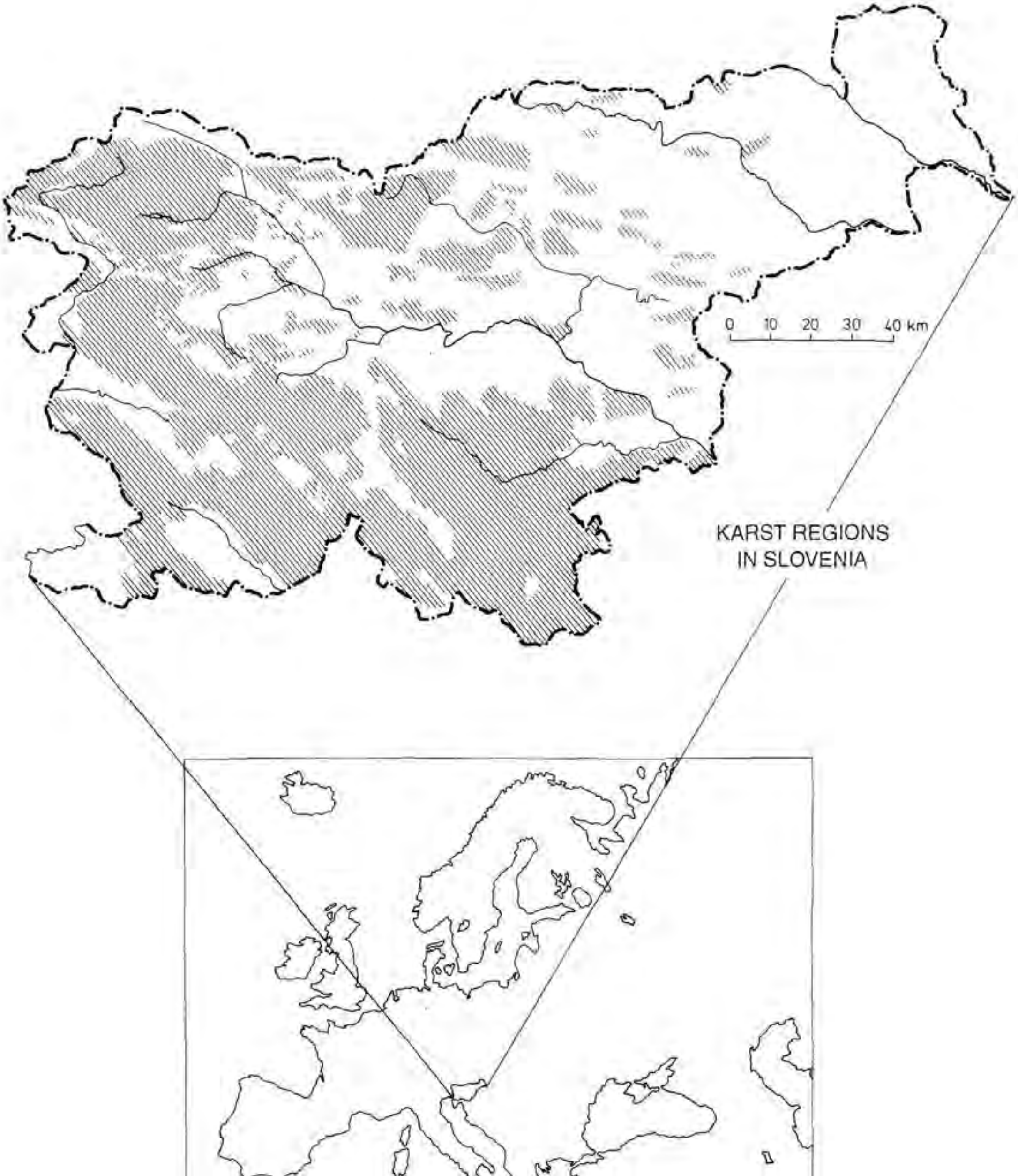


# NAŠE JAME

# OUR CAVES

35/1
LJUBLJANA 1993

GLASILO JAMARSKE ZVEZE SLOVENIJE
BULLETIN OF THE SPELEOLOGICAL ASSOCIATION OF SLOVENIA

**NAŠE JAME**
Glasilo Jamarske zveze Slovenije

**OUR CAVES**
Bulletin of the Speleological Association of Slovenia

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## CONTENTS

# EDITORIAL

*Naše jame (Our caves)*, the Bulletin of the Speleological Association of Slovenia, has been published since 1959. Although some of the articles and papers include more or less extensive abstracts in English, they provide only essential information to the foreign caver or speleologist. That is the reason why the Speleological Association of Slovenia decided to publish a special volume of *Naše jame* for the 11th International Congress exclusively in the English language. For the occasion, some of the articles, which briefly and from various points outline the Slovenian karst territory as well as the activities of the Slovenian researchers, have been selected.

Slovenia, the ex-Austrian province of the Duchy of Carniola (Vojvodina Kranjska) and later part of Yugoslavia as one of its federative republics, has been an independent republic since 1991. Almost one half of Slovenia is the karst territory, the major part of which belongs to the Dinaric karst. Beside being a karst land, Slovenia also represents the territory where speleological and karstological research was tackled for the first time in the history. The term *karstology* is derived from the Slovenian word for the region Kras (in German Karst, in Italian Carso). Many local words denoting various phenomena, e.g. *polje*, *dolina*, *ponor*, etc., were accepted into the International Speleological Terminology. In the 1830s, speleobiology was born in the cave Postojnska jama. The Slovenian karst represented the scientific workroom as well as the study to a number of foreign explorers. The foundation of the first speleological societies (Vienna 1879, Paris 1895) was encouraged particularly by the research in Slovenia, where also the Slovenians took a significant part in exploring. In 1889, the Slovenian caving club Anthron was founded in Postojna. That was the beginning of organized and planned research within the Slovenian karst region.

In Slovenia, there is the Institute of Karst Research (IZRK), which was organized in 1947 by the Slovenian Academy of Sciences and Arts (SAZU). The Institute publishes its own proceedings under the name of *Acta Carsologica*. The caving organization, today the Speleological Association of Slovenia (JZS), has been uninterruptedly active since 1910. Today it unites about 40 caving clubs with almost 1,000 active cavers. The JZS runs the Cave Register, which comprises about 6,400 researched speleological objects.

Twenty-four caves are developed as show caves, one of which is the renowned Postojnska jama, where in 1818 the modern caving tourism made a start. The tradition of cave visiting reaches back to at least the 17th century (one of the first show caves was Vilenica). As contribution to the significance of Slovenian caves, Škocjanske jame should be mentioned. These caves were included in the UNESCO World Natural and Cultural Heritage List in 1986. Individual caves have been visited since as early as the 13th century (which is evidenced by the inscriptions in Postojnska jama). Slovenian caves were used as hunting stations and periodical dwellings by man from the Paleolithic period up to the Middle Ages (which is evidenced by numerous archaeological finds).

Some of the caves were described already by the chronicler J. W. Valvasor in his book *Die Ehre deß Hertzogthums Crain (The Glory of the Duchy of Carniola)* as early as 1689.

There have been many international speleological events in Slovenia, among which is the 4th International Congress of Speleology (1965), where the International Union of Speleology (UIS) was founded on the initiative of the Slovenian speleologists. This year, the international school of karstology takes places in Slovenia as well as many international symposiums.

Slovenian cavers take part also in international research expeditions all over the world, and in Slovenia foreign speleologists research together with Slovenian cavers.

This volume of *Naše jame* should stimulate the cavers from the whole world to make personal contacts with Slovenia and its karstic phenomena, first by reading the articles but later maybe also by visiting the country.

*Marko Aljančič*

# KRAS AND KARST IN SLOVENIA

Peter Habič*

**Abstract**

This paper describes significant karst areas together with the best known karst features in Slovenia, and outlines the origin of the name and the main geographical characteristics of the Slovenian karst.

Key words: Kras (Karst), karst, karstology, geography, Slovenia.

## Short historical outline of karst investigations in Slovenia

The karst presents a distinctive type of ground with special karstic phenomena. It was named after the region Kras, which is situated in the hinterland of the Gulf of Trieste. The name is of Paleoeuropean origin (*karra* - stone); in the antiquity times, the form *Carusardius* was used. Since 1177, the Slovenian form *Grast* has been known and since 1230, the Croatian form *Kras*. In the Italian and German forms of the name, the original base is preserved (*carso* in Italian, *Karst* in German). In the international terminology, the German version Karst has been preserved, undoubtedly after the place-name Kras. The historical situation has to be recalled in order to understand why the karst developed in the westernmost part of the Dinaric range and not in some other part which is even more bare and rocky. At the time when the technical term *karst* was being introduced, most of the Dinaric karst areas were part of the Turkish empire, where communications were bad and natural sciences not really developed (Gams 1974; Kranjc 1989).

Information about the features of the Kras, particularly about the spring of the Timavo river, the Reka river and the caves Škocjanske jame (Škocjan Caves), was spread all over the world by the Greeks and the Romans (Strabo, Vergil, Pliny, etc.). From the 16th to the 19th century the periodic lake Cerkniško jezero (Lake Cerknica) was the most famous and the best described karst phenomenon (Valvasor, Steinberg). In the first descriptions (Hacquet 1778), the karst in popular

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usage denoted bare ground formed only in Cretaceous limestone. The name karst spread and Morlot (1848) used the designations "Lower Karst" for the Kras between the Gulf of Trieste and the Vipava Valley, and "Upper karst" for the wooded area betweeen Postojna and Vrhnika. Boué (1861) was the first, who used the new term in the title of his article (Gams 1974). During the last two centuries, several caves and other karst forms and curiosities were explored in the Kras, presenting today the properties of the "Classical Karst", from where not only the name of karstology derives but also the roots of speleology are found (Kranjc 1989).

