U

UKRAINE GYPSUM CAVES AND KARST

The extensive gypsum karst in the western Ukraine is renowned for its giant maze caves. It is internationally important as a model example of artesian speleogenesis (Klimchouk, 2000b). The region contains the five longest gypsum caves in the world. The host gypsum bed, ranging from a few metres to more than 40 m in thickness, is the main component of the Miocene evaporite formation that girdles the Carpathians to the northeast. The gypsum occurs on the southwestern edge of the Eastern European platform, where it extends along the Carpathian Foredeep for over 300 km in a belt ranging from several kilometres to 40–80 km wide (Figure 1). It occupies over 20 000 km^2, together with some separated areas that occur to the northeast of the unbroken belt.

Most Miocene rocks along the platform margin rest on the eroded terrigenous and carbonate Cretaceous sediments. The Miocene gypsum bed is variable in structure and texture. Most commonly it grades from microcrystalline massive gypsum in the lower part through to variably grained bedded gypsum in the middle, to megacrystalline rock in the upper horizon. A layer of evaporitic and epigenetic limestone, locally called “Ratynsky”, commonly overlies the gypsum. This layer ranges from half a metre to more than 25 m in thickness. The gypsum and the Ratynsky limestone comprise the Tyrassky Formation, which is overlain by the Upper Badenian unit, represented either by argillaceous and marly limestones and sandstone or, adjacent to the foredeep, by marls and clays of the Kosovsky Formation. The total thickness of the capping marls and clays ranges from 40–60 m in the platform interior to 80–100 m or more in the areas adjacent to the regional faults that separate the platform edge from the foredeep.

Ukraine Gypsum Caves and Karst: Figure 1. Location of the gypsum karst of the Western Ukraine.

The present distribution of Miocene formations and the levels of their denudation exposure vary in a regular manner from the platform interior towards the foredeep. The Tyrassky Formation dips 1–3° towards the foredeep and is disrupted by block faults in the transition zone. To the south and southwest of the major Dniester Valley, large tectonic blocks drop down as a series of steps, the thickness of the clay overburden increases, and the depth of erosional entrenchment decreases. Along the tectonic boundary with the foredeep the Tyrassky Formation drops to a depth of 1000 m or more. This variation—he result of differential neotectonic movement—played an important role in the hydrogeological evolution of the Miocene aquifer system, and resulted in the differentiation of the platform edge into four zones. The gypsum was entirely removed by denudation within the first zone, but the other three zones represent distinct types of karst: entrenched, subjacent, and deep seated (Klimchouk, 2000b). The gypsum bed is largely drained in the entrenched karst zone, is partly inundated in the subjacent karst zone, and remains under artesian confinement in the deep-seated karst zone.

In hydrogeological terms the region represents the southwestern portion of the Volyno-Podolsky artesian basin (Shestopalov, 1989). The Sarmatian and Kosovsky clays and marls serve as an upper confining sequence. The lower part of the Kosovsky Formation and the limestone bed of the Tyrassky Formation form the original upper aquifer (above the gypsum), and the Lower Badenian sandy carbonate beds, in places together with Cretaceous sediments, form the lower aquifer (below the gypsum), the latter being the major regional one. The hydrogeologic role of the gypsum unit has changed with time, from initially being an aquiclude, intervening between two aquifers, to a karstified aquifer with well-developed conduit permeability (Klimchouk, 1997a, 2000a, b). The regional flow is from the platform interior, where confining clays and the gypsum are largely denuded, toward the large and deep Dniester Valley and the Carpathian foredeep. In the northwest section of the gypsum belt the confined conditions prevail across its entire width. In its wide southeast section the deeply incised valleys of Dniester and its left-hand tributaries divide the Miocene sequence into a number of isolated, deeply drained interfluves capped with the clays (Podol'sky area). This is the entrenched karst zone where most of the explored, presently relict, maze caves are located. To the south-southeast of the Dniester (Bukovinsky area) the gypsum remains largely intact and is partly inundated (the subjacent karst zone). Further in this direction, as the depth of the gypsum below the clays increases and entrenchment decreases, the Miocene aquifer system becomes confined (the deep-seated karst zone). In this zone the groundwater flow pattern includes a lateral component in the lower aquifer (and in the upper aquifer, but to a lesser extent) and an upward component through the gypsum in areas of potentiometric lows, where extensive cave systems develop, as evidenced by numerous data from exploratory drilling.

