



## Eogenetic caves in conglomerate: an example from Udin Boršt, Slovenia

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### Abstract:

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Udin Boršt is a karstified terrace of carbonate rock, which is of fluvio-glacial origin, and is situated in the north-western part of Slovenia. There are 15 registered caves, which have been interpreted as caves in conglomerate, while karst of Udin Boršt itself was interpreted as conglomerate karst, shallow karst or isolated karst. In this article, caves in Udin Boršt have been interpreted as eogenetic caves. Based on porosity and bedding material, different types of caves and cave passages have developed. Four general types of eogenetic caves found in Udin Boršt are; linear stream caves, shelter caves, breakdown caves and vadose shafts.

**Keywords:** eogenetic; caves; conglomerate; Slovenia; Udin Boršt

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### INTRODUCTION

The northwestern part of the Ljubljana Basin between Kranj and Radovljica is called Gorenjske Dobre (Woodland of Upper Carniola) and consists mainly of different conglomerate terraces of Pleistocene age. Udin Boršt is one of the highest and most likely the oldest terraces in this area. It stretches about 7 km in a south - east direction and is up to 2.5 km wide. Based on various factors, the karst of Udin Boršt has been interpreted as conglomerate karst (Habič, 1981; Gabrovšek, 2005; Kranjc, 2005), shallow karst (Žlebnik, 1978) and isolated karst (Habič, 1981).

The aim of this paper is to describe the geological, morphological and genetic characteristics of the caves of Udin Boršt with special attention to porosity types which have a strong influence on the cave type or its morphology. As a result, a classification of the caves is introduced. Within the research a wide range of literature about the characteristics of eogenetic and conglomerate karst and caves and also about karst and caves in conglomerate of Udin Boršt was examined. The main part of the research was based on field work, which included detailed speleological analyses of caves and morphological analyses of the conglomerate terrace.

### REGIONAL CHARACTERISTICS

Udin Boršt is an approximately 10 to 50 m high conglomerate terrace and extends over an area of more than 15 km<sup>2</sup>. It lowers gently from the northwest (about 560 m above s. l.) to southeast (about 420 m above s. l.) (Fig. 1) and represents a remnant of a cemented Pleistocene fluvio-glacial fan of Tržiška Bistrica River.

According to Šifrer (1969, 1992) and Žlebnik (1971, 1978) the terrace belongs to early and middle Pleistocene (Günz and Mindel in the Penck and Brückner (1909) sense). However, recent investigations indicate that the terrace may even belong to the oldest Pleistocene (Donau) (Šifrer, 2005 cited by Prelovšek & Slabe, 2005). Consequently the conglomerate of the terrace is well cemented and resistant to erosion (Gantar, 1955a) and has thus enabled karst forms to develop.

The pebbles of conglomerate consist of carbonate (~ 90 %) and non-carbonate (~ 10 %) material (Knez et al., 2005), which was deposited over Middle Oligocene clays (Grad & Ferjančič, 1976). Carbonate material consists mainly of various limestones, while non-carbonate material consists mainly of quartz (Gantar, 1955a). Occasionally, lenses of sandy clay are interbedded in the conglomerate. The sand grains represent rounded limestone and angular quartz with traces of mica and iron oxide. The cement of the conglomerate is mostly calcite with traces of clay and iron oxide (Gantar, 1955a; Žlebnik, 1978).

The rock is very porous and permeable. During early diagenesis its primary intergranular (matrix) porosity has been partly reduced by internal precipitation of carbonate cement, but has later increased by

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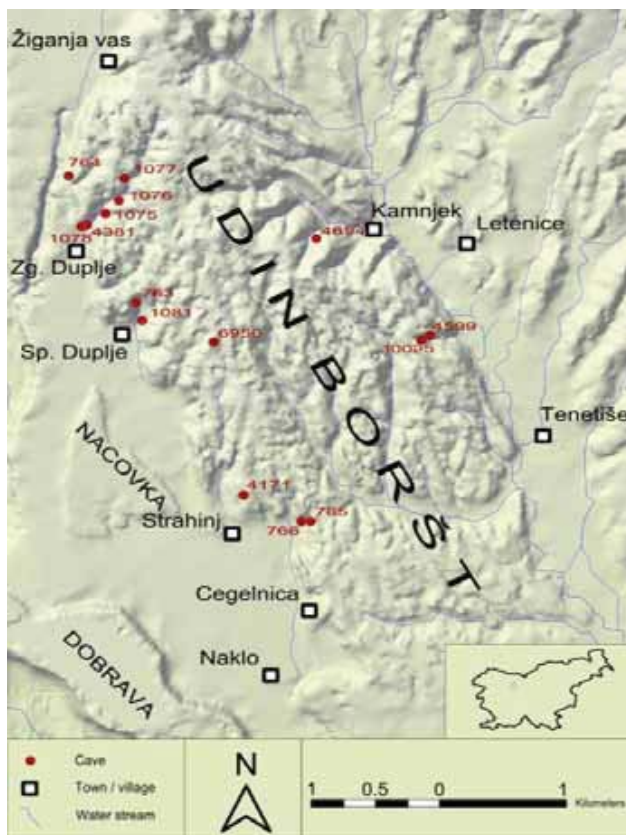


Fig. 1. A digital model relief of Udin Boršt and distribution of caves. Caves are labelled by their registration numbers: 763 – Arneževa Luknja; 764 – Dopulnek; 765 – Velika Lebinca; 766 – Mala Lebinca; 1075 – Dacarjevo Brezno; 1076 – Brezno v Kvikšovem Partu; 1077 – Jama v Arhovem Partu; 1078 – Arhova Jama; 1081 – Arneževa Zijalka; 4171 – Kadunčev Studenec; 4381 – Arhova Zijalka; 4599 – Pekel v Klemenčevem Gradišču; 4694 – Rokovnjača; 6950 – Kačja Jama nad Spodnjimi Dupljami; 10025 – Vojvodov Kevder.

solution of pebbles and cement. However, according to Gabrovšek (2005) the corrosion of cement is greater than the corrosion of carbonate pebbles. Despite fabric selective type (matrix porosity), new additional non-fabric selective secondary porosity has occurred as a result of neo-tectonic fractures (fissure/crack porosity). Namely, Udin Boršt is situated between the Sava Fault in the north and Kranj Fault in the south and belongs to the active tectonic units Ljubljanska Kotlina (Ljubljana Basin) and Ljubljansko Barje (Ljubljana Moor) (Grad & Ferjančič, 1976).