Gruber (1781) described the karst hydrological phenomena more realistically. Hacquet (1778) explained karst depressions to be formed as a result of limestone corrosion. He is a predecessor of the modern corrosion karst theory. Schmidl (1854, 1858) contributed to the knowledge of the caves in Inner Carniola (Notranjsko) and introduced some Slovenian popular names for the most impressive karst features into the literature (*jama, dolina, ponor*). These names were adopted later to be used internationally. Cvijić (1893) extended Schmidl's scheme and made the detailed classification of the karst phenomena. Together with Penck and Martel he founded the karst science (Gams 1974).

The discovery of the new parts of the cave Postojnska jama (Postojna Cave) in 1818 marked a new period of speleological and karstological investigations in Slovenia. The Postojnska jama was first opened to the public in 1819, and the number of visitors has continually been increasing since, as tourists from all over the world have always been attracted to the cave. Although the Postojnska jama is in the first place a show cave, it is very important from the scientific point of view with regard to the investigations of the history of cave sciences. Valvasor was the pioneer of investigations of the natural sciences in the Postojnska jama already in 1689. The first specimens of cave fauna were discovered (cave beetle in 1831) or rediscovered (*Proteus anguinus* in 1797); for this reason the Postojnska jama is generally regarded as the cradle of speleobiology.

When the interior parts of the cave were discovered, almost a continuous line of investigations can be followed in the field of natural sciences, from the digging of bones of "pre-diluvial" animals, insect hunting, studies of cave concretions, hydrology, meteorology, seismicity, to the modern studies of cave and karst processes. After all, the actual Institute of Karst Research was located at Postojna just on account of the cave. In 1929, after the First World War, when this territory belonged to Italy, the Italian Institute of Speleology was founded with a cave register, a small museum, and a biospeleological station. After the Second World War, in 1947, the Slovenian Academy of Sciences and Arts reopened the Speleological Institute, which was later renamed the Institute of Karst Research. In 40 years, the collaborators of the Institute have published more than 1,000 professional contributions, and more than 100 of them deal with the Postojnska jama in detail (Kranjc and Kogovšek 1989).

## Distribution of the karst in Slovenia

The knowledge of different characteristics of the karst area in Slovenia has been expanded by numerous geomorphological and hydrological studies as well as by speleological mapping carried out by the Institute of Karst Research. According to all the documentation which has been collected so far, some 9,000 km$^2$ or 44% of the territory of the Republic of Slovenia can be classified as a karst area. Over two thirds of this territory (6,300 km$^2$) consist of limestones, mainly Mesozoic, whereas the karst regions in other rocks (dolomite, conglomerate, calcarenite and breccia) occupy some 30% of the whole karst territory of Slovenia.

The karst in Slovenia is commonly divided in relation to geological, hydrological and geomorphological characteristics into three major units: (a) the Alpine karst, (b) the Dinaric karst and (c) the isolated karst of the intermediate area (sub-Alpine karst and sub-Dinaric karst).

a) *The Alpine karst* (the Julian Alps, the Karavanke, the Kamnik Alps and the Savinja Alps - situated in north-western Slovenia) can be classified, according to Herak's (1977) tectogenetic criteria, as the fractured orogenetic karst. The Paleozoic carbonate rocks have been preserved only in the form of lenses and are the basis of the karst in the Karavanke range.

Much thicker Mesozoic layers, mostly Upper Triassic and Jurassic limestones and dolomites, enabled the development of larger karst areas in the Julian and the Kamnik Alps. The Alpine karst region is dissected by deep valleys, lying between the ridges at an altitude from 1,000 to 2,800 m. The plateau-like areas below the highest peaks are small, but quite extensive on Komna, Pokljuka, Jelovica, Mežakla, etc., in the border part of the Alps.

At high levels of the Alpine karst, one can find all karst forms known in the Northern and Southern Limestone Alps (big dolines - *kontas*, small dolines with vertical walls - *kotlič* (sing.), all kinds of *karren*). Recently, the 11 km long Alpine cave Pološka jama and some potholes with the depth between 700 and 1,200 m (Črnelsko brezno 1,198 m, Skalarjevo brezno 911 m, Brezno pri Gamsovi glavici 817 m, Pološka jama 704 m) have been discovered. In other Alpine karst areas, karstic hydrology is often the only karst phenomenon. Underground waters can rise up to the impervious ground but flow out to normal valleys. Karst waters emerge at the sources in Quaternary deposits at the bottom of the valleys, or directly from the steep rocky slopes in the form of waterfalls (Savica, Boka, Soča, etc.). The Alpine karst waters are comparatively pure as the surface is barren, without thick layers of soil, and less populated.

b) *The Dinaric karst* comprises continuous karst areas in western and southern Slovenia. This is the orogenetic accumulation karst consisting mainly of Mesozoic and Paleogene tectonically fractured limestones and dolomites that are often overthrusted and thus attain, as second, great thickness. The impervious rock basis is deeply under the surface, but really important are the lithological and structural differences, the inserted layers of less permeable dolomites and particularly those of Eocene flysch, which in places constitute the basis or are inserted between karstified rocks and thus hinder or direct the outflow of water along the tectonical units. In this deep karst, almost all phenomena that are characteristic of the out-flow, through-flow or impounded contact karst, can be found.

The Dinaric karst can be divided into three elongated parallel belts according to geological, geomorphological and hydrological characteristics. These are the Littoral karst (or the peri-Adriatic karst), the karst of Notranjsko (or the High karst), and the karst of Dolenjsko (or the peri-Pannonian karst). On a small scale, different morphological units alternate in longitudinal Dinaric zones.

The karst surface is composed of inherited and recent forms which are the result of the geomorphological development in several phases. Traces of the old fluvial and fluviokarstic planation have been preserved since the period when the carbonate rocks were limited and impounded from all parts by impermeable rocks. After the general planation of the stirred up post-orogene geological base, there followed the period of erosional or solutional deepening and dissection. Particular areas were either uplifted or subsided by consecutive tectonic movements, uncovered, and free limestones and dolomites were exposed to the following karst transformation. There are some shapes preserved in relief which must have originated in the humid and dry warm Pliocene climate, but other forms originated in changeable cooler Pleistocene climatic conditions.

*The Littoral karst*, extending along the Adriatic coast, is further divided into the "original" Kras area (called also Tržaški Kras or Trieste Karst or Carso di Trieste), which is situated in the catchment area of the Timavo spring, and the karst of northern Istria, i.e. the Materija dry valley and the Slavnik mountains, situated in the catchment area of the Rižana and Osp karst resurgences. The Classical Kras (Classical Karst) is formed in Cretaceous limestones and dolomites, Paleocene limestone and Eocene flysch. In the Neogene, these series were folded and faulted. The rivers from the Vipava flysch rim and the surface-flowing Notranjska Reka, draining up to the present the flysch of the Brkini mountains in the southeast, have downcut wide dry valleys and karst plains in the Classical Kras. Radinja (1972) found the remains of the gravel accumulation of Neogene rivers. The brooks from the Brkini have eroded 12 blind valleys on the southern footslope (Gams 1962).

The longest blind valley is that of the Notranjska Reka-Vremska dolina with its terraced bottom (Radinja 1967). The river Reka sinks into the caves Škocjanske jame. There are two fresh collapse dolines and many older ones there. The Škocjanske jame present the largest natural curiosity of the whole Classical Kras, they are part of the typical morphogenetical unit of the contact karst, unique in Europe regarding its phenomena and dimensions.

A 1 Alpine karst; B Dinaric karst: 2 Low Littoral karst, 3 High karst of Notranjsko and Dolenjsko, 4 Low karst of Dolenjsko and Bela Krajina, 5 High

