvolga Highland and Ufimskoye Plateau (Dublyansky 2005). The rock sequence that contains the cave is around 100 m thick and belongs stratigraphically to the Kungurian Formation of the Permian. The latter is comprised of the Filippovsky Unit (predominantly carbonate) and the overlying Irenskaya Suite (predominantly sulfate).

The cave is a horizontal maze that extends along the side of the Sylva river valley (above its first terrace) extending 700 m into Ledyanaya Mount and 37–80 m beneath its surface. The main feature in the cave is large collapse chambers 30–200 m in length. There are about 70 underground lakes, 12 of which are rather large (130 up to 1500 m^2). Lakes occupy 11% of the cave's total area of 65 thousand m^2. The volume of the cave is 206 thousand m^3 (Kadebskaya 2004).

According to the modern view, the Kungur Ice Cave developed by rising flow from the underlying dolomites of the Filippovsky Unit. According to Andreychouk et al. (1990), "organ pipes" (Fig. 5b) that connect the cave to the above-lying (15–22 m) Ledyanopescherskaya and Nevolinskaya carbonate units formed as outlets from the hypogene system. Later on, the waters of the Sylva River played a role in the development of cavities and dissolution of Ledyanaya Mount. The modern period in the cave's development can be considered as late vadose (Fig. 5c).

Ordinskaya Cave, a largest known underwater cave in gypsum (Fig. 6) located 30 km south of Kungur Ice Cave, is the model object of hypogene speleogenesis. Ordinskaya Cave in the Fore-Urals region is the largest underwater cave of sulfate rocks in the world. The explored length of the cave is about 4900 m.

The regional distribution of karst features indicated that a large amount of recharge entered the lower passages during all stages of development. The groundwater in the cave is aggressive with respect to sulfate. Discharge of water with higher mineralization was documented during the spring floods. During summer low-flow periods, subaqueous springs discharge waters under artesian conditions with a lower solute content. In the cave, the degree of saturation of water increases from the bottom to the top in the spring season and is the reverse in the summer. Seasonal variations in the groundwater chemical composition reflect the contribution from the artesian system. The geological data indicate a strong relationship between the karst features and the regional fault network (Kadebskaya and Maksimovich 2017). Kazakovskaya Gora and Ordinskaya Cave represent unique natural features of great scientific, esthetic, and recreational importance. The cave, which was traditionally considered the result of downward infiltration and lateral groundwater flow, is actually formed by upward flow of artesian water along faults. The location and configuration of the cave were controlled by a diagonal fault system along with northeast trending normal faults. Finding upward-flowing feeder inlets in Ordinskaya Cave that discharge groundwater

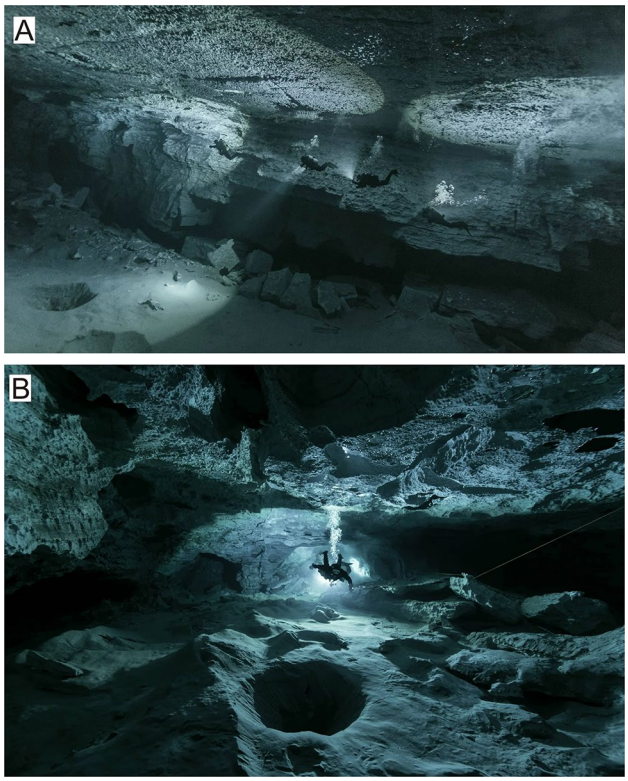

Fig. 6 Underwater part of the Ordinskaya cave (photo by Gorbunov): **a** Big hall; **b** subaqueous springs (feeders) and blind chimney in the lower part of Ordinskaya Cave (feeders)