Eleven large caves over 2 km in length are known in the region (see Table). Most of these caves are located north of the Dniester River. Two other large caves, Zoloushka and Bukovinka, occur in the Bukovinsky region, near the Prut River and the border with Moldova and Romania, generally in the area of artesian flow within the Miocene aquifer system but within local, particularly uplifted blocks, where entrenchment into the upper part of the gypsum caused unconfined (water-table) conditions to be established in the Holocene. Most of the caves have only one entrance, either through swallow holes at the interfluves or from gypsum outcrops in the slopes of the major valleys. Some caves and their entrance series were known to local people from time immemorial (e.g. Ozernaya, Kristal'naya, Mlynki, Verteba), but others were discovered by cavers via digs (e.g. Optimistychna, Slavka, Atlantida). Two caves (Zoloushka and Bukovinka) became accessible when opened by gypsum quarries. Systematic cave exploration and mapping in the region began in the 1960s.

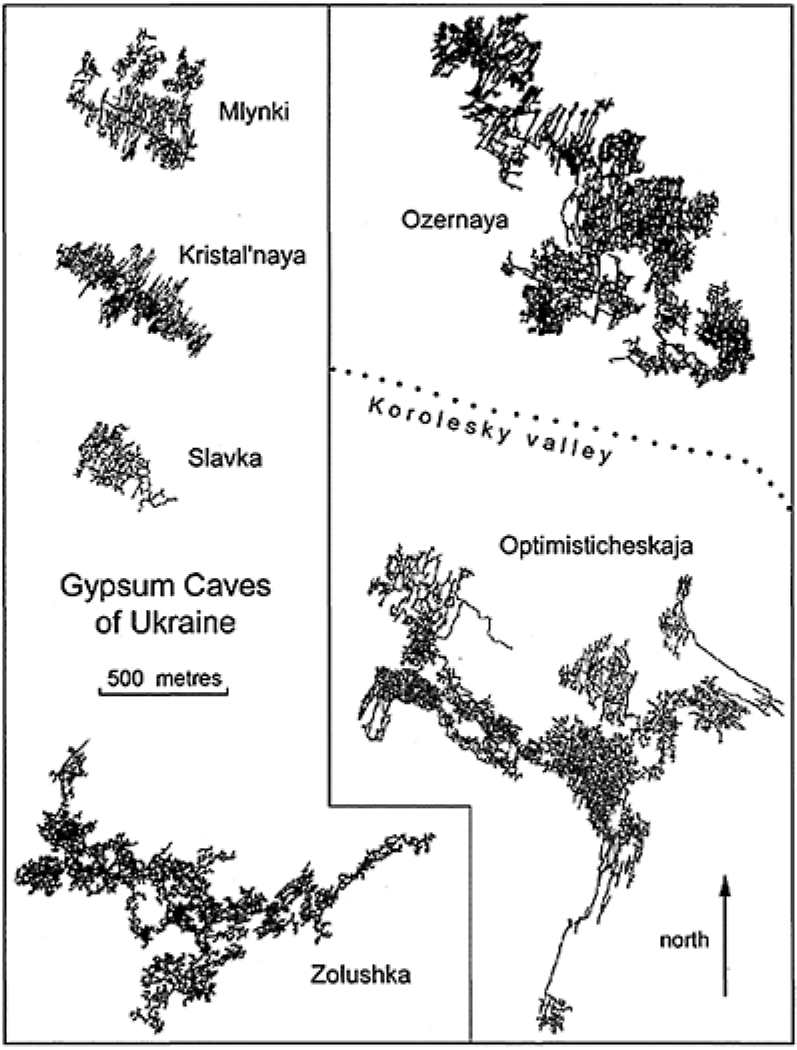
All the large gypsum caves in the region are mazes developed along vertical and steeply inclined fissures arranged into multistorey laterally extensive networks. Aggregating passages form lateral two- to four-storey systems that extend over areas of up to 1.5 km^2 (Figure 2). A notable feature of the mazes is the exceptionally high passage network density, which is characterized conveniently by using the ratio of a cave length to an area occupied by a cave system. This parameter varies from 118 (Verteba Cave) to 270 (Gostry Eovdy Cave) km km^{-2}, with the average value for the region being 164 km km^{-2}. Values of areal coverage and cave porosity (fractions of the total area and volume of the rock within a cave field, occupied by passages) vary for individual caves from 17.5 to 48.4% (average 29.5%) and from 2 to 12% (average 4.5%) respectively, being roughly an order of magnitude greater than these characteristics for typical unconfined caves. Optimistychna Cave (Optimisticheskaya in Russian spelling) is the longest gypsum cave, and the second-longest cave of any type known in the world, with more than 214 km of passages surveyed. By area and volume the largest caves are Ozernaya (330000 m^2 and 665000 m^3) and Zoloushka (305000 m^2 and 712000 m^3), followed by Optimistychna Cave (260000 m^2 and 520000 m^3).