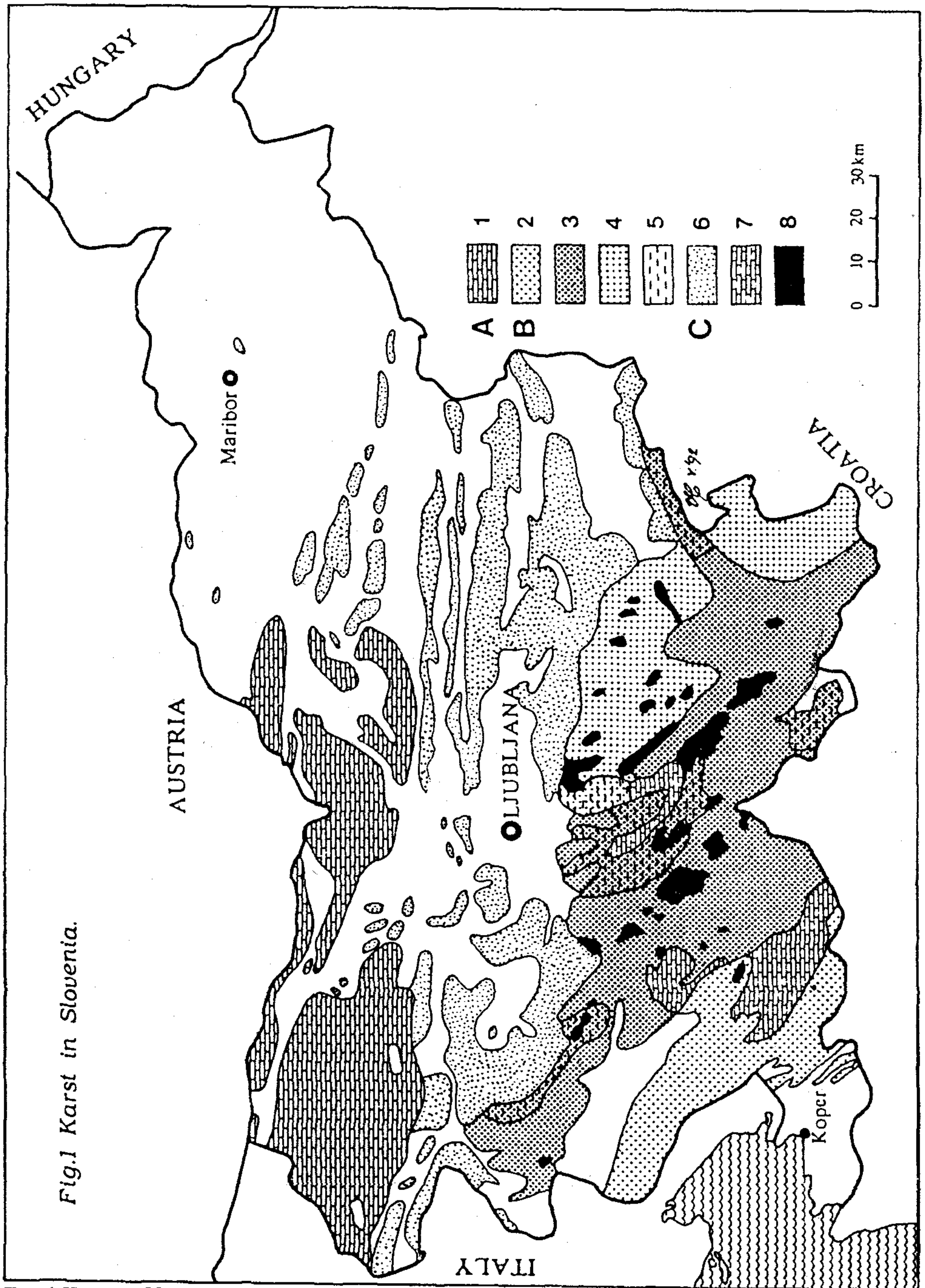


*Fig.1 Karst in Slovenia.*

*Fig. 1 Karst in Slovenia*

karst on dolomite; C 6 Isolated sub-Alpine and sub-Dinaric karst; 7 Fluvial surface with underground out-flow through the karst; 8 Karst polje, large karst depression.

In 1986, the natural reserve Škocjanske jame and its vicinity were included in the UNESCO World Natural and Cultural Heritage List as an example of the caves of extreme dimensions and the karstland with rich history and interesting cultural traditions.

By gradual karstification, which started with the erosional or tectonical lowering of the impermeable flysch border of the Kras, the valley of the Reka got incised more and more. At the ponors disappearing underground under 450 m a.s.l., a blind valley, 130 m deep, 5 km long and up to 2 km wide, was cut at four terrace levels. The actual Reka ponor lies beneath the 108 m high wall of Škocjan at 317 m a.s.l. The entrance passage is narrow and high, developed along a large fissure, therefore the passages range from 50 to 80 m. The axis of the Škocjanske jame is presented by the 2.5 km long underground canyon with no lateral active water channels, at the end of which there is a deep siphon. The underground continuation of the Reka between the Škocjanske jame and the 8.6 km long cave Kačna jama near Divača is unknown for the distance of 1,500 m. Unknown is also the underground flow between the Kačna jama and the 30 km distant Timavo springs. With the dry cave section, which is rich in speleothems and situated at a higher level, with its mighty stream canyon, with its archaeological and biological significance, the cave is, beside the Postojnska jama, the greatest jewel of the Slovenian karst, but still not entirely appreciated in tourism. So far, the cave research organizations of Slovenia have registered more than 700 caves and potholes within the Classical Kras area with about 500 km$^2$.

*The karst of Notranjsko* ("Inner Carniola") belongs to the central highest Dinaric belt and is separated from the Littoral karst by a narrow belt of impervious Eocene flysch. High, wooded and scarcely populated karst plateaus at an altitude from 800 to 1,700 m with intermediate lower valley-like karst depressions situated at an altitude between 400 and 600 m are predominant in this area. The karst is developed primarily in Triassic, Jurassic and Cretaceous limestones and dolomites, but there are also small sections of impervious marls, sandstones and schists that divert the surface waters and dam the undergeound streams, and thus influence the formation and the layout of the through-flow karst. The high out-flow karst can be subdivided in relation to the structural tectonic and morphogenetic characteristics into the following more or less coherent hydrogeological units: the Banjščice, Trnovski gozd, Hrušica, Nanos, Javorniki, Snežnik, Krim, Velika gora, Kočevski Rog and the central part of the Gorjanci mountains. Karst waters flow out of these units in several directions and feed the karst springs and exurgences in their border zones.

Lying between these high areas of the out-flow karst, there is the central part of the through-flow karst of Notranjsko. Across it, the surface and underground waters flow forming intermittent flowing streams that flood the karst poljes. A considerable part of the through-flow karst belongs to the drainage basin of the Ljubljanica river, but some waters drain also towards the rivers Kolpa and Krka. There is a string of karst poljes in the upper parts of the Ljubljanica tributary area including the Prezid, the Babno polje, the Rakitna, the Bloke, as well as the better known poljes of Lož, Cerknica and Planina, the Logatec contact polje and the Pivka Basin. The main resurgences for these waters are located along the western fringe of the Ljubljansko barje (Ljubljana Marshes) (Habič 1982). There is the famous Cerkniško polje (Cerknica Polje) with its periodic lake and numerous springs in the south-eastern part, and ponors in the central part as well as on the north-western side.

In the Notranjsko podolje region, only the polje of Postojna- Pivka contains a large flysch area. The rivers draining the flysch have formed many caves in Cretaceous limestone. The longest is the Postojnska jama (19.5 km), which is the most visited European cave (since the discovery in 1818 more than 25 millions of tourists). Other active caves are situated at the outlet side of the poljes (Predjama 7.5 km, Karlovica 7.3 km, Tkalca jama 2.8 km, Najdena jama 5 km, Logarček 2.3 km, Križna jama 8.1 km), and rarely at the spring side (Planina 6.1 km, Zelške jame 3 km). On 30 km of the triangle territory between Postojna, Lož, and Logatec, there are 60 km of cave passages, which is the greatest cave density in Slovenia (Gams 1974; Habič 1982a).

The second valley-like depression to the east of Notranjsko podolje includes the western part of Dolenjsko. The karst poljes of Grosuplje, Ribnica, and Kočevje belong to this unit as well as the Dobrepolje and the Gotenica-Morava dry valley. Waters drain both to the Krka and the Kolpa. The polje of Kočevje (about 60 km) is the largest polje in Slovenia; it also has the character of a peripheral polje, due to a small patch of Neogene sediments (Gams 1974).

*The karst of Dolenjsko* ("Lower Carniola") belongs to the shallow out-flow through-flow karst of the inner Dinaric or peri-Pannonian belt. The surface is covered with a thick layer of red karst soil, the typical terra rossa, which has enabled denser population in more continuous tracts of agricultural land use. Gentler forms, dolines, uvala-like depressions, even small karst poljes and rounded hills, are predominant in the karst relief. Waters derive from the impervious and dolomitic rims of the karst areas and flow only at small depth under the surface or even in shallow open canyons.

c) *The isolated karst* of the sub-Alpine and sub-Dinaric Slovenia is subdivided, according to geological, orographical and hydrographical characteristics, into several homogenous isolated units. The hydrological significance of the isolated karst depends on the location and size of carbonate rocks. Both the shallow and the deep, the out-flow and the through-flow karst areas can be found in this part of Slovenia beside the impounded karst with siphons and the dome karst with the gravitational drainage of the underground waters. Some forms of endokarst covered with impermeable rocks that caused trouble by intrusions of water to the coal mines, have also been identified. Karst waters deeply under the valleys with surface streams have been identified in the mining areas of Idrija, Velenje, Zagorje, Trbovlje, Mežica, etc. The isolated patches of the karst are important natural reservoirs of underground water for the local supply. Some caves are interesting for tourism (Pekel, Huda luknja, Železna jama, Kostanjeviška jama).

## Some geographical problems of the karst in Slovenia

The karst is a particularly delicate natural environment having been differently evaluated, conserved and used during the centuries. The former type of settlement and economic karst exploitation was mostly connected with natural possibilities of agriculture. In higher-lying regions, the Dinaric-Alpine cattle-breeding type of farming predominated, while in the lower-lying karst, the Mediterranean and sub-Pannonian agricultural types. For agriculture in the karst, the distribution and thickness of soil are of extreme importance. In this regard the depressions are more favourable - the population is denser there than on higher-situated karst plateaus.

Karst exploitation changes with the social development, influencing the origin of special types of karstland. Cultivating the semicovered karst, man has altered the character of the karst surface and built terraced slopes. The evidence of the huge amount of work done by cultivating the semicovered karst is given by the dry karst walls. The Slovenian karst was more deforestated and barren in the last century. During that time reforestation, predominantly with the Austrian pine (*Pinus nigra*), began. Recently, bushes and trees have started to grow on many abandoned pastures, since the karst area is in the most intense depopulation process in the whole Slovenia. The shortage of drinking- and industrial waters, and the scarcity of soil are a great obstacle for the economic development of karst areas.