with high HCO_3 content provides direct evidence that inflow of artesian waters from the Philippian limestones and dolomites continues today. Recharge to this confined aquifer system occurs in the Ufimskoye Plateau. Neotectonic activation induced vertical displacement of blocks and opened passageways for these waters to rise across the sulfate formation and to form caves there. A more complete description of the Orda cave as an object of hypogenic speleogenesis and its plan are presented in chapter 26 « The Role of Hypogene Speleogenesis in the Formation of the Ordinskaya Cave, Fore-Urals, Russia » (Klimchouk 2017).

The Kishertsko-Suksunsky region stretches as a narrow strip from the interfluves of the Sylva and the Shakva rivers to the southern border of the Perm Krai. Total discharge of karst springs with waters of HCO_3 and SO_4 composition is more than 2.5 m^3/s, and the sulfate springs discharge over 0.8 m^3/s. This indicates high karst activity in the region, where overlapped and covered (sub-alluvial) karst types prevail (Gorbunova et al. 1992).

Intense sinkhole formation in Ust'-Kishert' settlement is associated with fresh water influx from the adjacent Ufimsky Swell. Several karst fields with sinkhole lakes are identified in the settlement. In the broader region, large solution depressions are common with marshy lakes in their bottoms.

The biggest lake is Dikoye with dimensions of 400 × 140 m and depth about 7 m. In 1953 in Nizhnyaya Odina village a lake was formed in the bottom of another depression (122 × 94 m) with depth up to 19 m.

The Irgina River valley starting with Kluchi settlement is a discharge zone of fresh waters of carbonate aquifers of the Ufimsky Swell and sulfate aquifers of the Popovskaya Suite. Karst in the right bank of the Irgina River is associated with dissolution of gypsum and anhydrite of the Popovskaya Suite. The degree of karstification increases up to the depth of 125 m, then decreases slightly and remains roughly at the same level up to the depth of 200 m. This is the place where the well-known Brekhovsky Collapse had formed in 1953 in the bottom of the old sinkhole. Originally, it appeared as a collapse shaft with a diameter of 10 m and depth of 46 m (Maksimovich and Gorbunova 1965). Nine caves in various formations are known in the region mainly in gypsums and anhydrites, less often in dolomites. The largest are Varsanofyevoy Cave (200 m long) and Polyakovskaya Cave (200 m; Caves of the Volga region 2010).

Within the territory of Bashkortostan, in the catchments of the Ufa and the Yuryuzan' rivers, the most intense karstification is observed in the right steep slopes of river valleys where gypsum-anhydrite rocks of the Kungurian strata are exposed. Sulfate and carbonate rocks of the Lower Permian are karstified in the watersheds of the Belaya, Ufa and Tyuy rivers, particularly in Shchyuchyeozyorsko-Askinskii and Birskii karst regions.

The Ufimskoye Plateau is situated on the territories of the Perm Krai, Bashkortostan and the Sverdlovsk Region. Karst on this territory falls into carbonate and covered (subeluvial) types. Old depressions filled with clay sediments of the Neogene are preserved on the surface of the plateau.

Twenty caves up to 30 m length are known in limestones of the Artinskian Unit and dolomites of the Filippovsky Unit in the Ufimskoye Plateau within the territory of Perm Krai. In the southern part of the Ufimskoye plateau limestones and dolomites of the Sakmarian, Artinskian and Kungurian Stages are karstified (Abdrakhmanov et al. 2002). Karst is represented by various features, especially in river valleys that cut up to 100–150 m into limestones. Sinkholes are commonly small, and their density does not exceed 10–20 features per km^2.