Two different reliefs are recognised in Udin Boršt: karst relief, which dominates in the southern and south-western part of the terrace, and fluvio-denudational relief, which dominates in the northern and north-eastern part of the terrace. Most typical geomorphologic features are dolines, caves, erosion gullies and pocket valleys to name but a few. A detailed description of geomorphologic features in Udin Boršt is presented by Prelovšek & Slabe (2005).

The larger part of the terrace, which receives only autogenic recharge, is characterised by fast infiltration of rainfall to the underground where the base of the aquifer is impermeable Oligocene clay (Gabrovšek, 2005). In the area of Udin Boršt 39 springs with

relatively small seasonal oscillations in discharge are known. The total rate of flow of all of the springs is 25 l/s. However, surface runoff is also present. In the north-eastern and eastern part of the terrace many permanent and ephemeral watercourses appear. The mean runoff (surface and underground) for the whole Udin Boršt terrace is estimated to be about 470 l/s (Petrič, 2005).

## THEORETICAL BACKGROUND

### The term eogenetic

The term eogenetic, which equates broadly to early diagenesis (Worden & Burley, 2003), was introduced by Choquette & Pray (1970) and refers to “the time interval between final deposition and burial of the newly deposited sediment or rock below the depth of significant influence by processes that either operate from the surface or depend for their effectiveness on proximity to the surface” (Choquette & Pray, 1970, p. 219). These processes, controlled by the overall physical, biological and geochemical characteristics of the depositional system, may extend to only a few or several thousand metres below the sediment surface. The extension depends on the geometric arrangement of aquifers, aquitards, synsedimentary faults and aquifer permeability (Worden & Burley, 2003). Two other terms were coined for the time of deeper burial as mesogenetic stage, and the time associated with erosion of long-buried carbonates as telogenetic stage (Choquette & Pray, 1970).

The term eogenetic was later used in combination with the term karst as eogenetic karst (Vacher & Mylroie, 2002; Florea & Vacher, 2006; Grimes, 2006; Ginés & Ginés, 2007). It strongly overlaps with the term syngenetic karst (concurrent karstification and lithification), coined by Jennings (1968), but has a different viewpoint (Grimes, 2006). However, both are mostly related to karst in soft, porous and poorly-consolidated limestones during their eogenetic stage of diagenesis (Grimes, 2006), which is widespread along shorelines (Vacher & Mylroie, 2002).

### Porosity

According to Lucia (2007), karst aquifers are characterized by two types of porosity: interparticle and vuggy porosity, which strongly overlaps with primary (sometimes referred to as matrix porosity (Ford & Williams, 2007)) and secondary porosity (fracture, fissure, or conduit porosity (Ford & Williams, 2007)), from the sedimentology point of view (Choquette & Pray, 1970). Vugs are pore spaces within grains or crystals, or pore spaces which are significantly larger than grains or crystals (e.g. dissolved grains, fossil chambers, fractures, and large irregular cavities). They are further classified as separate-vugs and touching-vugs (Lucia, 2007). Primary porosity is created during rock deposition, while secondary porosity is created later (after final deposition) during diagenesis of the rock (Choquette & Pray, 1970). Furthermore, a term tertiary porosity was applied for dissolutional conduits or caves, meaning only fracture (fissure) porosity is considered to be secondary (Ford & Williams, 2007).

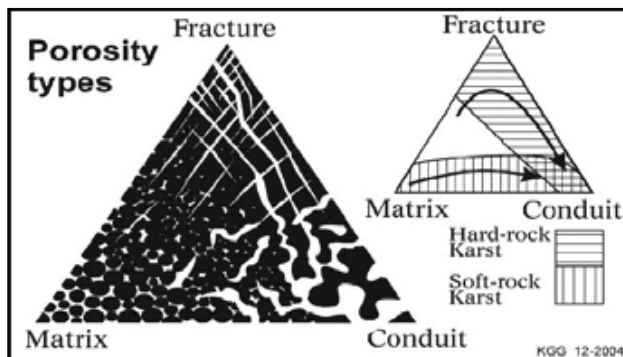


Fig. 2. A ternary diagram of simplified limestone porosity (Grimes, 2006).

During eogenesis (early diagenesis), primary porosity experiences significant modifications. The type of porosity can remain the same, yet its permeability is reduced by intergranular sedimentation of carbonate cement or replaced by solutional porosity. Nevertheless, a creation of new or additional porosity is possible by burrowing, sediment shrinkage or sediment distension. Where the solution is in a dependent relation with primary and secondary solid constituents (fabric elements), it is defined as fabric selective. Its independence to the fabric elements is defined as not fabric selective (Choquette & Pray, 1970).

A simplified limestone porosity as a ternary diagram was represented by Grimes (2006) (Fig. 2). The diagram shows an intergranular (matrix), fissure and conduit porosity types and their evolution.

### Eogenetic caves

Eogenetic caves have been described as one of the karst features in limestone during its eogenetic stage (Vacher & Mylroie, 2002). Today's eogenesis is largely recognised in most of the Quaternary calcareous sediments, which were deposited along the coastal margins, whether it is of aeolian (Brooke, 2001) or marine origin. Subsequently, eogenetic caves are commonly related to "coastal karst" (Vacher & Mylroie, 2002; Grimes, 2006; Smart et al., 2006; Ginés & Ginés, 2007; De Waele et al., 2009). However, caves with eogenetic characteristics have also been described inland (Florea et al., 2007).

