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І ПРИЛЕГЛИХ ТЕРИТОРІЙ**

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УДК 551.44; DOI [10.30970/gpc.2023.1.3958](https://doi.org/10.30970/gpc.2023.1.3958)**NON-KARSTIC SPELEOGENESIS IN SANDSTONE ROCKS OF UKRAINIAN CARPATHIANS****Bogdan Ridush***Yuriy Fedkovych Chernivtsi National University, Ukraine*b.ridush@chnu.edu.ua; <https://orcid.org/0000-0002-5896-6073>

Abstract. Due to the limited distribution of karst rocks and, accordingly, the small number of karst caves in the Ukrainian Carpathians, the caves of non-karst (pseudokarst, clastokarst) genesis attract considerable attention from cave researchers. The latter most often develop in massive and coarse-grained sandstone strata, usually found as part of flysch strata. The caves of non-karstic genesis are widely spread in the Cretaceous and Paleogene sandstone formations of the Ukrainian Carpathians. Most of them are developed in the massive sandstone of the Yamna Formation of the Palaeocene. The primary information about all caves on the territory of Ukraine is collected by the Commission for Accounting and Documentation of Caves of the Ukrainian Speleological Association (UkrSA), and by local caving clubs and individual researchers. Currently, the number of discovered caves in the sandstone of the Ukrainian Carpathians exceeds the number of mapped caves, not to mention their detailed description. The minimal information about each cavity includes the name, entrance coordinates, total length, and depth (amplitude) resulting from the cave survey. The additional description could contain knowledge about the history of the cave discovery, origin, geological settings, microclimate, sediments, inhabitants, paleontological and archaeological remains, etc. At present, many caves have been discovered in a few microregions: Kliuch Ridge, near Skole; the tract Drybka, between Yaremche and Yamna; on Sokilsky Ridge, and its south-eastern orographic continuation at tracts Protiat Kaminnia and Lekeche; Polonyna Runna; Lubnia Village; and Chorna Gora Ridge. Few yet not mapped cavities are known in Bubnyshche, Synytsia Mt., and some other sites. Most caves belong to three genetic types: tectonic, gravitational, and selective corrosion. The largest among tectonic caves is Tectonic (Dovbush) cave near Yamna Village, which is 388 m long. The longest selective-corrosion cave is 92 m long. Some caves with fissure-like morphology could also be of cryogenic origin. We suggest that the caves with the fissure-like morphology are the forms of paleoseismic dislocations.

Keywords: sandstone; pseudokarst; speleogenesis; selective corrosion; Ukrainian Carpathians.

НЕКАРСТОВИЙ СПЕЛЕОГЕНЕЗ У ПІСКОВИКАХ УКРАЇНСЬКИХ КАРПАТ**Богдан Рідуш***Чернівецький національний університет імені Юрія Федьковича*

Анотація. Через обмежене поширення карстових порід і, відповідно, невелику кількість карстових печер в Українських Карпатах значну увагу спелеологів привертають печери некарстового (псевдокарстового, кластокарстового) генезису. Останні найчастіше розвиваються в масивних і крупнозернистих товщах пісковиків, які зазвичай зустрічаються у складі флішових товщ. Печери некарстового генезису широко поширені в крейдових і палеогенових пісковиках Українських Карпат. Більшість з них утворені в масивних пісковиках ямненської світи палеоцену. Первинна інформація про всі печери на території України збирається Комісією з обліку та документації печер Української спелеологічної асоціації (УСА), а також місцевими спелеологічними клубами та окремими дослідниками. Нині кількість виявлених печер у пісковиках Українських Карпат перевищує кількість закартографованих печер, не кажучи вже про їхній детальний опис. Мінімальна інформація

про кожну порожнину включає назву, координати входу, загальну довжину та глибину (амплітуду), отриману в результаті дослідження печери. Додатковий опис може містити відомості про історію відкриття печери, походження, геологічні умови, мікроклімат, відкладення, мешканців, палеонтологічні та археологічні залишки тощо. Нині відкрито багато печер у кількох мікрорегіонах: хребет Ключ поблизу Сколе; урочище Дрібка між Яремче та Ямною; на Сокільському хребті та його південно-східному орографічному продовженні в урочищах Протяжне Каміння та Лекече; Полонина Рунна; село Лубня; та хребті Чорна Гора; Бубнище, гора Синиця та ін. Більшість печер належать до трьох генетичних типів: тектонічного, гравітаційного та селективної корозії. Найбільшою серед тектонічних печер є Тектонічна (Довбуша) біля села Ямна, довжина якої 388 м. Найдовша селективно-корозійна печера має довжину 92 м. Деякі печери з тріщиноподібною морфологією також можуть мати криогенне походження. Припускаємо, що печери тріщиноподібною морфологією є формами палеосейсмічних дислокацій.