For centuries, water shortage in the karst has been surmounted in different ways. Man used to catch rainwater from the roofs, kept it in wells, watered the cattle in pools where rainfall remained on a kneaded layer of red soil at the bottom of dolines. Beside the water supply, a great problem in the karst was posed by the flooding of karst poljes. Man cleaned and widened the swallow holes to accelerate the outflow. Later he tried to retain the water by irrigation dams, energy and tourism. With the increase of general need for water, the karst regions become an important water source, but at the same time waste waters augment together with the problems of conservation of the karst springs and the protection of their catchment areas.

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# HYDROGEOLOGICAL RESEARCH OF THE SLOVENIAN KARST

Dušan Novak*

**Astract**

**Hydrogeological investigations within the region of the Slovenian karst were at first directed to solving the questions concerning the usage of karst flood waters for hydroenergetic purposes, subsequently there appeared the need to intensify the protection of karst underground water with regard to drinking-water provisions. The sources of pollution have been exposed, and the regional hydrogeologic map completed.**

Slovenia is considered to be the land of the "Classical Karst", for which it is renowned particularly within the geographical sphere. Beside 7,000 km of extensive and continuous karstified region in S and SW Slovenia, there are also karstified regions in the Julian and the Savinja (Kamnik) Alps, some patches of karst are in the Karavanke range and the Alpine foothills, and there are isolated karst areas in the E and NE parts of Slovenia, formed in carbonate rocks of the sub-Pannonian hills. The whole karst territory of Slovenia occupies the area of 9,000 km. Slovenia with its 20,251 km is a karstic land which formed in limestone (during various periods of geological time from the Triassic to the Tertiary), in dolomite (under favourable conditions from the Palaeozoic to the Triassic), and in Pleistocene conglomerate. These rocks, which are liable to karstification, compose about 44% of the Slovenian territory. A relatively clear regional geological review is demonstrated by the basic geologic map (scale 1 : 100 000), completed on the basis of the previous work and the systematic mapping during the last decades. There are certainly different individual opinions of the geotectonic structure, which is to be understood, as the contact territory of the Alps and the Dinaric range is represented by active and complex tectonic conditions, and carbonate rocks of different ages and petrographic characteristics. Watering of the area is

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another important factor in the process of karstification. The annual amount of precipitation ranges between 1,500 and 3,000 mm.

Hydrogeological research of the Slovenian karst has been fairly intense. It was subsequent to geological investigations or contemporaneous with them with regard to the previous economic and hydroeconomic requirements. Besides, there were great requirements

to solve the floods in the karst poljes. After World War II it was required that karst waters should be used for hydroenergetic purposes (Novak 1988). Subsequent were the questions considering water provision as well as the protection of karst underground waters from the pollution.

The consequence of the research is karst regionalizing according to some other criteria. Some of the authors, i.e., M. Herak (1972), M. Komatina (1972), Djerković (1971), and some others of the earlier period, believe that karst should be treated as a complex phenomenon influenced also by lithostratigraphic conditions and the tectonic development of the territory. The geological structure of a region determines above all the development and type of karst, as well as the hydrogeological function of rocks, the courses, directions and types of water flow, the depth of karstification, the depth and type of underground water accumulation, the oscillation of the underground water-level, etc. According to these criteria, the karst of the Croatian Dinarides has been regionalized too, and in Bosnia the karst territory has been divided according to interacting relations of various categories of rocks and the consideration for lithological and stratigraphical conditions, as well as geomorphological development beside climatic and other characteristics (Novak 1979). According to the depth of karstification, J. Roglič (1976) divided the Dinarides into two zones, the Littoral and the Inner, the latter corresponding to the range of the inner Dinarides.

These criteria were also taken into consideration during hydrogeological analyses of the Slovenian karst (D. Novak 1979). The territory of south and southwestern Slovenia was divided into the:

*Adriatic zone*, which is an autochthonous and parautochthonous territory extending from the Adriatic Sea to the Vipava Valley. This is the region of the distinctive superficial and subterranean run-off to the Adriatic. Underground water emerges in resurgences on the coast and in *brojnice* (submarine springs). There are developed zones of vertical and horizontal percolation, as well as an extensive transition zone. The two zones of the deep percolation as well as the run-off through the siphons have also been observed.

*High karst*, which is distinctive of its nappe structure being as well characteristic of the nappe structures of the northern Alps. The consequence of the geological past is demonstrated by four nappes. The depth of the rocks liable to karstification is large. Characteristic is a disconnected river system with karst poljes, sinking streams, underground streams and resurgences. All hydrodynamic zones are being observed. One of the characteristics of the High karst is run-off of superficial and subterranean waters in different directions and, in some places, the run-off into various river basins.

*Inner karst*, which is situated in the eastern part of the karstified Slovenian territory. Also typical of this part of Slovenia is the overthrust structure covered by numerous faults which give the superficial development a specific character. The depth of karstified rocks, i.e. the karstified zone, is smaller, distinctive are the two thin zones of vertical and horizontal percolation, and in places a zone of deep percolation can be foreseen. Karst poljes are not characteristic and there are no large sinking streams. The typical fluviokarst, which is a compound of superficial washing away and karst erosion, is already developed.

Hydrogeologic investigations of the karst illuminate important questions about the connection between sinking streams and resurgences of underground water. The subject was of great significance already in the early times (Kranjc 1982) when various research methods were being used, these methods were being developed and were later successfully used in construction, mining and urbanization (Novak 1991). New tracers are being used. During the investigations of the Slovenian karst - the 3th SUWT 1972-1975 - the data of the tributary area of larger springs were collected, but it was realized that also the data of the run-off of high and flood waters are needed. In some regions, the run-off of underground waters into different water basins was established particularly during middle and higher waters (Bauer et al. 1976; Novak 1991).

Parallelly to all these investigations, the quality of underground water was observed and the risks of pollution were taken into consideration, too. Some of the karst regions are rather densely populated, but they have no appropriate sewage system or waste disposal sites. The Karst settlements are the sources of pollution which is caused by household waste waters as well as industrial effluents. The industry itself does not have appropriate purification plants. Waste waters are being spillt and refuse is being dumped at illegal disposal sites in dolines or potholes. Not all legal land fills are adequately built up and secured.

In the karst region there are significant drinking-water supplies. Karst underground waters are used as drinking water in Jesenice, Bohinj, Tolmin, Idrija, Vrhnika, Postojna, Nova Gorica, Ajdovščina, the Vipava Valley, the Karst, the Koper Littoral, and partly in Dolenjsko, Bela Krajina, etc. (Habič 1989). There are only five municipalities in Slovenia without the karst and karst waters (Habič 1989a).

Almost all human activities within the karst territory are concentrated in karst poljes which are areas with favourable conditions for agriculture, industry and communication network, in short, for urbanization which intensity is also large on the Karst plateaus. In karst poljes there are water streams and sinking rivers which disappear underground at the contact of a karst rock and some other rock. These waters drain off almost all the effluents of their own regions. Underground water emerges on the surface in more or less remote resurgences.

Plenty has been written about karst pollution (Novak 1985), and the subject has been discussed, particularly the communal and industrial waste waters, waste disposal sites, spillages of liquid manure out of farms, and traffic accidents (Habič 1989). Karst waters are in general inappropriate for drinking due to the bacteriological pollution of faecal origin. Chemical pollution is no rare occurance. There are more and more industrial plants which do not belong to the karst area. Examples of the pollution and drinking-water problems are the rivers Krupa and Notranjska Reka as well as the caves Škocjanske jame.

Underground water tracing should solve practical questions, discover and research the tributary area of the springs which are significant of drinking-water provision and should be thus protected from pollution. During water tracing attempts it was found out that underground water-flow velocities (Novak 1991) range between 0.2 and 29.6 cm/s, in the Alps between 0.002 and 24.0 cm/s, and in the isolated karst between 0.8 and 5.2 cm/s. In general, very remote springs can be influenced by pollution in a very short time. One of the major sources of pollution is dumping of waste material in dolines and caves, which has been pointed at by the cavers for a long time (Habe 1989), but the situation is getting even worse, which was demonstrated by the activities of the Speleological Association of Slovenia (Puc 1987) and the reports on the number of polluted caves in Slovenia (Hudoklin 1987; Drame 1989; Klepec 1989). The situation in Croatia is not much better (Božičević 1982). It was particularly pointed at the pollution of the Notranjska Reka river and the discovery of its polluted underground stream flowing through the cave Kačna jama, and later at the hazardous effects of tourist visiting, the latter was mentioned by the authors as early as 1829, when in the cave Postojnska jama breaking of dripstone formations was prohibited for the first time (Habe & Kranjc & and Simić 1991).

There were two symposiums on the pollution of karst*

II. Yugoslav Symposium on the Karst Protection and Show Caves by the UIS Commission, Sežana, May 1990 which dealt with numerous data and mistakes, as well as the recklessness. They pointed out that the seventies were very hazardous for the karst. By increasing of the urban planning, there were many new industrial plants which were built with inadequate purification plants. The communal public sewage system and the purifying of effluents were not at the same level.

It has been reported by the cavers that there were 44 caves in the region of Novo mesto, and another 13 which were used as disposal sites for carcass and various waste materials. The municipality of Črnomelj reported 11% of the caves being polluted, the municipality of Metlika 54%, and the municipality of Cerknica 20%, not to mention numerous other examples.

