

## Chapter II.11

### GYPSUM KARST OF THE PRE-URAL REGION, RUSSIA

Vjacheslav Andrejchuk

#### 1. General characteristics

Gypsum karst is a widespread phenomenon in the Ural region, predominantly along its western periphery. Sulphate rocks belong to various evaporitic formations deposited during different epochs of the Palaeozoic, from the Silurian to Permian. They occur within the sedimentary cover within a few hundred metres of the surface throughout a vast area, stretching from the arctic Novaja Zemlja Islands to the hot deserts of the pre-Caspian region. In tectonic terms, their extent corresponds to the western flank of the Eastern-European Platform and the adjacent Ural Foredeep.

Silurian, Devonian and Carboniferous sulphate rocks are overlain everywhere in the region by a thick cover of Permian deposits, that also contains abundant sulphate. The latter are commonly close to the surface and display well developed karst features. However, the areas where gypsum karst is found at the surface are small, relative to the area where sulphates are present within the upper few hundred metres of the geological sequence.

The largest areas of shallow gypsum occurrence (and hence of prominent karst features) lie within the Middle Pre-Urals (Fig.1), where the gypsiferous rocks form two areas of different size: a western area (within the platform flank) and an eastern area (within the foredeep). The tectonic and stratigraphical positions of gypsiferous sequences are shown in Fig.2 (which corresponds to the line A-B on Fig.1-C). The sulphate rocks of the Middle Pre-Urals are Early Permian (Kungurian) in age. The Kungurian Formation consists mainly of evaporites, and within it the Iremsky Member is composed entirely of gypsum intercalated with carbonates (Fig.3). Karst processes proceed most intensely at depths of 150-180m. In many places the upper part of the gypsiferous sequence has been destroyed by karstification, leaving characteristic karst breccias.

The settings of gypsum karst development depend mainly upon the depth of surface erosional entrenchment into the sulphate sequence. In most of the area river valleys incise quite deeply, but their floors remain within the sequence. Locally rivers incise down to the underlying carbonates of the Artinsky Formation. Such settings determine particular features of the hydrodynamics, including the presence of vadose and phreatic zones, the type of active groundwater circulation, the extent of recharge from the surface on inter-valley massifs and the degree of discharge along the river valleys.

Regional trends of gypsum karst development are related to the occurrence of sulphates on both sides of the Ufimsky Swell and to the hydraulic connections between karst groundwaters within carbonate rocks in the axial area of the structure and those within sulphates at the sides (see Fig.2). The axial area (locally known as the Ufimsky Plateau), is higher, and physically separates the two areas of sulphates. It is an extensive recharge area, while the western and eastern slo-

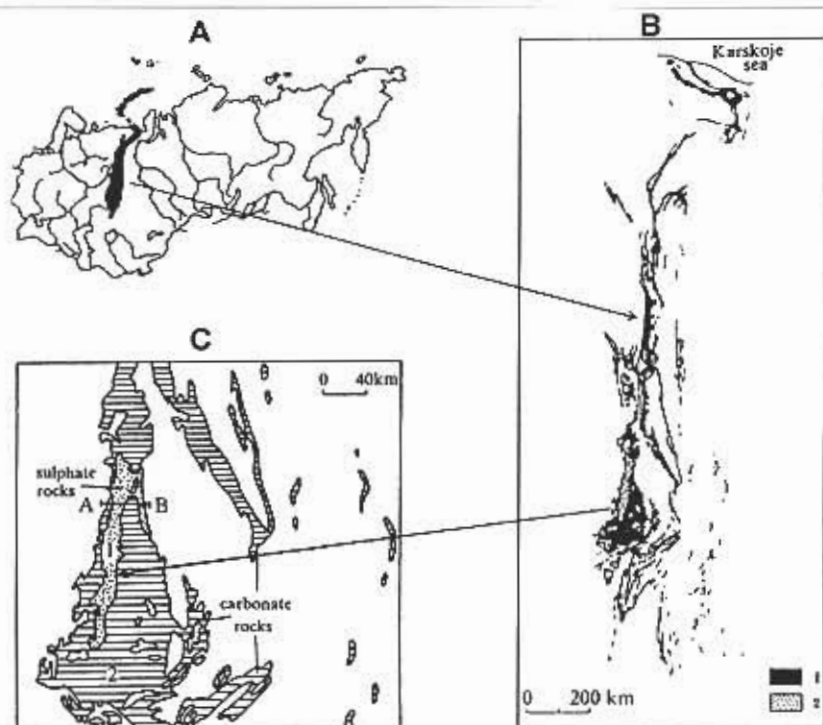


Fig.1. Location of gypsum karst areas in the Middle Pre-Urals: A = Urals on the map of the former USSR; B = distribution of carbonate (1) and sulphate rock in the Urals region; C = gypsum karst areas in the Middle Pre-Urals.