Overdeepening of the Ufa River valley and neotectonic adjustments created a dense fracture network which channel groundwaters to major drains (Abdrakhmanov et al. 2002). The latter are mainly linear and aligned to faults. In batyphreatic conditions, waters circulate through large karst channels and become confined. Springs with the highest discharges (Krasny Kluch, Sarva, Tyuba and others) are associated with the margins of basins (Fig. 2d).

The greatest amount of caves is found within ***the South Urals***. In the Ufimsko-Blagoveschensk karst region, most of the caves occur in massive and thick-layered gypsums and less often anhydrites of the Kungurian. The majority of cavities are located on the Urshak-Bel'skoye and Ufa-Simskoye interfluves. Caves tend to occur in river valleys and blind creeks and their entrances open in the foot of slopes. Generally, caves are low-angle passages, but seldom maze caves occur. All of them are now in the zone of vertical descending circulation and in the zone of seasonal water table fluctuations, at the level of the Holocene and Upper Pleistocene river terraces. Entrances to many caves are located in sinkholes. Often, there are permanent or perennial flows in them, or evidence of their recent activity. Not infrequently low spots in caves are occupied by lakes that are hydraulically connected with river waters. Sometimes gypsum caves occur within interfluves (Abdrakhmanov et al. 2002).

Schumiha, Nadezhda and Kurgazak caves (10)

Kurgazak karst spring is located on the left bank of the Yuryuzan' River in the Salavat region, 3 km south from "Yangantau" resort, near Komsomol settlement. Water temperature is 15–16 °C throughout the year. The water is of HCO_3–Mg–Ca composition with TDS of 0.4–0.7 g/L. High radon content is measured in the spring, indicating the deep-seated origin of the karst waters (Abdrakhmanov et al. 2002).

In the Tchelyabinsk Region, Sukhoatinskaya Cave is located in the Zilim-Inzer karst area in the Sim River catchment. The cave occurs in limestones of the Silurian and has length of 2130 m and depth of 75 m. It consists of several passages, which extend across the interfluve range almost through and are partly located below the water level of the Sukhaya Atya River (Baranov and Volkov 2012).

Several caves that represent relict springs are found in the Kamenka River valley. The caves in the region were drained after the flow of the Kamenka River had been diverted via a tunnel to the Ay River, to reduce the water flow to a productive coal mine.

As the result, Schumiha Cave (1120 m/− 74 m) became accessible for exploration by speleologists. It is flooded again nowadays.

Nadezhda Cave (250 m) is located 2 km apart from Schumiha and serves as swallow hole for waters of the Kamenka River. Another former spring cave, now drained, is Kurgazakskaya (530 m).

Volkov was the first to describe (oral communication) hypogene speleogenesis within the territory of the South Urals, with regard to Schumiha Cave. The cave represents a former spring that had been drained during the development of a mine. A considerable part of the cave is located below the Ay River level. At present, the cave is hydrodynamically connected with swallow holes formed on the contact of insoluble and carbonate formations. A stream

swallowed from the surface flows beneath the river and then ascends to it along a wing of a syncline. Speleologists recorded rather unusual, as for river-type caves, domes and rising blind chimneys (Fig. 7c, e). Nowadays, the cave is flooded again because of closure of mine exploration works. Abdullin (2009) described hypogene speleogenesis in Khlebodarovskaya (Podarochnaya) Cave (Fig. 7d, f, g). The cave occurs in steeply dipping limestones of the Mid-Carboniferous and represents a system of horizontal and inclined passages of NW and NE directions. The maze pattern, ceiling cupolas and chimneys, abundance of dead-end passages suggest the formation of the cave by upward leakages in the conditions of an artesian aquifer system (Abdullin 2009).