* *The international symposium "Karst Protection to the 160th Anniversary of the Tourist Development of Škocjanske jame", Sežana, October 1982;*

As has already been stated, this treatment affected the underground water, the springs are more or less polluted, because natural purifying is a long and slow process, water purifies only temporarily and mechanically, but there are no sufficient filtration and some other conditions for the bacteriological and biological purification of the water. The intensity of pollution in the Alps has been drastically increasing in the areas with tourist facilities (Novak 1991a).

The quality of underground water endangered human activities already in the remote past, deforestation and inappropriate approach to the flooding on karst poljes. The consequence of all that was in the first place erosion of soil, which is still in progress in the tourist resorts of the mountainous karst. The increasing intensity of drinking-water provision caused an increased quantity of effluents, and the increased quantities of liquid manure have been intensified by agriculture and stockbreeding. All these human interventions had no respect of the boundaries set by the natural possibilities of the environment.

The last water reservoirs of drinking-water are to be found only in the Alps. Recently, water sources in the water basins of the rivers Soča, Sava, Savinja and their tributaries have been threatened by tourist interests, i.e., summer and winter Alpine tourism and demands for the facilities in the high mountainous region, as ski-slopes and settlements with new tourist facilities, etc.

According to Plut (1989), the development policy should be based on the profound knowledge of all characteristics of the Slovenian territory. Subsequent should be the renewal of economy.

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# KARST DENUDATION MEASUREMENTS IN SLOVENIA AND THEIR GEOMORPHOLOGICAL VALUE

Ivan Gams*

**Astract**

As the Slovenian karst extends from the Alps to the Mediterranean Sea, the previous measurements of karst denudation on the surface, in the soil, in caves, and within the water basins are significant for the development of the karst phenomena in the zone from the periglacial to the Mediterranean climate. There have been restraint estimations about the surface development of the previous geological periods taking into account the present rate of karst denudation (solution), as the temperature and the quantity of precipitation were changing rapidly and intensely.

## Introduction

On the karst territory of the present Republic of Slovenia, covering about 8,500 km, there are various conditions for karst denudation, although from the karst rocks only carbonates (limestones, dolomites, partly conglomerates and breccias) are represented. The average annual temperatures are between 13.8 C (on the coast of the Adriatic Sea near Izola) and 1.8 C at 2,514 m above sea level, below the highest Slovenian peak Triglav (2,864 m). The average annual precipitations are between 3,500 and 1,200 mm, the major part of the Dinaric and the Alpine karst territory receives annualy above 1,500 mm. The mountainous slopes are mainly fluviokarstic (because of the significant denudation and erosion mainly without karstic close basins), the plateaus are karstic.

Measurements of karst water hardnesses were first carried out at the beginning of the 20th century (Kramer 1905), and systematic measurements of karst denudation at the beginning of the second half of this century. The first publications dealt with water mineralization according to the German hardness degrees (1 German hardness degree = DH is in the equivalent 17.8 mg $CaCO_3$/l). Karst denudation of the surface and soil is here calculated by microns of dissolved limestone, and that of larger river basins by $m^3$ of $CaCO_3$/km/annualy.

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## 1. Measurements on the carbonate surface

In 1977, the Commission on Karst Denudation of the International Union of Spelaeology entrusted in Sheffield the authour of this paper, as Chairman of the Commission, with the task to organize systematic measurements of karst denudation by means of the so-called standard rounded limestone tablets, 2-3 mm thick and 42 mm in diameter. In order to eliminate lithological factors, which affect karst denudation, the chairman of the commission sent to his collaborators from all of the continents, who organized 60 stations, limestone tablets, made of the limestone from a quarry near Lipica (a settlement in the Slovenian Karst region). The tablets were hung horizontally 1.5 m above the surface, placed on the surface and put into the soil at different depths.

After a year of exposure, the loss of weight in the tablets was measured by the laboratory scales. The loss was calculated to a day/cm of the surface. The results were partially published in the Proceedings of the Commission on Karst Denudation ISU, and the complete results for the whole world (Gams 1985, 1989). After that organized action many countries have been proceeding the measurements by means of the tablets made of their own limestones (or gypsum). These were particularly successful during the investigation of minute variations, e.g. at the sections across a doline, in surface water streams (in aggressive waters the losses were the largest), and in caves.

The results of this paper are stated only for Slovenia with six active stations. 1.5 m above the surface the largest solution losses were recorded in the mountain basins, as the air in those places is being polluted due to the temperature inversion and industry, and because of the fog present up to 150 days a year (Ljubljana). The denudation in these basins is on the average 19 microns/year, which is far more than that of two other stations in the Alpine high mountains. At 2,000 m above sea level, the loss of the tablets laid on the rock base was only 1.3-2.9 microns (Rebek 1965; Gams 1985).

The tablets placed on the bare ground proved on average a lower karst denudation.

Solution measurements, which were partly carried out by means of the microerosionmeter, on Mt. Kanin, with some metres of snowfall in winter and the total of 3 m of annual precipitation, resulted in winter at the bottom of snowed up dolines in up to 102 microns, and on elevations in 20-30 microns (Kunaver 1976, 1978, 1979). The hardness of water flowing from a glacier or snowfields in the high mountains is 10-30 mg/l (Gams 1966). When the water comes out of small accumulations of sand and rubble mixed with humus, the hardness is twice as large.

In the Dinaric karst, the measurements of karst denudation were less systematic on top of protruding rocks during the rainfall. The measurements prove the dependence of denudation on the velocity of water flow. Water hardness in steep, bare *rundkarren* during intense precipitations is often lower than that of the gentler ones during a weak rainfall. Water hardness in *kamenitzas* (*solution* *pans*) is often higher, and depends on the quantity of humus at the bottom of a kamenitza and the time of water stagnation (Gams 1966, 1969, 1981).

## 2. Measurements of solution in the soil

In the region of high mountains (1,700-2,514 m), the standard tablets put into the Alpine black soil resulted in only 5-8 microns of corrosion. It is supposed that frozen soil diminishes the solution during a considerable part of the year. In the lower karst, where the tablets were usually inserted 10-20 cm deep, the karst denudation with 7-9 microns was recorded (Rebek 1965; Gams 1985).

## 3. Water hardness in potholes and caves

In the high mountainous karst of the Kanin range (1,600-2,100 m), the hardness in four potholes was 70-93 mg $CaCO_3$/l (Kunaver 1976, 1978). In the mountains, there are usually no recent flowstone and dripstone formation processes in the caves situated at above 1,000 m above sea level, with the temperature below around 7 C, and the hardness of percolating water being less than 120 mg $CaCO_3$/l (Gams 1975). But there are many exceptions to the rule.

In the intensely fissured rocks of the lower karst covered by soil, the water after a moderate rainfall and after the percolation through some metres of limestone (as measured in a cave near Postojna), reaches 114-167 mg/$CaCO_3$/l (Gams 1966).

Hardness of percolating water was even more sistematically measured in the cave Postojnska jama in 1962-63 (Gams 1966). The measurements in particularly this cave and also other Slovenian caves were carried out by the Institute of Karst Research ZRC SAZU at Postojna (Kogovšek 1981, 1982, 1983, 1984, 1990; Kogovšek & Habič 1981). The measured hardnesses of water percolating through a hundred and more metres of ceiling limestones in those caves are between 160 and 240 mg $CaCO_3$/l. As a rule, hardnesses are highest in late autumn and early winter, and lowest in spring and summer. In some cases the quantity of percolating water influences water hardness, but in some cases it does not (particularly during the months with high water hardness). Karst denudation cannot be calculated from the hardnesses of percolating water for a particular surface, as the range of the area where the water comes from, is unknown. In the region of the low karst, it occurs only exceptionally that aggressive water with the hardness of under 70-90 mg $CaCO_3$/l reaches the caves some ten or some hundred metres beneath the surface. It is evident from one case (the cave Planinska jama) that the concentration of the suspended (not chemically dissolved) material reached up to 255 g/$m^3$ during very high waters (Kranjc & Kogovšek 1980; Kogovšek 1981). Percolating water in the lower Littoral karst with the sub-Mediterranean climate is as a rule harder than 210 mg $CaCO_3$/l.

Hardnesses of percolating water in the caves of the high mountains, beneath the rocky surface, are under 90 mg $CaCO_3$/l.