Ключові слова: пісковик; псевдокарст; спелеогенез; селективна корозія; Українські Карпати.

Introduction

Due to the limited distribution of karst rocks and, accordingly, the small number of karst caves in the Ukrainian Carpathians, the caves of non-karst (pseudokarst, clastokarst) genesis attract considerable attention of cave researchers. The latter most often develop in strata of massive and coarse-grained sandstones, which are often found as part of flysch strata.

Few works are devoted to the study of pseudokarst speleogenesis in the Ukrainian Carpathians. Classical geomorphological studies practically do not pay attention to speleofoms and karst processes in clastic formations (Kravchuk, 2005, etc.), probably due to their limited distribution. Most often, these caves attracted the attention of researchers as natural monuments (Korotenko et al., 1985) or potential objects of archaeology (Matskevych & Tarasenko, 1994).

Nevertheless, the cavities of gravitational genesis were studied by I. Turchynov (Turchynov, 1992). Geochemical aspects of karstogenesis in flysch were studied Korzhyk et al., 2006; Korzhyk & Stratiy, 2004). Periodically, the author (Ridush, 1995, 2006, 2018; Ridush and Kuprich, 2003; Ridush, 2010) addressed various aspects of cave research in the sandstones of the Ukrainian Carpathians.

There were numeral versions of karstological regionalization of the Ukrainian Carpathians in publications by G. Maksimovich (Maksimovich, 1958, 1962), B. Ivanov (Ivanov, 1965, 1972), O. Lomayev (Lomayev, 1970), (Dubljanskij & Lomayev, 1980). But the first speleological regionalization of the area, which took into account natural caves both of karst and non-karstic genesis, was published by Korzhyk and Ridush (Korzhyk & Ridush, 1990). Later, the little improved version of this scheme was published by (Korzhyk, 2011). Several articles by Korzhyk and co-authors analysed karst in the Flisch zone (Korzhyk et al., 2006; Korzhyk, 2007; Korzhyk & Stratiy, 2004). The detailed regional exploration on the Kliuch Ridge was provided by I. Turchynov (Turchynov, 1992). The genesis of some caves in sandstones, including historical artificial cavities, was analysed by the author (Ridush & Kuprich, 2003; Ridush, 1995, 2004, 2006, 2010, 2017, 2018).

The pseudokarst caves in conglomerates and sandstones in Zakarpatska oblast were explored by the local speleological clubs "Lynx" and "Selenit", with participation of other cavers (Levinets & Monych, 2006).

Quiet good the pseudokarst caves, particularly gravitational, are studied the Flysch areas of Poland (Margielewski & Urban, 2017; Zatorski, 2014) and Czechia (Lenart & Miklín, 2017). In Ukrainian Carpathians the exploration and mapping of caves is provided mainly by amateur cavers of Ukrainian Speleological Association and different local speleological clubs. The current results of exploration are represented on the website (The Inventory of Caves and Cavities of Ukraine, 2023).

The analysis of the publication list on the pseudokarst caves in the region and the results of our own field observations showed that a quite low percentage of the existing caves are revealed. Also, the origin of many of them is unclear. That is why it is necessary to underline this brunch's current state of the art. The paper is rather the introduction to the problem, emphasising paying attention to the genesis signs while exploring and surveying the new caves.

The pseudokarst cavities are usually developed in insoluble rocks and may be of different origin (Holler, 2019). The most common for the sandstone formations are tectonic and talus types. The last are also referred to as boulder caves. Also, the combinations of tectonic and talus caves often occur. The block creep caves formed by gravity sliding are usual. For several caves in the Pokuttia-Bukovinian Carpathians the specific type of speleogenesis: the selective-corrosion type, was revealed (Ridush, 2010).