The Zilim river valley karst landscape (11)

The Zilim River swallows into limestones downstream of the mouth of the Kurmazy river, and reappears to the surface downstream of the Ak-Uy River. There are exposed limestones with karren fields, dolines and caves in the Belaya River valley, in the segment from the mouth of the Avzyan River to the Baynazarovo settlement. Karst features are particularly well developed in the NW slope of the Zilair

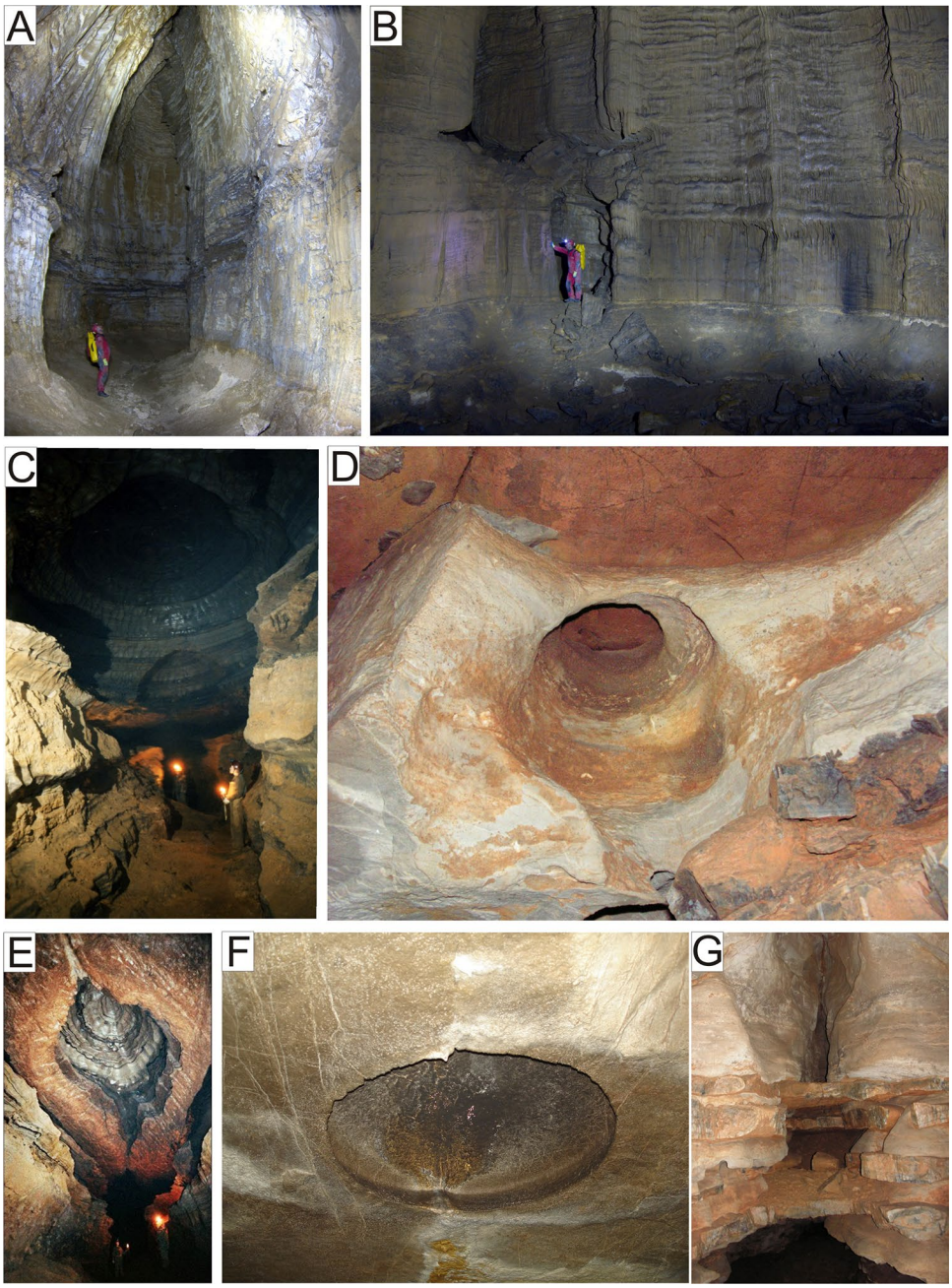

Fig. 7 **a**, **b** Rift-like passage in Kinderlinskaya Cave (the lower part of the cross section is obscured by the sediment fill) (photo by Zanda and Harna); **c**, **e** rift-like passages with spherical dome and rising chimney above them in Schumiha Cave (photo by Volkov); **d** ascending chimney in Khlebodarovskaya cave (photo by Abdullin); **f** dome in Khlebodarovskaya Cave (photo by Abdullin); **g** chert interlayers, forming bridges in the cross section of passages in Khlebodarovskaya Cave (photo by Abdullin)

Synclinorium. In the Zilim River catchment, fourteen large caves are known, including Kinderlinskaya (9113 m) and Oktyabrskaya (1523 m).