Due to diverse geologic (pre)disposition, hydrology, and other geographical factors, various different types of eogenetic caves have been described. In this paper, the selection of most representative eogenetic caves is presented.

Flank margin caves with a diverse irregular form of interconnected wide but rather small in height chambers are the result of mixing corrosion in the mixing zone of seawater and freshwater. They form parallel to the coast (Vacher & Mylroie, 2002; Grimes, 2006) and were recently discovered also in the coastal carbonate rocks (breccia) of the Adriatic Sea (Otoničar et al., 2010).

Based on a calcarenite of Australia, Grimes (2006) defined horizontal cave systems of low, wide, irregular, and interconnected chambers and passages as syngenetic maze caves. They form as a result of matrix porosity, lack of joint control, and slow water flow.

On the other hand, steep gradients or less permeable palaeo-topography may concentrate water flow to form linear stream caves (Bastian, 2003; Grimes, 2006).

Mylroie et al. (2001) mention stream caves at the contact between carbonate and non-carbonate rocks. The water flow focuses on the non-carbonate surface and enters the subsurface as a stream, which is generally perennial and accompanied by dissolutional closed depressions (Mylroie et al., 2001).

Linear caves which are found in present phreatic zone are described by Vacher & Mylroie (2002). They identify them as relict, unrelated to the present groundwater system features, which can be construed by model of connected conduit systems associated with groundwater flow in the telogenetic karst of continental settings.

As a result of concentrated meteoric water in the epikarstic zone, vadose pit caves may be formed (Vacher & Mylroie, 2002). Large solution pipes which are tubular vertical cavities of epikarstic zone on karst of porous limestones with matrix porosity (Grimes, 2009; De Waele et al., 2010) could also be considered as a type of eogenetic caves.

As a result of secondary porosity, triggered by fractures and fissures, fissure caves can evolve (Stafford et al., 2005). For example, deep and extensive fracture voids are described by Whitaker & Smart (1997) as a result of a karstified bank-marginal fracture system.

Modification of the cave by frequent collapses may result in breakdown caves which may have distinctive inclined fissures, which are narrow inclined spaces around the edges of collapsed domes above a collapsed original solutional cave (Grimes, 2006). Vacher & Mylroie (2002) describe them as collapse-origin caves, derived from stream caves. However, as rocks in eogenetic stage are generally characterized as soft, collapses in eogenetic caves are frequent and described by many authors (Florea, 2006; Smart et al., 2006; Ginés & Ginés, 2007; De Waele et al., 2009).

Collapsed and passable phreatic pockets along the water table, usually in islands with low relief, are defined as banana holes (Harris et al., 1995; Vacher & Mylroie, 2002). Similar shallow caves are described by Grimes (2006) beneath a calcrete hard-pan and subsidence of soft unconsolidated sand underneath it is reported as a possible additional cause of collapse.

### Caves in conglomerate

Caves in various conglomerate rocks, including the conglomerate in eogenetic stage, have been reported and described worldwide. Nevertheless, they have never been considered to be a type of eogenetic caves, nor the eogenetic viewpoint was presented. To mention a few:

- Vertical and horizontal caves in conglomerate with diverse underground morphology have been reported in Paleogene conglomerate in Catalonia, Spain. Fractures have influence on vertical caves (pot-holes) while horizontal caves are located in the levels with greater concentration of carbonates and fissures or are limited by interbeds of impervious material. Vertical and horizontal caves may be connected with each other (Bergadá et al., 1997).

- Caves in conglomerate of late Miocene age and lower Pleistocene age in Montello Hill, Italy, are mostly horizontal and have developed at the water table. In addition, caves are situated at different elevations, which indicate the old water table levels (Zampieri et al., 2005). Interbeds of sandstone, marl and clay lenses have greater influence on cave development than fractures (Ferrarese & Sauro, 2005). In correspondence with marls and clay levels, caves are wider and have flat roofs. Otherwise, if developed entirely in the conglomerate, they have circular or gorge height to width ratio (Zampieri et al., 2005).
- Four cavities were found during the construction of a motorway in the Early Oligocene carbonate conglomerates of the Jura mountains, NW Switzerland. Tectonic discontinuities are believed to be a controlling factor in the origin of the cavities. Furthermore, one of the cavities might also be linked to some lithological features (Lapaire et al., 2006).
- A large area of the Köprüçay basin, Turkey, is covered by Miocene carbonates with dominant calcareous components and carbonate cement. Karstification occurred along fractures, joints and fault zones. Amongst other karstic features, numerous caves have also been found, including the Kuruköprü Cave with a total length of 530 m (Günay, 1985; Değirmenci & Günay, 1993).
- In China, the Longmen Dong Cave in Cretaceous conglomerate (Zhang, 2011) is reported to have more than 13 km surveyed passages and is thus the longest cave in conglomerate in China. The cave represents a complicated system of underground streams and waterfalls (Lushan 2003 expedition report).
- The longest known cave in conglomerate in the world is Bol'shaya Oreshnaya Cave in Russia. It has more than 47 km surveyed phreatic inclined and horizontal passages in Ordovician conglomerate (Filippov, 2004). However, based on the age of the conglomerate, it is most probably no longer eogenetic.

### CAVES OF UDIN BORŠT

Based on the geology, the conglomerate of Udin Boršt has never been buried. It is therefore still in eogenetic stage and hence caves are eogenetic as well.