Results and methods

The primary information about all caves on the territory of Ukraine is collected by the Commission for Accounting and Documentation of Caves of the Ukrainian Speleological Association (UkrSA), but also by local caving clubs and individual researchers (Klimchuk et al., 2008). At present the number of discovered caves in the sandstone of Ukrainian Carpathians exceeds the number of mapped caves, not to mention their detailed description. The minimal information about each cavity includes the name, entrance coordinates, total length and depth (amplitude) resulting from the cave survey. The additional description could contain knowledge about the history of the cave discovery, origin, geological settings, microclimate, sediments, inhabitants, paleontological and archaeological remains, etc. Recently, information about the cave inventory can be observed online (The Inventory of Caves and Cavities of Ukraine, 2023).

Microregions and caves

Kliuch Ridge (Skole). The region was explored yet in 1986–1991 by Lviv caving clubs. At least, eight caves were discovered and described (Turchinov, 1992). In recent years the region is additionally explored by joint expeditions of UkrSA. Caves developed in massive sandstone of Yamna Formation. The longest one is *Prokhidnyi Dvir Cave*, 520 m long and 40 m deep (Fig. 1, Tab. 1). In the neighbourhood, there are several other sites with numerous outcrops of Yamna sandstones, containing cavities of non-karst origin: Urych, Syniovydne, Rozgirche, Bubnyshche (Fig. 1), that remained not mapped. Some of them were artificially developed in historical time (B. T. Ridush, 2006).

Yaremche – Yamna. Many caves were found in the tract Drybka, that is located between Yaremche and Yamna Village, is the place of concentration of numerous caves in sandstone (Fig. 1). Among them, the longest one is *Tectonic (Dovbush) Cave*, with the total length of 388 m (Fig. 2, Tab. 1).

Sokilskyi Ridge. Few caves and even a “karst bridge” are known within several sites of Sokilskyi Ridge in Ivano-Frankivska oblast, and its south-eastern orographic

continuation at tracts Protiate Kaminnia and Lekeche in Chernivetska oblast (Fig. 1) (Korzhyk, 2007; Ridush & Kuprich, 2003; Ridush, 1995, 2010). The longest caves are *Lekeche-4* and *Sokolyna* (Tab. 1). The characteristic for the region are the caves of selective corrosion origin. Meanwhile, the tectonic caves also present.

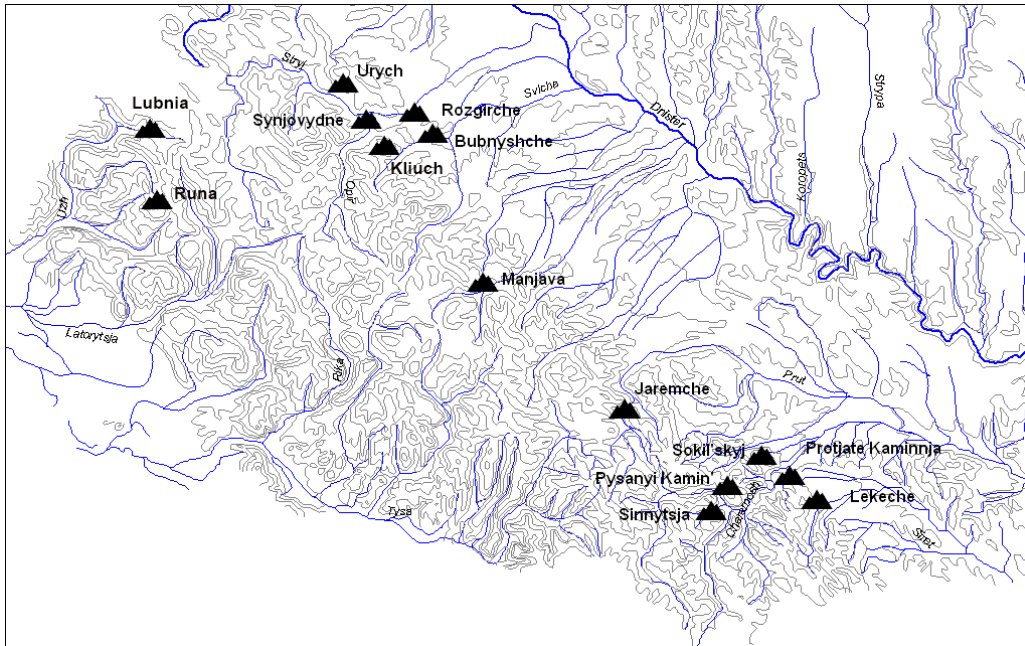


Fig. 1. The main locations of non-karstic caves in sandstones, in Ukrainian Carpathians

Polonyzna Runa. Only one cave of the same name – *Runa*, is 190 m long (Tab. 1) (Levinets & Monych, 2006). It is developed in the sandstone of Liutska Formation (Paleocene).