Kinderlinskaya Cave is the deepest in the Urals and has amplitude of 215 m (Caves of the Volga region, 2010). The cave is located in the Gafuri region of Bashkortostan, near the mouth of the Zilim River's left tributary, the Kinderlya River. It occurs in the Devonian bituminous limestones on the eastern slope of the Tashastinskaya syncline. The entrance is located on the southern slope of a karst massive.

The cave is characterized by a maze pattern, vertical chimneys, arched ceilings, and other morphological features suggesting its hypogene origin. The cave represents an inclined system of passages developed in north, northeast and northwest directions, and forms four stories. The trapezoid entrance 12×7 m faces south. Cavities are small in area but their height reaches 80–90 m (Fig. 7a, b). The most remarkable are Klassichesky, Atlantida and Figur chambers.

On the western slope of the South Urals, limestones of the Devonian and dolomites are heavily karstified and fractured. Karst features are represented by sinkholes and caves. Numerous sinkholes (with diameters ranging from 3 to 60 m and depths ranging from 1 to 10 m), often oriented along tectonic disruptions and ancient valleys, are arranged in chains stretching across dividing ridges and valley slopes. Density of sinkholes in valleys grows toward mouths (from 5 to 19 features per km^2). Sinkholes are normally filled with diluvium, but sometimes buried sinkholes filled with clay can be observed.

Aurgazinsk karst landscape and Vertolyotnaya cave (12)

Another notable karst region in the South Urals is called Ryazano-Okhlebininsky. In the right bank of the Belaya River, along the Ufa-Sterlitamak railway, dolines, collapse sinkholes, and lakes are observed, mainly concentrated in outcrops of the Kungurian gypsum. Some lakes in thee region periodically disappear. For instance, Ural Lake situated near the Tolbazy railway station disappear every 5–6 years. Also, karst ravines and gorges up to 500 m length and 50 m width (for instance, near the Okhlebinino settlement), as well as blind valleys, characterize this region. Heavily karstified gypsum cliffs are observed along the river banks. The largest cave of the region is Vertolyotnaya (Akhmerovsky Proval) located in the Saryelga river valley within the Ryazano-Okhlebinino Swell. The cave was first explored by Ufa speleologists in 1996. It has length of 1768 m, and amplitude of the dry part is 50 m. Karstified rocks are represented by interlayered sulfates (gypsum and anhydrite) and carbonates (limestones, chalky clays, less often dolomitized limestones). Thickness of carbonate beds varies from 0.05 m to 5 m. The entrance is located in the vertical wall of karst collapse with a diameter of 80 m and depth of 20 m. Cave consists of parallel inclined galleries of the SE orientation with lengths up to 100 m, widths up to 40 m and height up to 6 m. Several passages diverge from the main galleries in the SW direction. Some of them form the dry upper story of the cave. There is a lake with a depth more than 30 m. During river floods the water level rises 4 m above the lake's low stage (Martin et al. 1993). During the initial stage of formation of this cave, ascending leakage of waters from the underlying sediments into the gypsum–anhydrite sequence probably occurred. As the result of dissolution at the bottom of the gypsum-anhydrite bed, large cavities were formed (Fig. 8). A massive collapse that occurred in 1990s has opened the caves to the surface.

Assinskiye mineral wells in the Central-Urals Upland (Fig. 2e) discharge waters from the depth of 950–1000 m. Water is of chloride sodium composition and TDS up to 18–20 g/L has abnormally high helium content, which is by three–four orders of magnitude higher than the background contents.