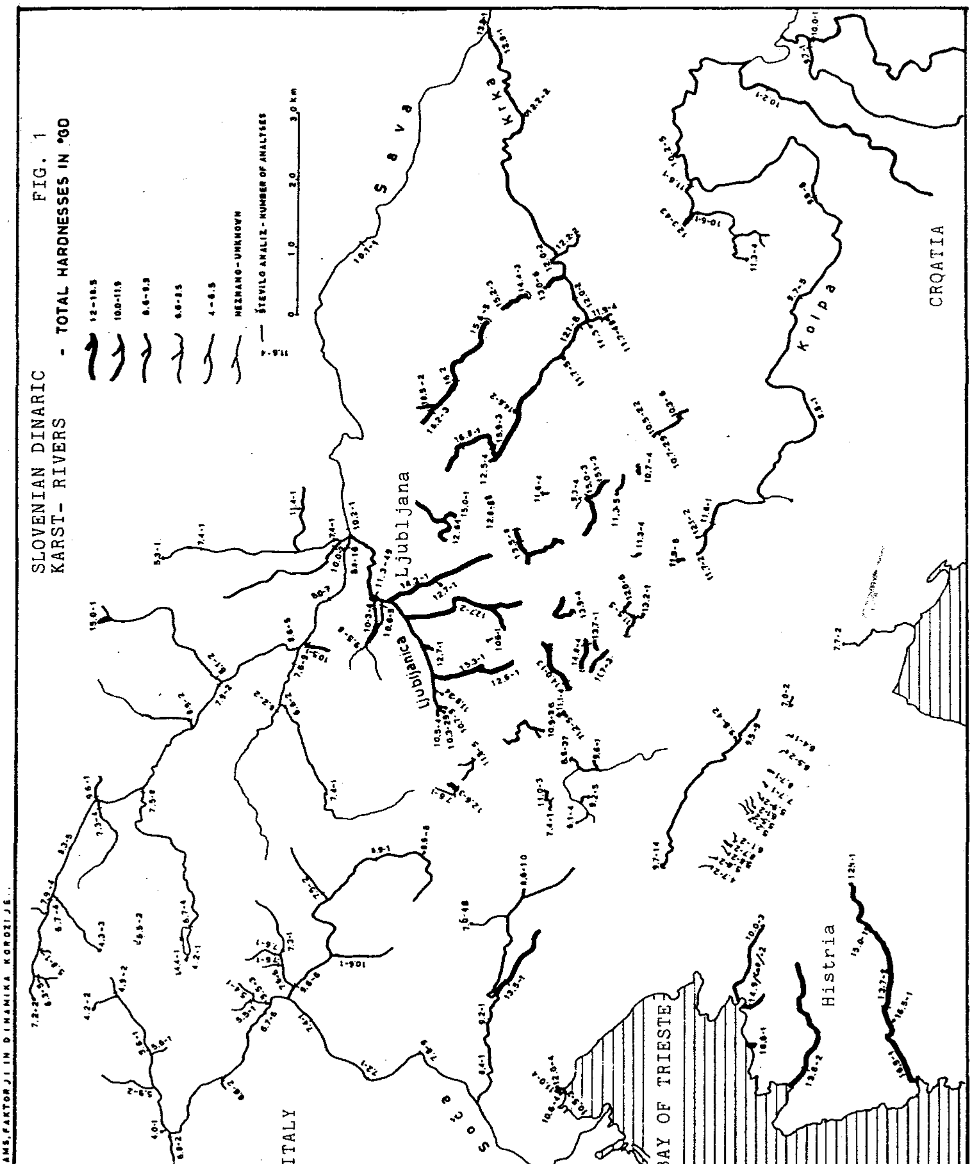
## 4. Karst denudation calculated from the spring water hardness and specific run-off

The majority of systematic measurements of temperatures and water chemistry was carried out at karst springs. Seasonal oscillation of carbonate hardness in the high mountainous deep karst is insignificant, with the maximum hardness reached in winter (Novak 1971, 1978). In the karst of moderate altitudes, the highest hardnesses are usually in late autumn and early winter, and the lowest in spring and summer. In the deep karst, hardnesses of some of the springs are without major seasonal oscillation. During the year, $MgCO_3$ and $CaCO_3$ which are dissolved in water do not oscillate synchronously even at the same springs (Kolbezen 1976; Zupan & Kolbezen 1976). The positive correlation between the temperature and water hardness at karst springs is unquestionable. But the difference between the cold water with low hardness in the high mountainous region, and the warmer and harder water of the low karst (in SE Slovenia, the Slovenian Littoral and Istria) is at the same time influenced by various annual precipitations (Gams 1966, 1972, 1976, 1981). These precipitations amount to over 2,000 mm in the Alps and to under 1,300 mm in the low karst. That is why the influence of the temperature and the quantity of precipitations cannot be separated. The hardness of karst springs with the water from the rocky high mountainous karst is 75-90 mg $CaCO_3$/l, together with the lower border wooded karst a little higher (Belič 1961), and that in the low Littoral zone beneath the deep and heay soil up to 300 mg $CaCO_3$/l (Fig. 1).

Unfortunately, the range of the river basins in the high mountainous region as well as that of some small surface karst river basins is unknown. But supposingly, there are specific run-offs with up to 80 l/km/sec in the Alpine karst of the Julian Alps above the tree limit and grass line. Therefore, low water hardnesses in this case do not as well cause lower denudation which can be calculated out of the water run-off from a river basin as well as the total hardness.

The factor of not entirely known watersheds in the karst underground world loses its significance with regard to larger river basins. The total water hardness of the dolomite river basins, situated between the middle and lower altitudes, is as a rule a little higher than that of the adjacent limestone river basins (magnesium carbonate represents up to 50% of the dissolved minerals in dolomite waters). But the specific run-off is slightly lower in the dolomite type of terrain.

Karst denudation, calculated out of the average run-off (l/sec/km), the area of a river basin and the average annual water hardness, reaches in the Slovenian as well as the adjacent Istrian karst the values between 20 and about 100 $m^3$ $CaCO_3$/km/annualy (see Fig. 2; according to Gams 1966, 1979). In the minor river


SLOVENIAN DINARIC KARST- RIVERS
FIG. 1
- TOTAL HARDNESSES IN °dD
NEZNANO - UNKNOWN
ŠTEVILO ANALIZ - NUMBER OF ANALYSES
Sava
Krka
Kolpa
Ljubljana
Ljubljanica
Soča
ITALY
CROATIA
Histria
BAY OF TRIESTE

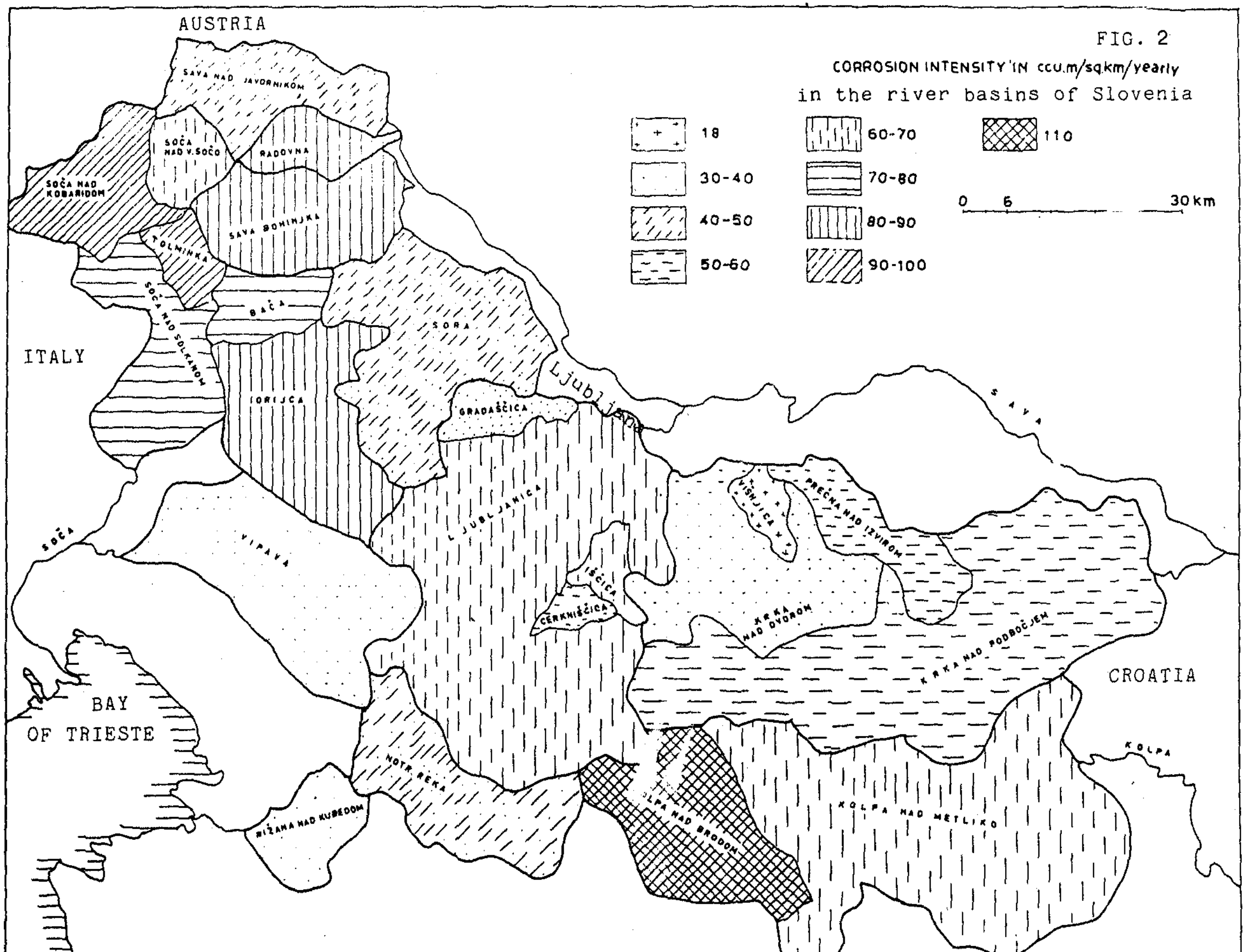



FIG. 2
CORROSION INTENSITY IN ccu.m/sq.km/yearly
in the river basins of Slovenia

basins with the approximately known watershed and abundant annual precipitations, it reaches up to 130 $m^3$ $CaCO_3$/km/annualy (Habič 1968; Kolbezen 1976). Karst denudation declines according to the decreasing of annual precipitations as well as the specific run-off, and according to the increasing of the annual evapotranspiration (which is between 450 and 800 mm; in the rocky high mountainous karst considerably less).