pes of the structure are essentially discharge zones (Fig.4). On the western slope large karst springs commonly lie along the contact between sulphate and carbonate rocks, while on the eastern slope the whole of a narrow, elongated area of sulphates along the contact with the carbonate rocks is the discharge zone for groundwaters from the Ufimsky Plateau. Springs are commonly of upwelling type.

The western area of gypsum karst in this region stretches from north to south for almost 200km, with a width between 20-40km. Most of the area is drained via the valleys of the Sylva and Iren' rivers, which entrench into the sulphates to depths of 30-90m locally. The thickness of the sulphate sequence reaches 100-150m, and it is covered by 0-50m of eluvial and karst-breakdown deposits. Inter-valley massifs comprise relatively flat and slightly hilly plateaux, with patterns of dry valleys and dolines. The thick cover of loose sediments allows thick soils to form, although the stage of drainage development and surface run-off locally determines the dryness of the land. This influences the formation of stepp and stepp-forest landscapes whereas, according to general climatic zonation considerations, there should be southern taiga and mixed forest landscapes in this area, as represented in adjacent non-karstified areas.

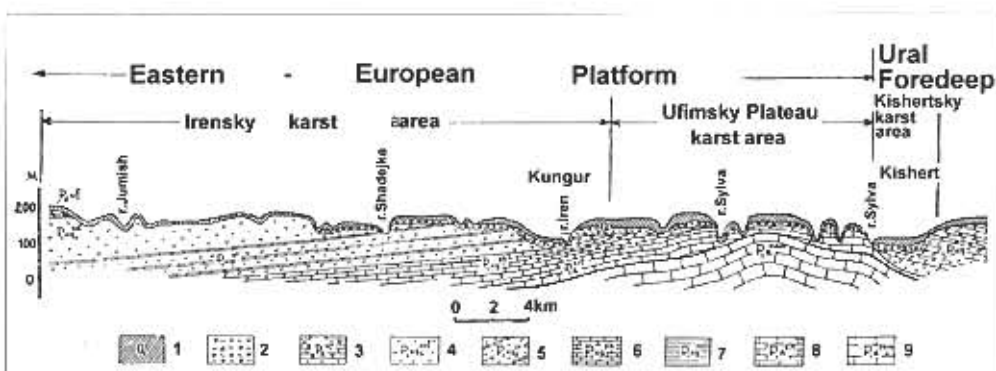


Fig.2 Geological section of the Ufimsky Swell at the latitude of Kungur city (After V.S.Lukin). 1 = alluvial and fluvioglacial terrace deposits; 2 = karst-collapse deposits; 3, 5, 7 = terrigenous rocks of different ages; 4 = sulphate rocks (gypsum and anhydrite with limestone beds); 6 = carbonate rocks (limestone, dolomite); 8 = reef limestone; 9 = silicified limestone.

Water tables within the karst aquifers lie at depths of 30-80m, depending upon local relief. The discharges of the karst springs are commonly within 1-40 L/s, some reaching 100 L/s and more. Karst waters have an  $\text{SO}_4\text{-Ca}$  composition and TDS contents between 2 to 3 g/L.

The superficial karst morphology is quite varied. On the rocky outcrops of the rivers Iren', Asla and Sudinka, rillenkarren develop. On the inter-valley massif between the Asla and Sudinka rivers there are fissure-like and cylindrical pits up to 20m deep. However, dolines are the most typical landforms. Their diameters normally range between 5-30m, but locally reach 50-100m or more. Depths commonly lie within the range 1-2 to 10-15m. Doline density varies between 50-250 units per  $\text{km}^2$ . The highest densities are recorded in zones aligned along the valleys, and numbers decrease towards the watersheds, according to the increase in overburden thickness. Dolines commonly form fields, or are aligned along tectonic lines. Fluvio-karstic ravines, also characteristic for the area, are drained by large dolines.

Some 150 caves in gypsum have been explored within the western area, the longest being Kungurskaja (5600m), Zujatskaja (1410m), Nizhnemikhajlovskaja (1400m), Kichmenskaja Ledjanaja (470m) and Bol'shaja Mechkinskaja (350m).