Lubnia Village. Few caves developed in sandstones of uncertain geological age. The longest one is “*Rolling Stones*” Cave, 106 m long, and almost 26 m deep (Levinets & Monych, 2006). The three floors of the cave are just the projection of one slightly inclined tectonic fissure.

Chorna Gora Ridge. At list two caves are known on the slopes of Petros Mt., one of which is 185 m long and 28 m deep. Caves are developed in sandstones of the Chornogora Formation (Cretaceous) (Levinets & Monych, 2006; Tsurkan & Pylypiuk, 2015). Recently, the new cave of probably tectonic origin was reported in the same beds close to the top of Pip Ivan Mt, but until now it was not mapped.

The cavities of mixes origin can be observed on the Sinnytsia (Synytsia) Mt. (Dovbushevi Komory) near Kryvorivnia Village (Ivano-Frankivska oblast) (Fig. 1).

Discussion

The origin of caves on the Kliuch R. is described as gravitational type. The local sandstones belong to Yamna Formation. From the typical Yamna sandstones they differ by the carbonate cement and interbeds of argillite (Turchinov, 1992). The special geotechnical examination of this sandstone showed the absence of any cement (Voloshyn, 2012). Anyway, due to these interbeds and inclined bedding, the gravitational origin can be explained. Meanwhile, the *Piligrim Cave* demonstrates the shape of the

cross-section of the upper gallery, typical for tectonic caves. At the same time, on the left wall, a distinct form of solution can be seen (Fig. 3, A). In the other part of the gallery, the forms and deposits of frost weathering can be observed (Fig. 3, B).

Table 1. The selected largest caves in sandstones of Ukrainian Carpathians (after (The Inventory of Caves and Cavities of Ukraine, 2023; B. T. Ridush, 2010; Turchinov, 1992))

Cave name	Location	Total length, m	Projective length, m	Amplitude, m
Prokhidnyi Dvir	Kliuch R., Skole, Lvivska oblast	520.0	-	40 (+5/-35)
Tectonic (Dovbush)	Drybka tract, Yaremche, Ivano-Frankivska oblast	388.0	353.0	35,0
Kholodnogo Vitru (Cold Wind)	Kliuch R., Lvivska oblast	232.0	208.0	24.0
Runa	Lypovets V., Zakarpatska oblast	190.0	148.0	9.0
Petros-1	Petros Mt., Zakarpatska oblast	185.5	-	27.5
Piligrim	Kliuch R., Skole, Lvivska oblast	175.0	-	15.0
“Rolling Stones”	Lubnia V., Zakarpatska oblast	138.0	106.7	25.7
Seven Bats	Kliuch R., Skole, Lvivska oblast	135.0	-	34.0
Veselka (Rainbow)	Kliuch R., Skole, Lvivska oblast	120.0	-	22.0
Three Bats	Kliuch R., Skole, Lvivska oblast	102.0	-	20
Lekeche-4	Beregomet, Chernivetska oblast	96.5	96.5	18.0
Sokolyna	Pidzakharychi, Chernivetska oblast	92.0	92.0	14.5
Yeti	Drybka tract, Yaremche, Ivano-Frankivska oblast	94.0	82.0	11.5
Liodiana (Ice Cave)	Kliuch R., Skole, Lvivska oblast	75.0	-	24.0
Tygryna	Sokilskyi R., Ivano-Frankivska oblast	72.0	-	10.0
Sribnoi Steli	Kliuch R., Skole, Lvivska oblast	55.0	47.0	8.0
Dovbusha - Pidzakharychi	Pizakharychi Village, Chernivetska oblast	39.0	39.0	6.5