There are 15 registered caves in Udin Boršt (Table 1; Fig. 1) (Cave register of SAS, 2010), which are not uniform in distribution. Only three of them are situated in the eastern part of the terrace, while the others are situated in the western part (Fig. 1). The asymmetrical distribution of the caves is according to Gabrovšek (2005) most probably dependent on the contact geometry of the conglomerate and the impermeable bedrock. Namely, the Oligocene clay underlying the terrace has an incidence towards southwest what

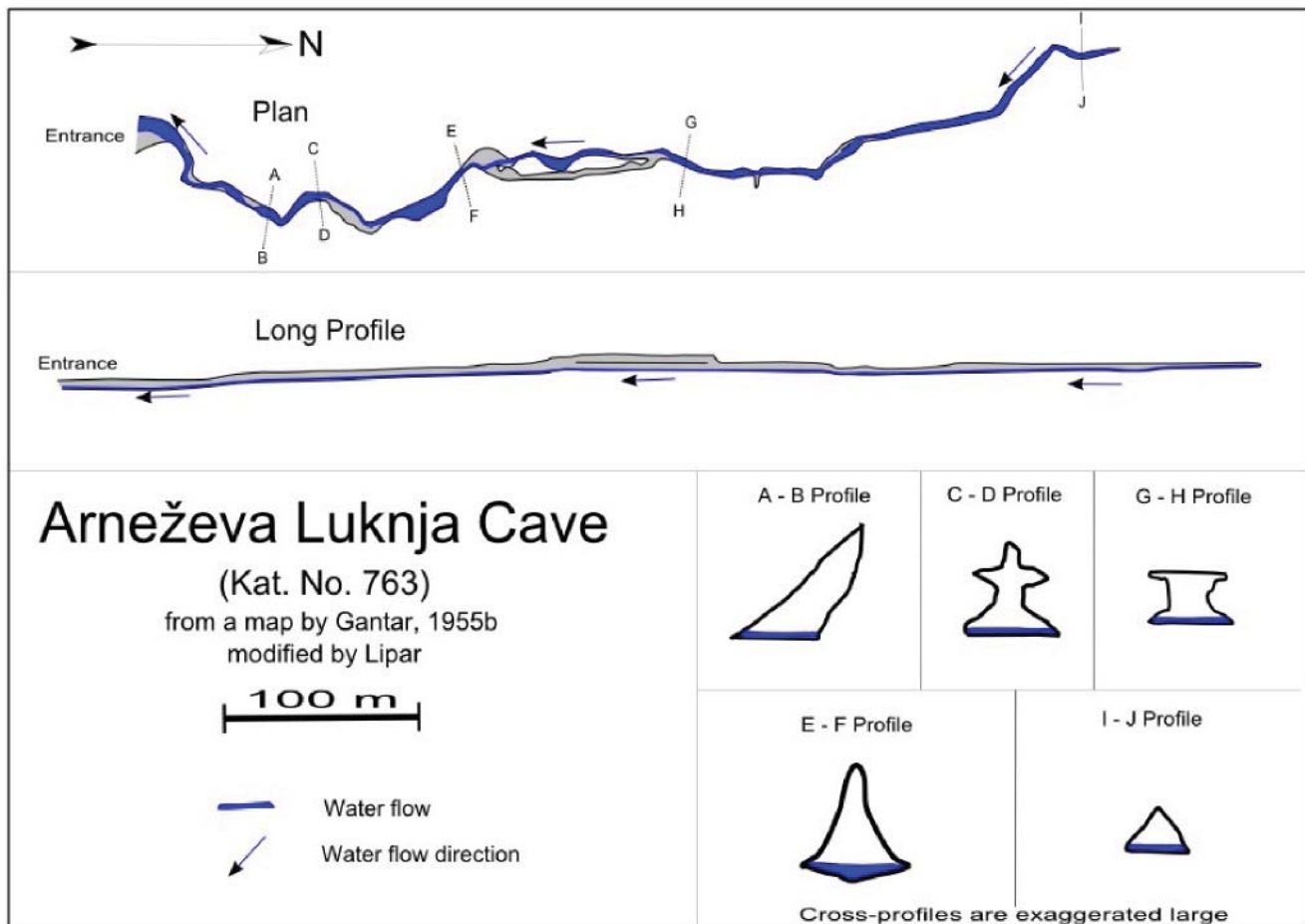


Fig. 3. Arneževa Luknja Cave map.

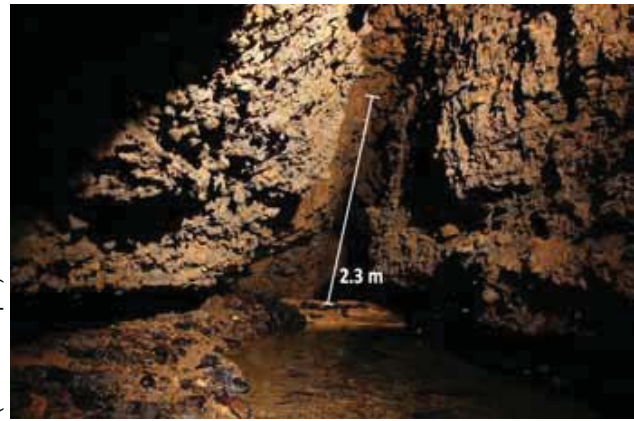
caused that the cave systems feed to point discharges on the western edge of the terrace. Certain caves that are functioning as permanent or ephemeral springs are situated in pocket valleys which are spaced on average every 500 m along the terrace edge.

The caves in the western part of Udin Boršt are formed sub-parallel to the valley of Tržiška Bistrica and have commonly north to south trending passages. Because the passages have formed predominantly along joint sets, the cave pattern is markedly linear although passages at different levels have formed. Extending inland, the passages eventually become too narrow for further explorations. Caves with vertical shaft entrances are found more inland, on slopes or in dolines. The passage density for Udin Boršt is approx. 180 m/km<sup>2</sup> for the total 2728 m of explored passages. However, in general the caves of Udin Boršt are isolated and never in sufficient density to develop a network cave pattern.

Based on detailed speleological analyses and morphographic characteristics of the caves in Udin Boršt, four different types of eogenetic caves were defined; linear stream caves, shelter caves, breakdown caves and vadose shafts. A combination of different types of passages with different origin is also common.