The eastern area corresponds to the narrow junction belt between the Eastern-European Plain and the Ural Foredeep (see Fig.2). The sulphate rocks dip toward the foredeep where they are replaced by terrigenous sediments. The whole area is a discharge zone for karst groundwaters from the Ufimsky Plateau (Fig.4). Deep water discharges as surface springs, and also passes into alluvium and karst breccias. When passing into the sulphates, fresh  $\text{HCO}_3\text{-Ca}$  waters derived from the adjacent carbonates acquire an  $\text{SO}_4\text{-Ca}$  composition and their TDS content increases to 2.6-3.0 g/L. The total spring discharge in this relatively small area exceeds  $2\text{m}^3/\text{s}$ .

Superficial karst forms are quite varied and include dolines, karst valleys and lakes. Karst depressions are also quite typical of the area. They reach 1-2km in lateral dimensions and are loca-

Lithology	Strata
0 20 40 60 80	Lunezsky: <i>gypsum, anhydrite</i>
80	Tjujsky: <i>limestone, dolomite</i>
100 120	Demidkovsky: <i>gypsum</i>
140	Jelkinsky: <i>dolomite</i>
160	Shalashninsky: <i>gypsum, anhydrite</i>
180	Nevolinsky <i>dolomite</i>
	Ledjano-Peschersky: <i>gypsum, anhydrite</i>

Fig.3. Divisions of the Iremsky Member of the Kungurian Formation (After Gorbunova et al, 1992).

ted along the contact between carbonates and sulphates in areas of focused discharge of the karst groundwaters. There are some large upwelling karst springs and lakes at the bottoms of the depressions, which give rise to small rivers that connect adjacent depressions, producing elongated karst-erosional valleys (Fig. 5). These depressions resemble poljes in terms of size, morphology and hydrology. The largest depressions are Nizkovskaja, Dreminskaja, Burtzevskaja, Masuevskaja and Suksunsko-Sovetinskaja.

Within the eastern area seven relatively small caves have been explored. The longest is Varsanofjeva Cave (200m), located in the Masuevsky depression. Its entrance is located at the foot of the collapse called Volchja Jama (Wolf's Pit), which is 50m deep and 100m in diameter.

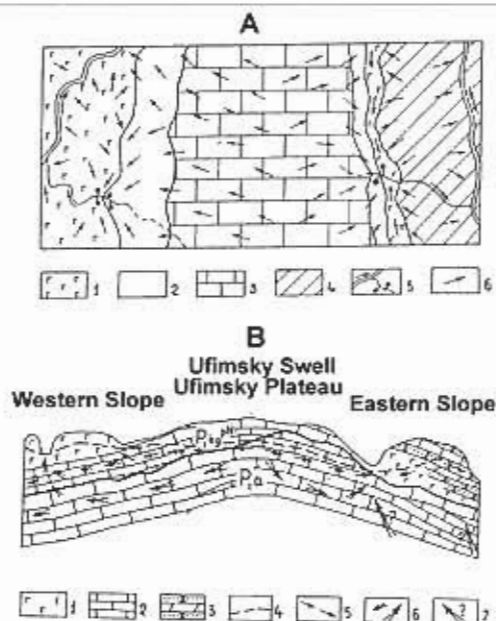


Fig. 4. The general scheme of groundwater circulation within the Ufimsky Plateau (After Turyshev, 1962). A = plan: 1 = sulphate rocks of the western and eastern slopes of the Ufimsky Plateau; 2 = karst-breakdown deposits, karst breccias; 3 = carbonate rocks; 4 = terrigenous rocks of the Urals Foredeep; 5 = river courses and karst springs; 6 = directions of groundwater flow. B = profile: 1 = sulphate rocks; 2 = carbonate rocks; 3 = terrigenous rocks; 4 = potentiometric surface of groundwaters; 5, 6, 7 = directions of groundwater flow.