## 5. Consequences for the karst geomorphology according to the conclusions of karst denudation in Slovenia

The results support the opinion that the primary factor for the rate of karst denudation is water run-off. The significance of air temperature is double; the low temperature diminishes the activity of organisms and the formation of organic acid in soil, and high in the mountains it decreases evapotranspiration and increases specific run-off. The activity of organisms at a high temperature and an appropriate humidity is higher, the chemical process of solution faster and confined to the upper layers of the karst rocks.

According to the two above mentioned statements, the statement of many karst geomorphologists that in the recent temperate climate, karst denudation was more intense in the pre-Quaternary geological past with the higher temperature, is controversial. At higher temperatures, evapotranspiration which diminishes the specific run-off is higher, too. And the run-off is the main factor. During that period, karst denudation was higher only when there was a considerably larger amount of precipitations. From our results it is evident that in the cold areas (and the periods) with the temperatures below zero, karst denudation was reduced because of the permafrost. As the dolomite terrain consists of the more connected soil cover, in the cold climate of the Pleistocene, there was more superficial drainage of rainwater. The water was flowing as far as the ponors situated in the border limestones of the contact karst (Gams 1966, 1986).

The reestablishment of equilibrium between the partial pressure of $CO_2$ in the air and that in the water, which is in contact with the superficial carbonates, after some days of water stagnation (e.g. in a solution pan/kamenitza) the water hardness (within Slovenia) reaches 70-82 mg $CaCO_3$/l. As the measured water hardness is lower above the tree limit in the high mountainous karst of the Julian Alps, the percolation water is capable of corroding practically down to the depth of over 1,000 m. In other words, that water does not deposit flowstone in the Alpine caves and is capable of hollowing deep potholes. During the cold periods of the Pleistocene when the temperature was lower by 8-10 C, such conditions were up to 1,000 m lower than today and affected the present lower karst. Here in the covered karst, the water with more than 8 C after the dispersed percolation in fissures or in a cave deposits flowstone already at a depth of some metres or some ten metres. This water is no longer capable of forming deep cavities. Deeper situated horizontal caves are as a rule either a relic of the past conditions or the product of allogenic rivers, i.e. waters flowing from the non-karst region. Most of the caves formed the aggressive sinking rivers. They are a typical feature of the contact karst or the contact fluviokarst (Gams 1986). The present potholes of the Slovenian low karst could have therefore formed either from deep fissures filled up with loam, or as ponor caves, or in the cold periods of the Pleistocene, or by the evacuation of loose material.

When all the carbonates dissolved in karst waters would derive from the karst surface, the above mentioned karst denudation in Slovenia with its 20 to 100 (or 130) $m^3$ $CaCO_3$/anually would mean the same amount of surface lowering expressed in microns a year. This results, according to the exposed limestone tablets in the air, between 20 and 30 microns on the bare rocky surface. After the calculation of denudation from the hardness and specific run-off, the denudation within larger river basins would be between 20 and 100 (exceptionally 130) microns. Apparently, in the covered karst of the warmer regions, most denudation occurs in the rocks covered by soil or near loam pockets. The solution rapidly diminishes from the rocky surface towards the first cavity or fissure with the $CO_2$ concentration in the underground air, which is similar to that of the open air. Now the flowstone deposition can take place.

When all dissolved carbonates carried along annualy by the most known Slovenian river Ljubljanica would derive from the rocky surface, the solution would have lowered the surface since the end of the Miocene for 600 m.

The calculated karst denudation in Slovenia is in negative correlation with the height of the relief, so that denudation was not the main factor of the relief development. This fact is understandable in the young Alpine orogeny which includes the whole Slovenia; here different altitudes are the results of the different tectonic uplifting and sinking which started at the beginning of the Pliocene and has been in progress up to the present.

Karst denudation today cannot interpret the relief development, which started in the far geological past due to the very changeable temperature and precipitation conditions of the past geological periods, as some of the karst areas were covered by unpermeable sediments. Even more impossible would be the conclusion on the basis of the variety of karst denudation which refers to the intensity of the development of karst surface phenomena. The rate of karst denudation in Slovenia is namely not in positive correlation with them.

The Slovenian as well as foreign measurements of karst denudation support the opinion that the solution was always active wherever the karst sediments were in contact with the aggressive precipitation or thermal water in the geological past. Under favourable conditions, karst caves and surface solution were being developed through the whole geological past (including the Palaeozoic) which extends back to the period when karst sediments were uplifted above the sea level, or back to the period when the karst was uncovered from beneath the impermeable sediment nappe. The development was dictated mainly by the specific run-off and the temperature, which influenced major biological processes, in connection with appropriate humidity and evapotranspiration or the depth of soil.

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# REFLECTIONS OF SPELEOARCHAEOLOGY IN SLOVENIA

France Leben*

Archaeological deposits of the karst caves in Slovenia were first investigated by the natural scientists from Trieste and Vienna 120 years ago, in the late 19th century, when they started to visit, research and record numerous caves of the Karst. The most part of this Littoral area was up to the end of World War II under Italian rule. After the War, systematic archaeological investigations in western Slovenia were finally taken over by the Slovene experts.

In the present Republic of Slovenia there are 160 archaeological cave sites registered. The excavations as well as the documentation material of the research work (containing above all more than a thousand bibliographical units) provide enough material evidence to form a clear idea of the existence of troglodytes and their extinction. The abundance of cave archaeological sites and their heritage in the adjacent regions of Friuli-Venezia Giulia in Italy and Istria throws a new light upon prehistoric cultural and civilizational activities in the area of the south-eastern Alps.

Archaeological research of deposits carried out by means of all required analyses, and the characteristics and evaluation of the finds, express the habitational or the cultic function of cave rooms. The skeletal and separate human bone remains (found at thirty sites) give evidence of the spiritual culture, and the anthropological analyses that of human age and population within a particular cultural horizon. Such finds are also to be mentioned. After all, other interdisciplinary studies with the analyses of rock, animal and organic remains also contribute to cave archaeology valuable and essential information about material production, raw materials, nutrition, economy and residential environment.

Prehistoric cave sites in Slovenia may be divided on the basis of the investigations of material culture into two cultural and gravitational regions, the Adriatic-littoral zone and the continental zone, situated within the pre-Alpine

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territory (in the prehistoric times a meeting place of the Mediterranean, Alpine and Pannonian civilizational currents). The archaeological heritage of Pleistocene and Holocene sediments presents, according to the previous results of scientific research, a chronological and cultural mirror within the framework of the Central European relative and absolute chronology.

There are thirty cave sites from the Old Stone Age with the cultures of the Middle Palaeolithic (Mousterian) and the Upper Palaeolithic (Aurignacian, Gravettian, Epigravettian). Most characteristic sites from these cultural periods of Ice Age man are the following caves: Potočka zijalka, Mokriška jama, Špehovka, Betalov spodmol, Postojnska jama, Parska golobina, Županov spodmol, Ovčja jama, Jama v Lozi, Matjaževe kamre, Ciganska jama, Marovška zijalka, Lukenjska jama, etc. The only site with excavated separate human bones and a part of mandible with teeth is called Jama pri Loki, which is situated on the edge of the Karst; the remains belong, according to the anthropological analysis, to late Pleistocene man of Mediterranean race.

From the Mesolithic period there are nine cave sites registered and restricted by the microlithic stone industry mostly to the Tardenoisian cultural complex. One of the valuable finds is a bone harpoon found in the cave Špehovka, but numerous bone and horn artifacts discovered in the cave Mala Triglavca have not been clearly identified within the system of the pre-Alpine, i.e. karst Mesolithic cultures.

No more than a decade ago, the first finds from the New Stone Age were discovered in the Slovenian Karst region. The finds are dated chronologically to the late Neolithic. The pottery found at four cave sites (Trhlovca, Mala Triglavca, Podmol and Acijev spodmol), gives evidence of the Adriatic Neolithic influence with the northern directions of the Danilo Culture (Trieste type) and the Hvar Culture (karst type). Within the continental zone there is one previously known neo-Eneolithic site called Ajdovska (Kartuševa) jama with the Danubian elements of the so-called Alpine facies of the Lengyel Culture. In the cave with three sections of mass graves, twenty-five skeletons of adults and children have been anthropologically identified.

The Copper Age material heritage has been recorded in thirty caves. The cultural inventory gives all characteristics of a pre-Alpine Eneolithic civilization which formed in Slovenia from other related cultural groups in the third millennium B.C. (Lasinja, Ljubljana, Retz-Gajary, Balaton, Vučedol). Most characteristic cave sites are the following: Kevderc and Lubniška jama, Bezgečeva jama, Podmol, Lukenjska jama, Ciganska jama, Ajdovska (Jermanova) jama, etc. In the cave Tominčeva jama, skeletal remains of at least ten persons have been discovered in a lateral niche; in a side passage of the entrance part to the Postojnska jama cave, the remains of three human skeletons have been encountered; in the upper passage of the cave Lukenjska jama, an unresearched burial place has been evidenced. The remains of eight human skeletons from a lateral passage of the Koblarska jama cave are supposed to belong to an early prehistoric period.