Most of the caves (10) are **linear stream caves** (Fig. 3); Velika Lebinca, Arneževa Luknja, Dacarjevo Brezno, Dopulnek, Arhova Jama, Arneževa Zijalka, Kadunčev Studenec, Pekel v Klemenčevem Gradišču, Vojvodov Kevder and Rokovnjača. They are located on the scarps of the terraces and are usually functioning as permanent or ephemeral springs. The entrances are in general higher than 1 m and a few meters wide. With distance upstream from the entrance horizontal passages become narrower. They developed in the epiphreatic zone and have permanent or ephemeral active streams. Ephemeral streams appear also in short side passages as tributaries to the main water flow. In some cases vertical passages lead to a higher level of passages which are hydrological inactive. More than half of the passages in horizontal linear stream caves are controlled by fissures/joints (Fig. 4) and could thus be partly interpreted also as fissure caves, as mentioned by Stafford et al. (2005). However, low and wide passages reflect matrix porosity and bedding material type influence (Fig. 5).

The longest cave of this type is Velika Lebinca Cave. It is situated in the south-western part of Udin Boršt, near the settlement of Strahinj. The cave entrance is located at the beginning of a pocket valley which is about 100 m wide and 150 m long. The cave is 1154 m long and 16 m deep (Cave register of IZRK, 2010). The shelter type entrance is located 430 m above sea level and is around 30 m wide and 2 m high. The inner parts of the cave represent horizontal passages which become narrower with the distance from the entrance. Most of them are situated at the piezometric level and have an active water flow. On the other hand, some of them are in a higher level and hydrological inactive. Except for some short sections, the passages are controlled by joints.



(Photo: M. Lipar).

Fig. 4. Fissure/joint control passage in Arneževa Luknja Cave



(Photo: M. Lipar).

Fig. 5. Wide and low passage with no visible joint control. The rock type in this section is calcareous sandstone. The scalloped bedrock is seen on the left side of the photo, while on the right side loose blocks are seen

Another typical linear stream cave is Arneževa Luknja Cave (Fig. 3). It is situated in the western part of Udin Boršt, near the settlement Spodnje Duplje. The cave entrance is located at the beginning of a pocket valley which is about 130 m wide and 300 m long. The cave is 815 m long and 13 m deep (Cave register of SAS, 2010). The shelter type entrance is 464 m above sea level and is around 16 m wide and 2.5 m high, but becomes narrower after the first few meters. A mainly horizontal passage forms the inner parts of the cave. In some sections short side passages are indicated, mostly in the middle part of the cave. Locally, vertical passages lead to a higher horizontal level of the cave. The main passage is very diverse in size, ranging from 3 m in height and 5 m in width to hardly passable. It is situated at the piezometric level and has an active water stream which can be followed upstream from the entrance to the very end of the cave, while the passages at the higher level are constantly dry. Most parts of the passages are controlled by joints and are widest at the piezometric level with narrowing rooftop (Fig. 4). However, some passages are wide and low with no visible joint control (Fig. 5) and randomly scattered stalactites (Fig. 6). This indicates that in such parts the most important morphographic influences were the bedding material characteristics and



Fig. 6. Randomly scattered stalactites on the cave roof, which indicate matrix porosity (Photo: M. Lipar).

matrix porosity. Fine-grained beds or lenses are easily eroded, hence passages are wider in these sections and narrower in sections with bigger pebbles (with diameters of 1 to 10 cm).

Numerous small caves in Udin Boršt can be defined as **shelter caves** (Fig. 7). Ford & Williams (2007) explain shelter type caves (also termed frost pockets) as a result of frost shattering, which can appear on all stronger rocks where there are wetted fractures. However, they appear to be most abundant in the carbonate rocks because they are wetted via solutionally enlarged openings (Ford & Williams, 2007). As the solution is the trigger process for large scale frost weathering about the point of groundwater emergence (Ford & Williams, 2007), they can be considered among the other types of caves listed in this paper. According to modern Slovenian standard of minimum cave length (10 m), shelter caves Arhova Zijalka and Mala Lebinca are registered in the Cave register of Speleological Association of Slovenia. However, other (e.g. smaller) shelter caves are formed in Udin Boršt. All shelter caves occur on the edge walls of the terrace or side walls of valleys (Fig. 8). In some cases they are functioning as springs or water comes to the surface a few meters lower. Most of the water flows are not active

in periods of no rain, moreover, a lot of shelter caves are completely dry. The entrances are in general up to few meters high and up to 10 m wide. The shelters commonly extend less than 10 m into the hill with no continuations of the cave (in case of continuations, caves have been interpreted as linear stream caves). Regarding the shelter caves with active streams, the water is coming into the shelter only by intergranular pores with no visible passage in the sediment. Also in the hydrological inactive shelters there are no evidences of fissures, cracks or passage indications. Some broken fragments that can be found on the shelter floors and range in sizes from sand to rocks with diameters up to 10 cm, indicate that the shelters were formed by the combined action of corrosion and frost weathering.

The largest shelter cave is Arhova Zijalka Cave (Fig. 7). It is situated in the north-western part of Udin Boršt, at the edge of the settlement Zgornje Duplje. The entrance is located on a steep slope under ~7 meters high rock wall on the elevation of 443 m above sea level. The cave extends 10 m into the rock. The entrance is 5 m high and 13 m wide. The whole cave is in the shape of a semicircle and gets lower in the inner part. There are no visible fissures, cracks or passage indications in the conglomerate.

In recent hydrological conditions Arhova Zijalka Cave is situated in the vadose zone, although it is genetically an old spring cave. In periods of intensive rainfall, the water still flows out of the conglomerate about 1 m lower, otherwise the spring is mostly inactive. The cave was formed partly by corrosion of water that was coming through intergranular pores, and partly by crumbling of the external parts of the terrace wall due to freezing of water in pores in cool seasons.

Caves, which represent collapsed domes with rubble floor, are categorised as **breakdown caves**. They are usually formed by collapses over pre-existing solutional caves. The collapse can be a consequence either of a crushed zone due to joints or of instability of the rock due to enlarged chambers in combination with weak cementation of the surrounding rock. Most of them are dry with no active water flows. In Udin Boršt, only Kačja Jama nad Spodnjimi Dupljami (except its entrance) could be categorised as a breakdown cave. However, a significant part of Kadunčev Studenec Cave is also a breakdown chamber, but the linear stream passage is still reachable through collapsed conglomerate blocks. Furthermore, several collapses have been noted in other caves in Udin Boršt, but do not have a significant influence on the cave type definition.