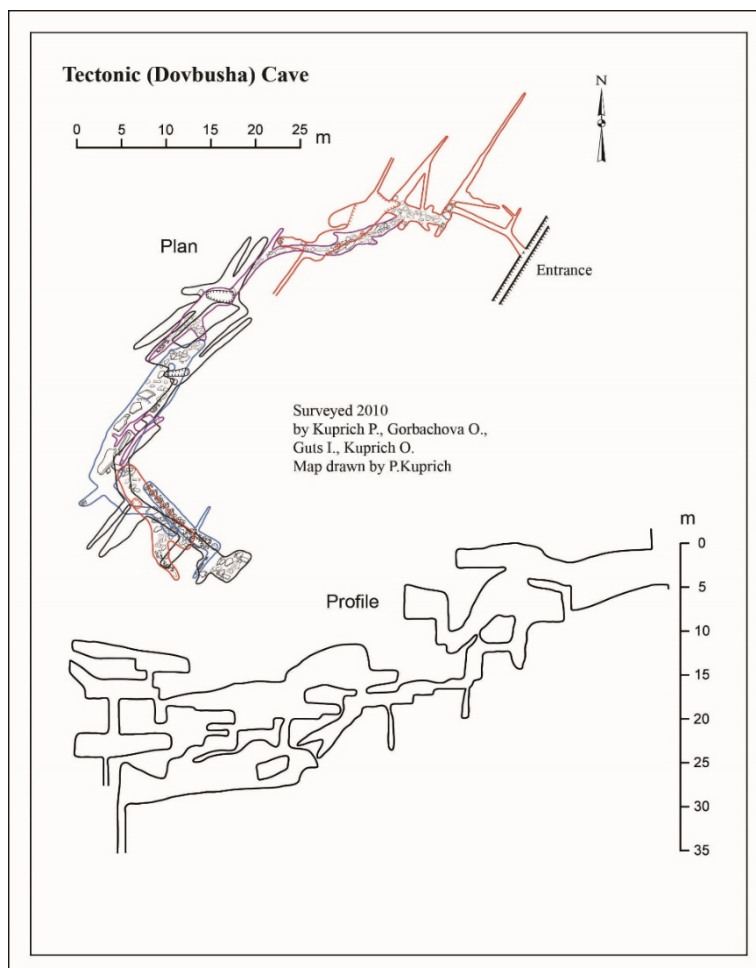


Fig. 2. Tectonic (Dovbush) Cave near Yamna Village

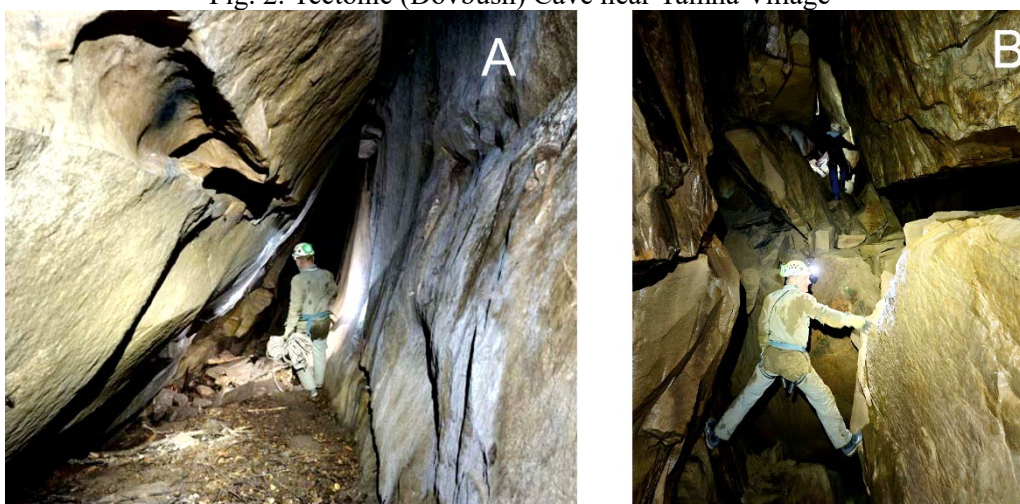


Fig. 3. Pilgrim Cave (Kliuch Ridge). Photos by A. Ryshtun

Tectonic agent is usually present in both karstic and non-karstic genesis of caves. Most evidently, it can be seen in the morphology of Tectonic (Dovbush) Cave near Yaremche (Fig. 1). Such forms can be considered as seismic dislocations, which likely appeared because of a single seismic event. In this case, the question of the age of this event appears.

The absence of loess and loam on the surface of the cave indicates the extreme geological youth of these formations. It means that during the active aeolian spreading of loess during the Last Glacial Maximum, these cavities did not exist or were already filled with something, most likely ice.