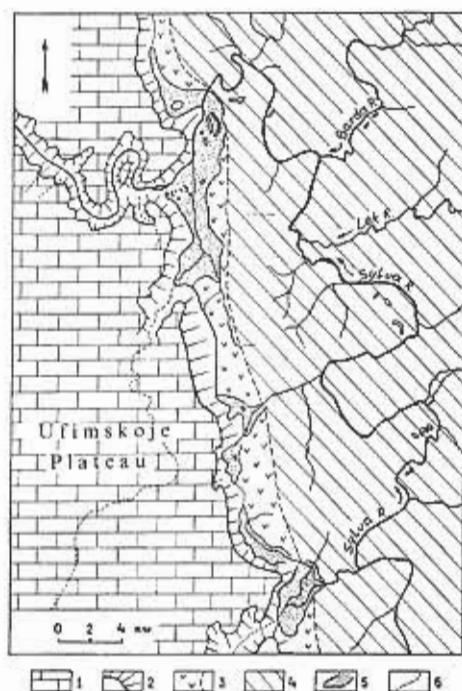


Fig. 5. The area of sulphate rocks with karst depressions on the contact between carbonate rocks of the Ufimsky Plateau and terrigenous rocks of the Ural Foredeep. 1 = carbonate rocks, 2 = slopes of the Ufimsky Plateau, 3 = terrigenous rocks, 4 = karst (fluviokarst) depressions with large springs in their floors, 6 = dry valleys.

The gypsum karst of the Middle Pre-Urals is remarkable in many respects. Below only some aspects specific to the region are briefly outlined.

## 2. The fissure structure of sulphate rocks and karstification

The sulphate rocks of the Pre-Urals, have experienced several cycles of uplift-subsidence, gypsum-anhydrite-gypsum conversions, and re-crystallisation during Mesozoic and Cainozoic times. This, along with other factors such as the stratification of the sequences, determines the distribution within them of zones of enhanced fissuring. Not only tectonic, but also lithogenetic, bedding and unloading fissures are well-developed. For this reason fissure permeability tends to be rather homogenous and isotropic. Such structural conditions have played an important role in determining particular features of speleogenesis. The high density of partings favours rapid saturation of the circulating waters and prevents development of substantial caves below the zone of active circulation. Large caves, such as the Kungurskaja Cave, are located within the zone of water table fluctuations and lateral groundwater circulation. Caves in the region are characterised by comparatively small dimensions and an abundance of breakdown, which complicates speleological investigations. The type of fissuring described above is the main reason that large maze caves, like those developed in the relatively more massive gypsum, with distinct fissuring, in the Western Ukraine, are not formed in the Pre-Urals.

### 3. Morphogenesis of river valleys

Valleys of relatively large rivers (Sylva, Iren', Babka) change their morphology sharply when they enter the gypsum karst areas. Whatever the shapes of the valleys outside these limits (whether symmetrical-terraced, V-shaped or canyon-like), within the gypsum karst areas they become wide and assume a trough shape. Valley floors (lower terraces) reach 0.5 to 3km in width, while outside the limits of the gypsum karst areas their widths do not exceed 0.1km. River beds take on a meandering form, and old meanders are abandoned, leaving ox-bow ("mort") lakes. The valley sides are steep, and one side tends to be cliff-like, 50-90m high, displaying rocky outcrops with numerous fissures and caves. The trough-like valley morphology influences the hydrological regime of the rivers. It reduces high flow rises in water level elevation, as water is able to flood across a wide valley floor and backflood into internal parts of the karstified massifs, where water tables are a few meters lower during such periods. The step-sided shapes and the widening of valleys within the gypsum areas can be explained by the effects of active dissolution and erosion at the bases of gypsum outcrops and by rapid wall retreat due to breakdown, followed by dissolution of gypsum clasts by river water.

### 4. Speleogenesis

Caves in the gypsum karst of the Pre-Urals were formed in different settings. The most extensive caves (Kungurskaja, Novomikhajlovskaja and others) developed in the near-valley parts of the massifs, in the zone of water table fluctuations related to backflood intrusion of fresh river water. This view is supported by the shapes of passage cross-sections, which display horizontal notching (Fig.6). Studies have shown (Lukin, 1967, Andrejchuk, 1992) that such polygonal cross-sections form due to notching at the water table caused by hydrochemical stratification of water in cave lakes, and due to the localised protective action of fine-grained sedimentary cover deposited on inwardly inclined facets (1).

Flat ceilings in polygonal cross-section passages have formed due to water table fluctuations. When the water table rises, water dissolves pendants and protrusions, creating flat surfaces that can be traced throughout extensive areas.

Polygonal cross-sections, which are so typical of the caves in this region, represent a combination of flat ceilings and inclined walls. The process of their formation, and the complication superimposed on the background by the gradual lowering of average and high-flow river water and water table levels, are shown schematically in Fig. 6. In large caves that develop during prolonged periods, the passage cross-sections acquire complex shapes, with numerous wall notches and flat surfaces at various ceiling levels. Thus, polygonal cross-sections appear to provide strong evidence of cave development within the water table zone.

(1) See chapters I.5 and II.6 for an alternative explanation of facets and flat ceilings, which involves natural convection effects (Editor's note).