Maze caves in the region were developed under confined conditions, due to upward transverse groundwater circulation between aquifers below and above the gypsum (Klimchouk, 1992, 2000b) (see Speleogenesis: Deep Seated and Confined Settings). According to the morphology, arrangement and hydrologic function of the cave mesoforms during the main (artesian) speleogenetic stage, three major components can be distinguished in the cave systems (Figure 3):

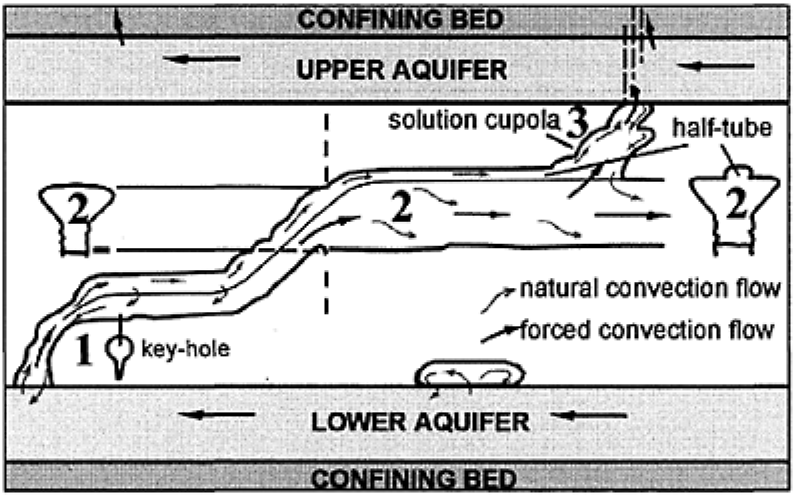
1. **Feeding channels,** the lowermost components in a system: vertical or subvertical conduits through which water rose from the sub-gypsum aquifer to the master passage networks. Such conduits are commonly separate but sometimes they form small networks at the lowermost part of the gypsum. The feeding channels join

Ukraine Gypsum Caves and Karst: Table. Morphometric parameters of large gypsum caves in the Western Ukraine.

No.	Cave	Length (km)	Average cross-sectional area (m^2)	Density of passages (km km^{-2})	Areal coverage (%)	Cave porosity (%)
1	Optimistychna	214.0	2.8	147	17.6	2.0
2	Ozernaya	117.0	6.0	150	44.6	5.0
3	Zoloushka	92.0	8.0	142	48.4	3.8
4	Mlynki	27.0	3.3	141	37.6	3.4
5	Kristal’naya	22.0	5.0	169	29.2	6.0
6	Slavka	9.1	3.7	139	27.6	3.4
7	Verteba	7.8	6.0	118	34.7	12.0
8	Atlantida	2.52	4.5	168	30.0	4.0
9	Bukovinka	2.4	2.5	120	21.5	4.4
10	Ugryn	2.12	3.8	177	33.3	5.7
11	Gostry Govdy	2.0	1.7	270	17.5	4.0



Ukraine Gypsum Caves and Karst: Figure 2. The very long gypsum caves of Ukraine drawn to the same scale. Ozernaya and Optimisticheskaja (Optimistychna) are shown in relation to each other, but the others are each at separate sites (after surveys by the cave clubs of L'vov, Ternopol, Chernivtsky, Kiev, and others).