Of course, the basis was primary tectonic cracking and even the opening of the largest direct galleries, as the entrance to the Tectonic, caused by seismic dislocations. But the further grinding and especially the movement of the blocks on the surface is difficult to explain by anything other than underground ice.

Currently, the Tectonic cave entrance altitude is close to 550 m a.s.l. If, during the Late Pleistocene, there was permafrost on the plain, it is even more so here. Even recently, ice was preserved deep in some caves all over the year, like in Liodiana Cave (Ice Cave) (Fig. 4). In the modern climate, it was accumulated due to the effect of “cold bag”. But just a few centuries ago, during the Little Ice Age, the conditions for ice accumulation were even more preferable. The mechanism of selective corrosion on some sites was described in previous publications (B. T. Ridush, 2010). Here we can add that the undirect indicator of cavities’ origin could be such microforms as tafoni. They are quite numerous on the walls of the sandstone residual cliffs and sometimes inside caves (Bayrak & Zinko, 2023). As shown by A. Klimchouk, typical tafoni and honeycombs in classical karst areas may indicate past ascending flow events and the potential presence of hypogene karst systems (Klimchouk, 2017). In our case, they can also indicate an ascending flow, but in non-karstic settings.

Conclusions

The non-karstic caves in sandstones demonstrate a variety of origins, with the prevailing of one type in the selected regions. For example, the Sokilsky Ridge and orographic continuation on the right side of the Cheremosh River contain many caves of selective corrosion origin. Meanwhile, the caves of similar origin can be observed at other sites, The Drybka site near Yamna contains caves of mainly tectonic or tectonic-cryogenic origin. The site of the Kliuch Ridge is known for the caves of gravitational origin. The role of the cryogenic agent in the speleogenesis of caves in sandstones should be discussed. We suggest that the caves with the fissure-like morphology are the forms of paleoseismic dislocations.

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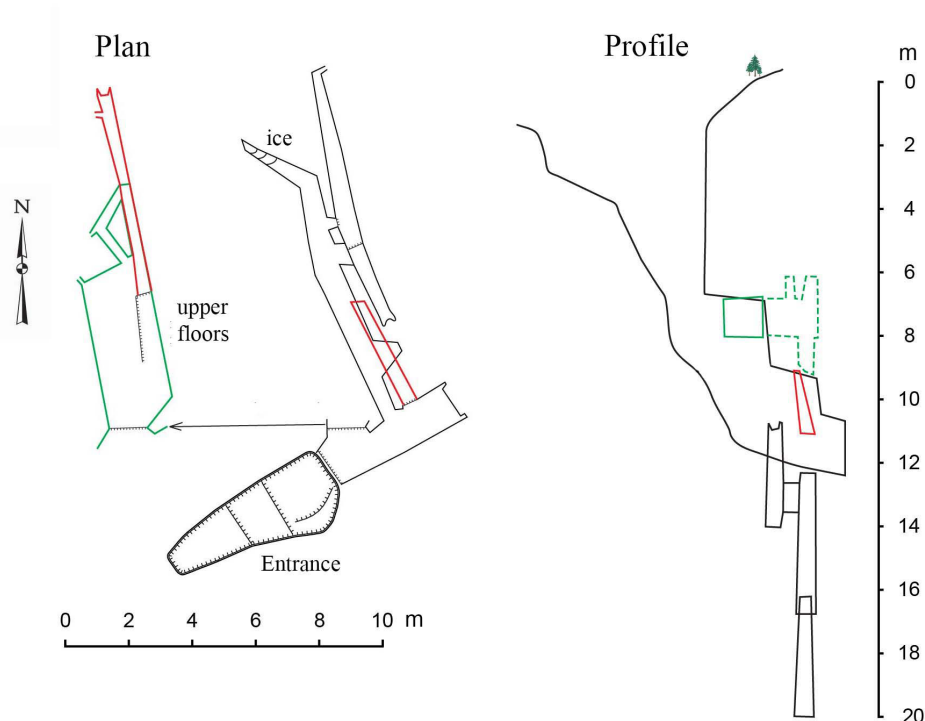
Lioldiana (Ice) cave

Fig. 4. Lioldiana (Ice) Cave (Kliuch Ridge) (survey by I. Turchynov, modified from (Ryshtun, 2022))

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