Shulgan-Tash cave (13)

Shulgan-Tash cave is located on the territory of Bashkortostan within the Southern Urals and is part of the same reserve (Karst Bashkortostan 2002). The cave is a system of galleries, corridors and halls located at three hypsometric levels in a karst massif on the right bank of the Belaya River. The massif is composed of limestones of the Vizean stage of the Lower Carboniferous. The oldest is the middle floor, where the common cavity with the "sinusoidality" vertical profile. The presence of a large number of caverns with brown iron minerals, including goethite, in the cavities of the cave, are hydrogrogite formations of the "glass head" type, which are relicts of sulfide lead–zinc mineralization and are characterized by elevated levels of microimpurities of metals

Fig. 8 Bed of a temporary stream in Vertolyotnaya cave

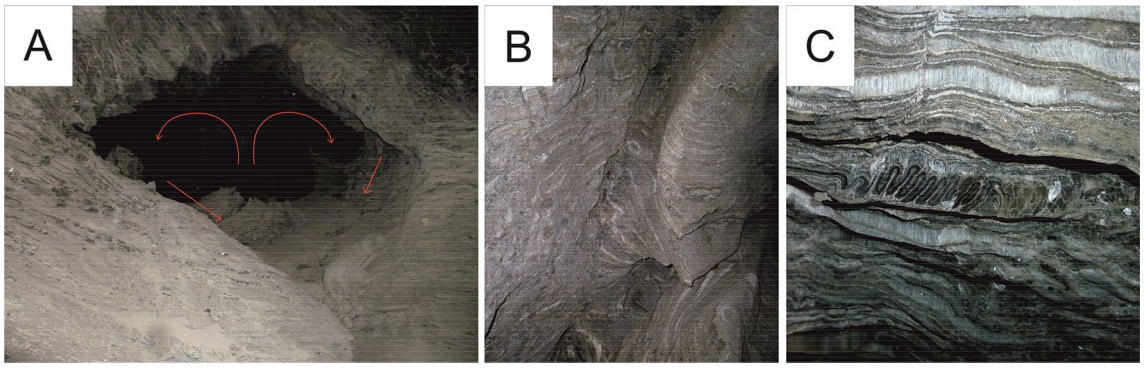

Fig. 9 The morphology of the passages and grottoes in the Confertka cave: **a** the main passages between the grottoes have a rhomb-shaped section; **b** the grotto with dome-shaped cavities on the roof; **c** enterolithic structure of gypsum in the walls of the cave

(Co, Zn, Pb, Ni, Mo, etc.) also confirm the hypothesis of development at the earliest stage (about 3 million years ago) of cavities of the cave under the influence of hydrothermokarst waters (Lyakhnitsky 2006).

"Kzyladyrsk" karst landscape (14)

"Kzyladyrsk" karst landscape is the largest in the Orenburg region in terms of area (18 km^2) and a variety of karst processes in the steppe zone. This section linearly extends in the northwest direction for 16 km from the hill ridge of the watershed between the rivers to the valley of the river Burli; the average width of the area 1–1.5 km with heights from 190 to 375 m (Pavleytchik 2011). There are a large number of caves and grottos. Basically it is a small sub-horizontal cave length up to 330 m. In many grottoes and caves, there are lakes that are part of the underground flow of groundwater. Underground waters are referred to as sulfate–hydrocarbonate–calcium hydrochemical facies, and have a high enough mineralization (more than 2500 mg/L), typical for the areas of development of sulfate karst. In many caves of this region, there are domes formed with underflow from below and rising of underground waters. The most noteworthy in this respect is the Confertka Cave, which is now unwatered. Gypsum has an enterolithic structure, which indicates their long-term recrystallization in flooded conditions (Fig. 9).

Summary

Hypogene karstification occurs where the ascending flow of reactive fluids is structurally and/or stratigraphically focused and where dissolution inducing disequilibrium conditions are supported for a sufficiently long time—mainly in zones of discharge and/or interaction of fluid flow systems and regimes of different nature, depth and scales (Klimchouk 2017). The same manifestations are recorded within the Urals. Hypogene karst processes actively develop in regions underlain by sulfates, carbonates and salt formations throughout the Urals. Even though more than nine thousand publications have been written about the caves of the Urals, there are substantial gaps in understanding of karst evolution such as water exchange conditions, climate, geomorphologic and tectonic history of the territory, and transformation of the soluble formations. Hydrodynamic conditions of confined and unconfined aquifers are ultimately reflected in the morphology of conduits and cavities forming in rocks.