Ukraine Gypsum Caves and Karst: Figure 3. Main morphogenetic features of maze cave systems in the western Ukraine shown according to their hydrologic functionality. 1=feeding channels, 2=master passages, 3=outlet features.

master passages located at the next upper level and scatter uniformly through their networks

2. Master passages: horizontal passages that form laterally extensive networks within certain horizons in the middle part of the gypsum bed (Figure 4). They received dispersed recharge from numerous feeding channels and conducted flow laterally to the nearest outlet feature

3. Outlet features: domes, cupolas, and vertical channels (dome pits) that rise from the ceiling of the master passages to the bottom of the overlying bed. They discharged water from cave systems to the overlying aquifer.

The predominant sediments in the maze caves of the region are successions of fine clays, with minor beds of silty clays. These fill passages to a variable extent and can reach 5–7 m in thickness. Breakdown deposits are also common. They include chip, slab, and block breakdown material from the gypsum, as well as more massive breakdown from the overlying formations. Calcite speleothems (stalactites, stalagmites, flowstones, and helictites)

Ukraine Gypsum Caves and Karst: Figure 4. “Master passage” in Ozernaya Cave. (Photo by John Gunn)

occur locally in zones of vertical water percolation from overlying formations. Gypsum crystals of different habits and sizes are the most common cave decorations. They are of largely subaerial origin. Hydroxides of Fe and Mn occur as powdery layers within the clay fill of many caves, indicating repeated transitional cycles from a reducing to an oxidizing geochemical environment. Massive deposition of Fe/Mn compounds in the form of powdery masses, coatings, stalactites, and stalagmites has occurred in Zoloushka Cave, where a rapid dewatering caused by groundwater abstraction during the last 50 years gave rise to a number of transitional geochemical processes, some of which appear to show considerable microbial involvement (Andrejchuk & Klimchouk, 2001).

The Western Ukrainian maze caves provide the most outstanding and unambiguous evidence for the transverse artesian speleogenetic model. The artesian speleogenesis in the Podol’sky region took place mainly during the late Pliocene through to the middle Pleistocene. It was induced by incision of the Dniester valley and its left-hand tributaries into the confining clays, and respective activation of the upward transverse groundwater flow within the underlying artesian system. Breaching of artesian confinement and further incision of the valleys during the middle Pleistocene caused substantial acceleration of groundwater circulation within the Miocene artesian system. The majority of passage growth probably occurred during this transitional period. Where the water table was established in the gypsum for a prolonged time, further widening of passages occurred due to horizontal notching at the water table. Eventually, with the water table dropping below the lower gypsum contact, cave systems in the entrenched karst zone became largely relict. Cave development under confined or semiconfined conditions continues today within the zones of deepseated and subjacent karst.

There are large bioepigenetic deposits of native sulfur in the pre-Carpathian region, within the deep-seated karst zone, associated with the Miocene gypsum bed. Sulfur is embedded in epigenetic calcite that partially (at the top) or wholly replaces the gypsum. The artesian "ascending" speleogenesis in the gypsum layer played a fundamental role in the origin of the sulfur deposits (Klimchouk, 1997b). This is not only because it provided the large amounts of dissolved sulfates needed to fuel the largescale sulfate reduction, but also because speleogenesis opened pathways for the flow of groundwater between the lower and upper aquifers through maze cave systems in the gypsum. Such a flow pattern and speleogenetic evolution within the gypsum provided the spatial and temporal framework within which the sulfur cycle processes took place, as well as controlling the geochemical environments, and the migration of reactants and reaction products between them.

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See also **Evaporite Karst; Speleogenesis: Deep Seated and Confined Settings**

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Further Reading

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