Kačja Jama nad Spodnjimi Dupljami (Fig. 9) is situated on the terrace in the western part of Udin Boršt, near the settlement Spodnje Duplje. The entrance, which is a 4 m deep vertical shaft with a

diameter of 0.5 m, is located on the top of an inclined slope at elevation of 504 m above sea level. The cave is 13 m long and 6 m deep (Cave register of SAS, 2010). In the inner part two chambers are formed. The western chamber is rounded with a diameter of 2.2 m and 1.6 m high. The central chamber is 7 m long, 4 m wide and up to 2.5 m high. The cave has no active water flow and only in the eastern wall of the cave there is a visible trace of joint control. Under the entrance shaft the floor is covered with sediments washed in from the surface. The floor in the inner parts of the cave is covered with breakdown rubble (most visible in the northern part of the central chamber) (Fig. 10) and individual pebbles prevailing in the entrance part of the central chamber. The fine-grained sediment from below the entrance shaft is washed to the lowest parts in both chambers. In the lowest parts of western and central chamber it covers the whole floor and flattens it. Except in the western chamber where the walls are covered with flowstone, the bedding composition of the conglomerate is well visible. In the lower part up to 40 cm thick layer of sandstone is exposed. Above this layer, conglomerate of well sorted pebbles that range in diameters from few millimeters up to 30 cm appear. The cave was formed by a collapse, most likely over a horizontal stream cave which followed the joint control in the east-west direction (still visible in the eastern part of the cave) (Fig. 9). As the fine-grained bedding material is less resistant to corrosion and erosion processes, the horizontal cave was most probably

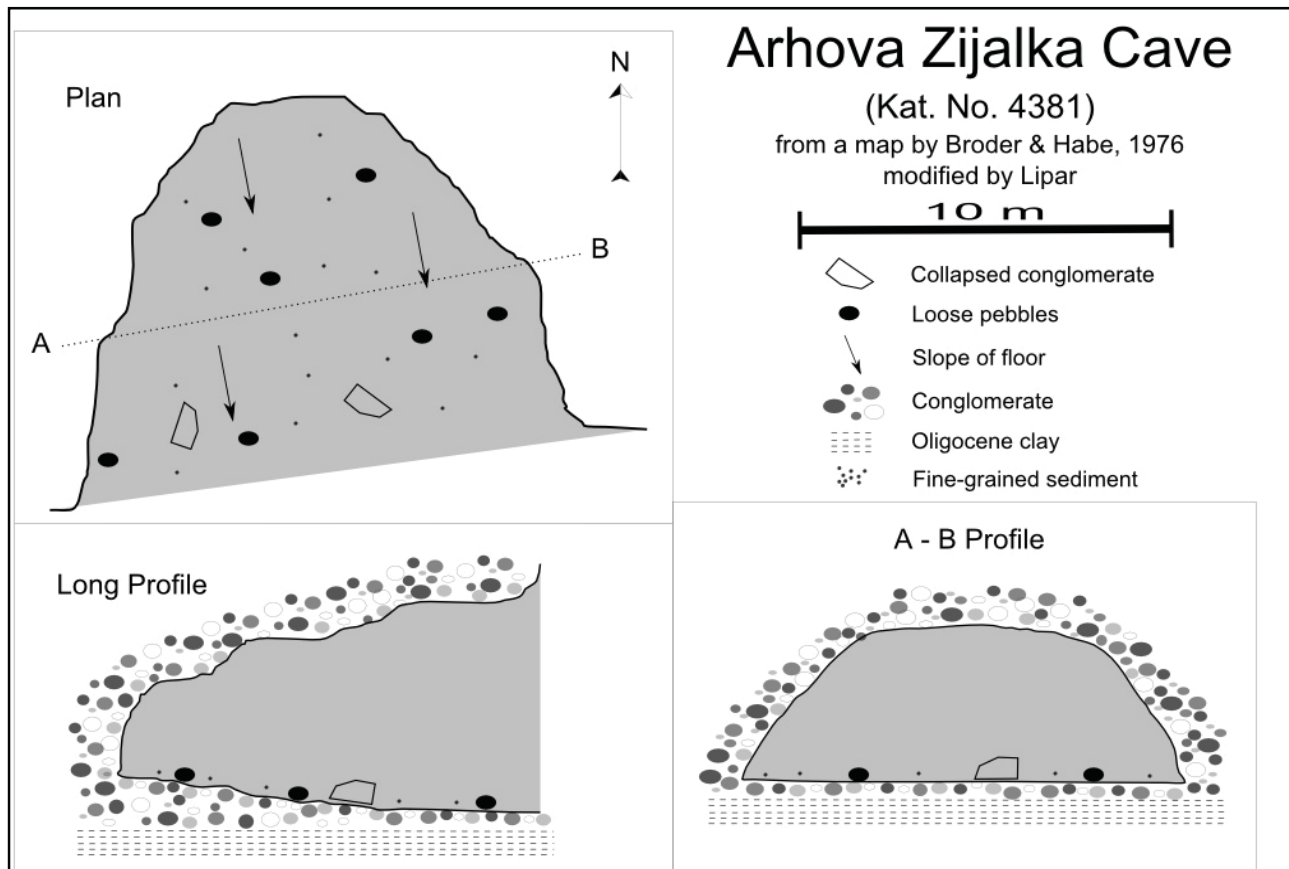


Fig. 7. Arhova Zijalka Cave map.



Fig. 8. Small shelter caves (pointers), distributed along the side wall of the valley. Exposed Oligocene clay in erosional gullies, which were formed under shelter caves, indicate, that the level of shelter caves formation was highly influenced by the contact between permeable and impermeable rock and consequently by the piezometric level (Photo: M. Lipar).

formed in the sandstone under the contact with the conglomerate above, which progressively broke down into the underlying cavern.