It is unique that in the zone of permafrost in the territory of the Polar Urals there are preserved ancient manifestations of hypogenic speleogenesis, which make it possible to judge the hydrogeological and geological processes in the past. In evaporites (gypsum–anhydrite) of the Permian period, located from the Northern to the Southern Urals, hypogenic karst is characterized by large dips, through which karst waters are discharged from the underlying layers. The ideal model object of modern hypogenic speleogenesis is the Orda cave.

Nowadays, we are in the initial stage of the recognition and interpretation of hypogene karst processes and features in the Urals, and further studies are needed to reveal their actual distribution and importance.

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References

Abdrakhmanov RF, Martin VI, Popov VT et al (2002) Karst Bashkortostana (Karst of Bashkortostan). RA "Informreklama", Ufa (in Russian)

Abdullin SR (2009) Proiyvlenie gipogennogo karsta na Iuznom Urale (Manifestation of hypogene karst in the South Ural). Speleology and Karstology, Simferopol, pp 73–75 (in Russian)

Andreychouk VN, Lavrov IA (1992) Puyvinskaia peschera i problema gidrotermalnogo karsta Rutilovogo plato (Pripolyrnii Ural) (Puyvin cave and the problem of the hydrothermal karst of the Rutilovoye Plateau (Nether-Polar Urals). Paper presented at the 3rd speleological conferences on the research of caves of the Urals, Perm State University, Perm, pp 31–38 (in Russian)

Andreychouk VN, Dorofeev EP, Lukin VS (1990) Organnie trubi v karbonatno-sulfatnoi krovle pescher (Organ pipes in carbonate-sulphate roof of the caves). Pescheri, Perm, pp 16–23 (in Russian)

Baranov SM, Volkov LD (2012) Pescheri Chelyabinskoi oblasti (Caves of Chelyabinsk Region). Abris, Chelyabinsk (in Russian)

Bukanov VV (1974) Gornyi hrustal Pripoljarnogo Urala, Leningrad (in Russian)

Chibilev AA (2011) Ural: prirodnoye raznoobrazie i evro-aziatskaya granica (The Urals: natural diversity and Euro-Asian borderline). UrO RAN, Yekaterinburg (in Russian)

Dublyansky VN (2005) Kungurskaia Lediynaia Peschera: opit rezimnih nabludeni (Kungur ice cave: monitoring observations experience). UrO RAN, Yekaterinburg (in Russian)

Dublyansky VN, Dublyanskaya GN, Lavrov IA (2001) Klassifikacia, ispolzovanie i ohrana podzemnih prostranstv (Classification, use and protection of underground spaces). UrO RAN, Yekaterinburg (in Russian)

Geologicheskoe nasledie Respubliki Komi (Rossia) (2008): Geological heritage of Komi Republic (Russia), Syktyvkar (in Russian)

Gorbunova KA (1979) Morphologiya i gidrogeologiya gipsovogo karsta (Morphology and hydrogeology of gypsum karst). Publishing House of Perm State University, Perm (in Russian)

Gorbunova KA, Kostarev VP, Andreychouk VN et al (1992) Karst i pescheri Permskoi oblasti (Karst and caves of Perm region). Publishing House of Perm State University, Perm (in Russian)

Kadebskaya OI (2004) Geoekologicheskoe sostoyanye Kungurskoi Lediynoi Pescheri i prilegayschei territorii, ee ohrana i ratsionalnoe ispolzovanie (Geoecological state of Kungur Ice Cave and adjacent territory, their protection and rational use). Dissertation, Perm State University (in Russian)

Kadebskaya OI, Maksimovich NG (2017) The role of hypogene speleogenesis in the formation of the Ordinskaya cave, Fore-Urals, Russia. Springer, New York, pp 431–446