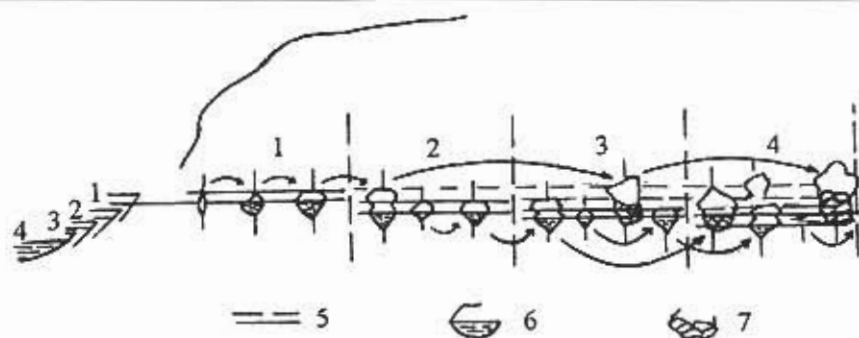


Fig. 6. Development of polygonal cave passage cross-sections in a gypsum massif entrenched by a river valley.

## 5. The evolution of sulphate karst

The sulphate karst of the Pre-Urals has been developing under continental conditions since Mesozoic times. During this period repeated cycles of uplift and subsidence have occurred. This cyclicity has resulted in the presence of over-deepened valleys (up to 60m) that have subsequently been filled with Neogene sediments, karstified horizons that occur well below the recent erosional base level (2), lithified karst breccias, and numerous areas of breakdown.

A significant feature that results from this prolonged sulphate karst evolution is the presence of various sedimentary and residual rock accumulations. Locally, within the intervalley massifs and in old karst depressions, white and coloured Neogene clays, and quartz sands and gravels occur. Everywhere the sulphate rocks are covered by clayey-carbonate deposits (5-50m, and locally more, in thickness), representing the residual material produced during disintegration of the upper parts of the sulphate succession. These deposits are composed by residual clays and clasts of dolomite and limestone that were originally interbeds within the sulphates and have been broken in the course of cavity development. The thickness of such cover is greatest within the Ufimsky Plateau (see Fig.2) where, during the Mesozoic and Cenozoic, the sulphate sequence was wholly disintegrated due to the effects of the most active uplifts. The disintegration process is illustrated in Fig. 7.

(2) Such horizons can also be a result of recent intrastratal karstification; see Chapter 1.4 (Editor's note).



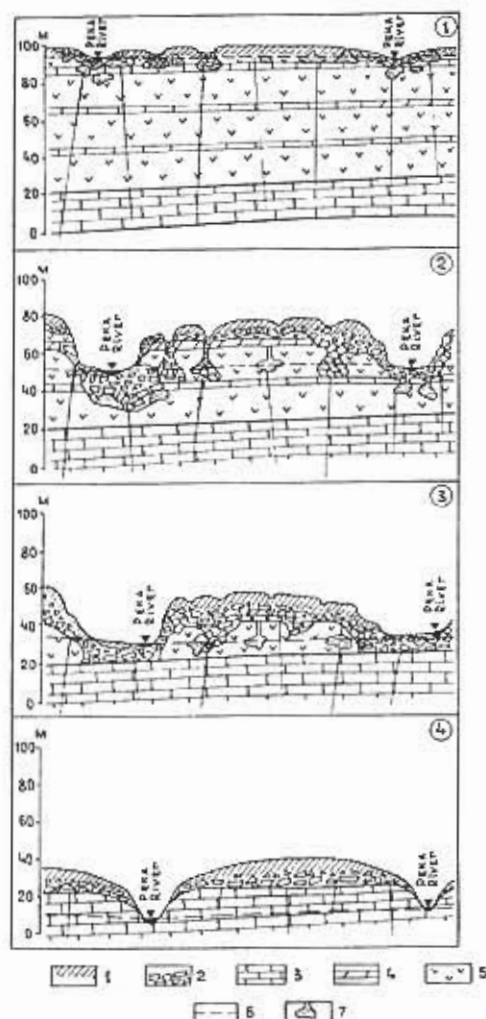


Fig. 7. Karstic disintegration of sulphate rocks within an intervalley massif.

- 1 = loose eluvial sediments (clays, loams),  
 2 = karst breakdown deposits,  
 3 = limestone,  
 4 = dolomite,  
 5 = sulphate rocks,  
 6 = groundwater level,  
 7 = underground cavities.

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