**Vadose shafts** are common within the inner part of Udin Boršt's terrace (Fig. 9). They can represent a whole cave (simple vertical shafts with no prospect for continuation) or just the entrance parts of caves of other types. In the second case the entrance parts and the inner cave passages are not necessarily genetically connected. Vertical shafts were formed in the vadose zone by sinking rainfall waters.

The majority of vertical shafts are less than 10 m deep and consequently not registered in the Cave register of SAS. However, vertical shafts represent the entrance of Dacarjevo Brezno Cave and Kačja Jama nad Spodnjimi Dupljami Cave. Most likely also the two inaccessible caves (at least their entrances) belong to this cave type; Brezno v Kvikšovem Pratu Cave and Jama v Arhovem Partu Cave. The first is described as a vertical shaft at least 3 m deep, but has no map for further interpretation. The second is described as a 5 m deep vertical shaft that leads to a more or less horizontal cave passage (possibly a linear stream cave or breakdown cave). Nevertheless, it also has no map and therefore an exact interpretation is not possible.

## DISCUSSION

The conglomerate of Udin Boršt has not gone through any deep burial, but went only through meteoric diagenesis, which means it is still in eogenetic stage and has thus eogenetic caves. However, not all conglomerates throughout the world are in eogenetic stage, hence caves in conglomerate should not be equaled to eogenetic caves.

The rock of Udin Boršt is very porous and permeable. During eogenesis its primary intergranular (matrix) porosity has been partly reduced by internal sedimentation of carbonate cement, but later increased by solution. Despite fabric selective type (primary matrix porosity), new additional (secondary) non-fabric selective solutional porosity has occurred as a result of neo-tectonic fractures (fissure/crack porosity) as well as tertiary porosity (conduits and caves).

Four different types of eogenetic caves have been interpreted: linear stream caves, shelter caves, breakdown caves and vadose shafts.

Linear stream caves of Udin Boršt have developed at the piezometric level in the epiphreatic zone and are permanently or ephemerally inundated by water flows. In some caves a higher level of hydrological inactive passages is reachable, which consequently means that



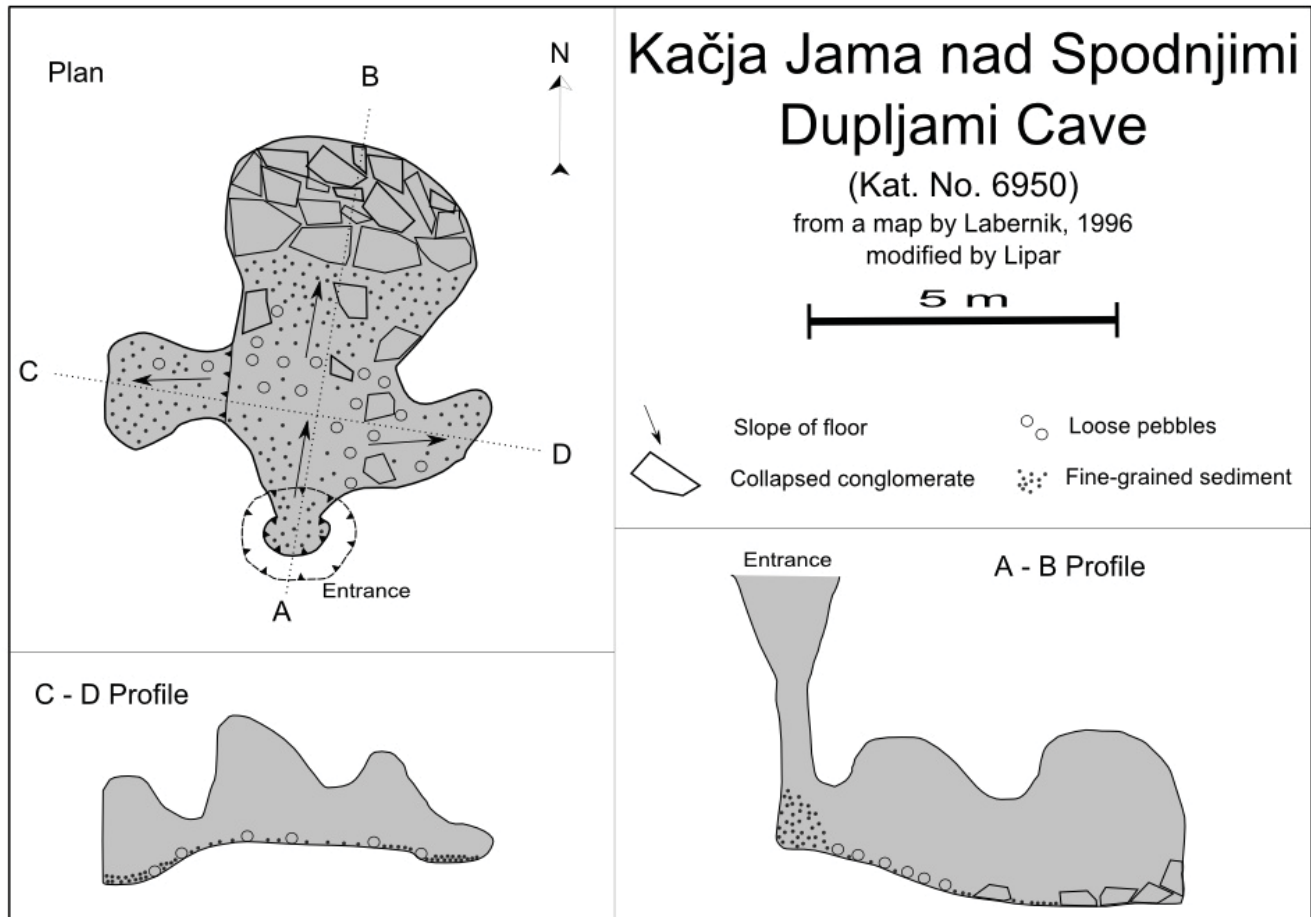


Fig. 9. Kačja Jama nad Spodnjimi Dupljami Cave map.

the piezometric level must have changed in the past.