Khromykh VG, Belyayev SY (2010) Devonskie rifi vostochnogo sklona Poliyrnogo Urala (Reeves of the Devonian on the eastern slope of the Polar Urals). Litosfera, Moskva, pp 25–34 (in Russian)

Klimchouk AB (2017) Hypogene Karst Regions and Caves of the World. Springer, New York

Kostarev VP (1990) Karst Urala i Priuralya (Karst of the Urals and Cisurals). Dissertation, Perm State University (in Russian)

Lavrov IA, Andreychouk VN (1993) Pescheri Urala i Priuralya (Caves of the Urals and Cisurals). Pescheri, Perm, pp 6–29 (in Russian)

Lobanov YE (1974) Krupneishie pescheri Urala i Priuralya (The largest caves of the Urals and Cisurals). Peschery, Perm, pp 59–63 (in Russian)

Lyakhnitsky YS (2006) Long-term studies of Shulgan-Tash cave by VSEGEI group and Lyakhnitsky Yu. S. RGO, as the basis for the salvation of its Paleolithic painting. Study of the reserved nature of the South Urals. Ufa, pp 331–383

Maksimovich GA (1958) Raionirovanie karsta Urala i Priuralya (Zoning of the karst of the Urals and Cisurals). Paper presented at the 4th Urals physiographical and economical geographical zoning conference, Perm State University, Perm, pp 1–3 (in Russian)

Maksimovich GA, Gorbunova KA (1965) Tipy karsta Urala (Karst types of the Urals). Works of Moscow nature investigators society, Moskva, pp 33–41 (in Russian)

Maksimovich GA, Kostarev VP (1973) Karstovie rayoni Urala i Priuralya (Karst regions of the Urals and Cisurals). Voprosy fizicheskoy geografii Urala, Perm, pp 166–177 (in Russian)

Martin VI, Smirnov AI, Sokolov YV (1993) Pescheri Bashkirii (Caves of Bashkiria). Pescheri, Perm, pp 30–59 (in Russian)

Mityusheva TP (2010) Geochemical and isotopic characteristics of waters of hydrosulphuric springs Pre-Ural Foredeep (Russia). In: Birkle P, Torres-Alvarado IS (eds) Proceedings of the 13th international conference on water–rock interaction, Guanajuato, Mexico, 16–20 August 2010. CRC Press, Taylor & Francis Group, pp 407-410

Mityusheva TP, Simakova YS, Lavrushin VY (2007) Mineral formation in the springs of the mineral waters of the European North-East. In: Bullen TD, Wang Y (eds) Proceedings of 12-th symposium on water–rock interaction (WRI-12), vol 1, Kunming, China, pp 437–440

Pavleytchik VM (2011) Karstovie landshafti Yuznogo Preduralya (Karst landscapes of the South Cisurals). UrO RAN, Yekaterinburg (in Russian)

Pescheri Povoljya, Urala i Priuralya statisticheskii spravochnik (2010) Caves of the Volga region, Urals and Cis-Urals: statistical databook, Naberezhnye Tchelny (in Russian)

Shakirov AV (2011) Fiziko-geograficheskoe raionirovanie Urala (Physiographic zoning of the Urals). UrO RAN, Yekaterinburg (in Russian)

Shestov IN (2009) Larevskiye istochniki i ozera (Larevskiye springs and lakes). Geologitcheskiye pamyatniki permskogo kraya: encycl. UrO RAN, Perm, pp 474–476 (in Russian)

Tsurikhin EA, Vasil'ev SN (2013) Issledovanie pescher Sosvinskogo podraiona Severo-Uralskogo speleologicheskogo raiona (Study of the caves of the Sosvinsky subdistrict of the North-Ural speleological region). ASU magazine, pp 16–20 (in Russian)

Tsyganko MV, Khalevin AN, Tsurikhin EA (2014) Karstovaia polost v shahte "Krasnaya Shapotchka" (Karst cavity in "Krasnaya Shapotchka" mine). ASU magazine, pp 26–27 (in Russian)

Valuysky SV (2000) Pescheri Permskoi oblasti (Caves of Perm Region). Bank kulturnoy informacii, Yekaterinburg (in Russian)