Passages with a relatively high and narrowing ceiling are often seen in horizontal linear stream caves in Udin Boršt, reflecting the strong influence of fissure porosity. A similar influence on development of the caves in conglomerate was described by Bergadá et al. (1997), Lapaire et al. (2006) and Değirmenci & Günay (1993). Fissures are generally quite visible, even at the entrances of certain caves. Where a second cross-fracture exists, side passages developed. Strong indicators for joint control are also stalactites, which follow the cracks. Continental setting of conglomerate of Udin Boršt and strong influence of fissure porosity allow us to partly construe linear stream caves also by the traditional branchwork model (Palmer, 1991) of telogenetic karst of continental settings.

However, there are certain parts of the passages in linear stream caves (for example in Arneževa Luknja Cave) that do not have any visible fractures or any other fissure porosity influence, thus they have a matrix porosity style (Fig. 5). Control by matrix porosity is indicated also by speleothems, stalactites, which are scattered randomly on the cave roof with no visible cracks which normally influence overall positions of the stalactites (Fig. 6). These areas occur between sections of fracture-controlled passages where a carbonate bedding material had a main influence on its development. Passages with no visible fissure control are narrower when the conglomerate beds consist of bigger (between 1 and 10 cm) pebbles and

these areas resemble typical phreatic passages (very similar to other cave passages in conglomerate, for example in Italy (Ferrarese & Sauro, 2005)). Yet when the beds are fine-grained (calcareous sandstone), the poorly cemented material with no visible fissure control is easily eroded resulting in the development of wide and low passages (Fig. 7). They could be compared to calcarenite caves with matrix porosity (for example in Australia (Grimes, 2006)), or to caves evolved at the contact of the conglomerate and lenses of marls and clay in Italy (Zampieri et al., 2005). In other words, regarding sections with fine-grained beds or lenses respectively from other sections of conglomerate, we



(Photo: M. Lipar).

Fig. 10. A breakdown chamber in Kačja Jama nad Spodnjimi Dupljami Cave (gloves for scale); A: original rock wall; B: collapsed material

can define cave passages evolved herewith as classical eogenetic cave passages in calcareous sandstone that are most often described in literature (Vacher & Mylroie, 2002; Grimes, 2006).

Shelter caves most probably result from spring sapping by diffusely-fed streams through matrix porosity. Entrances usually do not reflect any visible fissures. Moreover, cave passages end abruptly with no small passages, and water (permanent or ephemeral) flows into the caves intergranularly. Since there were no important factors to collect surrounding water into a strong flow, a number of small streams developed. Hence usually a great number of shelter caves occur on the same level very close to each other. This level might be an old piezometric level. In addition to corrosion, physical weathering (e.g. frost weathering) is the same process that forms many rock shelters throughout the world and plays also a great role on the later evolution of eogenetic shelter caves in conglomerate.

Breakdown chambers are seen in numerous caves in Udin Boršt. Yet Kačja Jama nad Spodnjimi Dupljami Cave is almost totally produced by collapse and represents the breakdown cave type. Common features in Udin Boršt are also shallow vertical shafts. They are formed by focused sinking vertical water flow and may lead to longer horizontal passages, which were formed by different morphogenetic processes and could thus be defined as different cave types.

Some similarities may be recognised with eogenetic caves in calcareous sandstones, but mostly because of similar factors of speleogenesis (e. g. wide and low passages due to similar rock characteristics; breakdown caves due to collapses; fissure style passages due to fracture voids). Nevertheless, generally the characteristics of eogenetic caves in calcarenite and eogenetic caves in conglomerate should be distinguished and compared only from the rock-diagenesis (e. g. eogenetic) point of view.

## CONCLUSION

In Udin Boršt, which is a karstified terrace of limestone conglomerate in the eogenetic stage, 15 caves are known. Four general types of eogenetic caves have been introduced:

- linear stream caves, which have developed in the epiphreatic zone and are mostly influenced by fissure porosity with sections of prevailing matrix porosity and bedding material type;
- shelter caves, which are influenced by matrix porosity and physical weathering;
- breakdown caves, where the prevailing modification process is a collapse;
- vadose shafts, formed by focused sinking vertical water flow.

Speleogenesis similarities become apparent when comparing eogenetic caves in calcareous sandstone to eogenetic caves in conglomerate. Nevertheless, due to different general characteristics, eogenetic caves in conglomerate and eogenetic caves in calcareous sandstone should be considered different.

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Table 1. The fifteen registered caves in Udin Boršt.

\* Inaccessible caves with buried or destroyed entrances of which surveys are not available, so that they can not be categorised nor interpreted.

Source: Cave register of SAS, 2010.

Reg. number	Name	Entrance altitude (m)	Length (m)	Depth (m)	Cave type
763	Arneževa Luknja (Fig. 3)	464	815	13	Linear stream cave
764	Dopulnek	471	306	6	Linear stream cave
765	Velika Lebinca	430	1154	16	Linear stream cave
766	Mala Lebinca	422	6	1	Shelter cave
1075	Dacarjevo Brezno	489	307	19	Vadose shaft + linear stream cave
1076	Brezno v Kvikšovem Partu	496	3	3	*inaccessible
1077	Jama v Arhovem Partu	510	13	5	*inaccessible
1078	Arhova Jama	470	25	3	Linear stream cave
1081	Arneževa Zijalka	447	19	4	Linear Stream cave
4171	Kadunčev Studenec	457	20	6	Linear stream cave
4381	Arhova Zijalka (Fig. 7)	443	10	1	Shelter cave
4599	Pekel v Klemenčevem Gradišču	463	17	6	Linear stream cave
4694	Rokovnjača	485	10	1	Linear stream cave
6950	Kačja Jama nad Spodnjimi Dupljami (Fig. 9)	504	13	6	Vadose shaft + breakdown cave
10025	Vojvodov Kevder	472	10	2	Linear stream cave