There are about thirty Bronze Age cave sites recorded in the archaeological register. Most distinctive finds from the cave deposits are either of the early or late cultural periods, while there have been no finds of the Middle Bronze Age (B) evidenced. First of all, the cave Predjama (western Slovenia) should be mentioned, as its ceramics have the continental and the karst (Castellieri) Bronze Age elements. From both cultural and gravitational zones there are some significant cave sites, as Tominčeva jama, Ozka spilja, Kovačeva jama, Veliki zjot, Lukenjska jama, etc. A hoard find of bronze objects was encountered at the entrance to the Mačkovca cave, which is situated in the vicinity of Postojna. Well known are the infant and female skeletons from the Predjama, and the male skeleton from the cave Šibernica at Bled.

Excavations of the Urnfield Culture - the transitional prehistoric period between the Late Bronze Age and the Early Iron Age (from 1,200 to 800 B.C.) - have been recorded in more than twenty caves. They represent ceramic finds with characteristic typological nature of the period. Among all the sites there are two caves of great significance: the most precious inventory is represented by the cultic-ritual hoard of hundreds of bronze objects, found at the bottom of the entrance shaft to the cave Mušja jama in the vicinity of Škocjan, and the trade hoard from the Ajdovska jama cave at Silovec. So far there has not been any evidence of cremated urn burials in Slovenian caves, except for the remains of the so-called grave pottery, found in the cave Pavlakova jama in the vicinity of Zreče, which may represent this group.

From the Early Iron Age, so far only casual finds have been recorded in the caves. A prolific find is the Hallstatt period deposit containing skeletal burials, discovered in the cave Tominčeva jama. Another find of great significance is the bronze helmet from the Svetina Hall in the caves Škocjanske jame. The remains of male and female skeletons with grave goods from the cave Okostna jama may be ascribed to a cultic ritual; it is the complete find from the 5th century B.C. Dislocated human bones from the Hallstatt period were discovered in the cave Liljevka, two infant skeletons in the cave Mornova zijalka, and the bone remains of three adults and an infant skull in the Pecova jama.

The least material evidence of prehistoric cave deposits is held of the Late Iron Age, i.e. the last four centuries B.C. The only valuable finds are the bronze possessions of a skeleton from the cave Gorenja jama, and the late La-Tène helmet, found in the cave Mušja jama.

The major archaeological evidence from the Roman period, above thirty cave sites, is mostly represented by the finds of Roman provincial pottery, discovered in the superficial layers. The finds are often even more precisely dated by individual metal objects, especially coins. A votive tablet with the Greek inscription from the 2nd century gives evidence of a cave deity; the find was discovered in the cave

Bezen above Mohorini in the Karst region. The human bone remains with grave goods from the Roman and the late antiquity periods have been discovered in seven caves.

The remains from the Migration Period and the early Middle Ages, which were excavated in some Slovenian caves, are individual objects which have been found casually; on the contrary, it is possible to find medieval as well as recent pottery at any place.

The purpose of this paper is to outline and point out the earlier conditions concerning the archaeological research in Slovenian caves. A clear evidence are the extensive bibliography, documentation material of the archives, museum collections and records of the visits to the caves, held in the cave register of the Spelaeological Association of Slovenia. The basic and complete database from the Archaeological Register is obtained at the Institute of Archaeology - the Centre of Scientific Research of the Slovenian Academy of Sciences and Arts, which is the only institution checking, completing and proceeding the subject as well as the mission of the book edition - *Archaeological Sites in Slovenia* (*Arheološka najdišča Slovenije*), Ljubljana 1975.

# CAVE FAUNA AND SPELEOBIOLOGY IN SLOVENIA

Boris Sket*

Despite being a small country, Slovenia has the second highest absolute number (over 170 spp. + sspp.) and by far the highest species density of aquatic hypogean fauna in the world. Terrestrial fauna is richer in the southern parts of the Dinaric karst. A short history of investigations has been given. The diversity and distribution of some of the most significant groups has been illustrated. The most important distribution patterns have been presented.

## A brief history of investigations

The world's first record of a cave animal was more than 300 years ago in Slovenia. The great Slovenian author J.V. Valvasor (1689) mentioned an "earthworm, alike to a lizard" which was brought to the surface by a swollen spring; Steinberg (1761) gave a similar report and Laurenti in 1768 described the creature as *Proteus anguinus*. It appeared to be an amphibian which was seen for the first time in its original habitat, in caves, by Jeršinovič von Loewengreif in 1797. That was in fact the first reliable report on the existence of a specialized cave fauna. The proteus is still the largest known cave animal.

In 1831, the local cave guide Luka Čeč discovered new parts of the Postojna Caves - and a new creature, a cave beetle. One of the most specialized cave beetles was named *Leptodirus hochenwarti* (Schmidt 1832). These two beautiful cave animals denoted the beginning of speleobiology (biospeleology). In 1840's the discoveries of cave fauna began in other parts of the world (Caucasus, USA, Pyrenees). Apart from a few local or naturalized researchers (Schmidt, Freyer, Robič), most investigation in Slovenia was by foreigners, particularly in the surroundings of Postojna and its caves. The Dane Schioedte (1848, etc.) described a number of aquatic and terrestrial arthropods, Schiner (1854) established the first classification of cave biota. The fauna of present Slovenia formed an

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important part of Hamann's (1896) compilation. Megušar (1914) wrote the first ecological study of caves and Seliškar (1923) the first biological study (doctoral thesis on scent organs of cave crickets).

A new era of Slovene and Slovenian speleobiology began in 1924, when biologists took the prime role in the revival of the Slovene caving society. J. Hadži, A. Seliškar, R. Kenk, E. Pretner fulfilled or organized extensive field investigations, described a number of new taxa, and established a cave laboratory in the Podpeška jama, in 1928. In 1930 in Postojna, which was at that time under Italian rule, another cave laboratory was established by Perko.

The present group of Slovenian speleobiologists began their activities in 1950's. They extended the field of their interests to ecology, biogeography, etc., but none of them has ever been able to devote himself solely or at least predominantly to speleobiology. On the other hand, one has to emphasize that the research field of the Slovene speleobiologists has always been the entire Dinaric karst area as well as the neighbouring isolated karsts together with interstitial waters.

## The most important facts on aquatic fauna

Some years ago we (Sket et al. 1991) summarized the data on the abundance of fauna in Yugoslavia and its parts. Athough a high precedence of Dinaric caves was expected,, a large number of stygobites in Slovenia itself came out as a surprise. Among all the districts established by Botosaneanu (1986), Slovenia is among the smallest ones but still ranks as second in the total number of stygobitic taxa. This puts it far ahead in the relative number of taxa (counted to the surface unit). Subdivision of the Dinarides makes the calculation of faunistic richness higher, but taxa density in the entire Dinaric region (1.7a + 1.7b + 1.7c + 1.7d + 1.7f) appears to be far higher than in any non-Dinaric region.

Among Protozoa, a noteworthy faunula of epizoic Ciliata has been found (Hadži, 1940) on a single specimen of the isopod *Monolistra spinosissima*. It contained 9 species of Peritricha and Suctoria, some of them evidently specialized to particular parts of the body and probably to the specific troglobitic carrier. Also the undescribed cave species of Folliculinidae, one of few freshwater species, is worth mentioning.

The cave hydrozoan *Velkovrhia enigmatica* Matjašič & Sket was first found in Slovenia in 1977 although its range seems to be holo-Dinaric. It is a small, collonial animal which differs from freshwater hydras also by the presence of a periderm and well developed gonophores.

Also of interest are the flatworms Temnocephalida, a group of small, epizoic or parasitic turbellarians, inhabiting in Europe mostly cave shrimps. There are 13 species in Slovenia (cf. Matjašič 1990).

More than 45 stygobitic taxa of Gastropoda from Slovenian caves and interstitial waters have been described or mentioned (Bole & Velkovrh 1986).

Some of them belong to entirely stygobitic genera, like the needle shaped *Iglica*, the broadly conical *Hauffenia*, and the flat *Hadziella*. Some others are only adapted populations or subpopulations of surface species, like *Bythinella schmidti* or *Graziana spp*. For some species, like *Mervicia eximia* Bole, the shell is still the only known part of the body, making the exact classification of this peculiarly shaped creature impossible. Apart from the above mentioned prosobranchs, some pulmonates also inhabit our cave waters. While *Acroloxus* tetensi Kuščer is entirely troglomorphic, the similar *Ancylus fluviatilis* Mueller established in the Postojna-Planina Cave System a population with a clinal variability towards eye reduction.

The range of the Dinaric cave clam *Congeria kusceri* Bole spreads into the SE part of the Slovenian territory. This is probably the only troglobitic bivalvian in the world and is an interesting relic of the Pliocene lakes in the area.

Like the hydrozoan and probably the clam, *Marifugia cavatica* Absolon & Hrabe is the only known hypogean tube worm (Polychaeta: Serpulidae). This animal too, must have escaped to the cave waters from the Pliocene lakes. It retained a free trochophoran larva in its development (Matjašič & Sket 1966).

Of Oligochaeta, *Peloscolex velutinus* (Grube), covered by yellow scales, is a regular inhabitant of sinking rivers. Stygobitic are some thread-like *Trichodrilus* spp. as well as the large and beautifully iridescent *Haplotaxis bureschi* (Mich.) which ranges from Slovenia to Bulgaria.

The extremely euryecious and tiny *Chydorus sphaericus* (O.F.M.) is the most common cladoceran in sinking rivers and hyporheic waters, while *Alona sketi* Brancelj (1992) has been discovered recently. It is one of the few stygobitic cladocerans in the world.

Copepoda are well represented in the caves as well as in interstitial waters. In both types of waters some generalist surface species are most common, but the stygobitic ones are also numerous. They often belong to the same genera, like *Acanthocyclops, Diacyclops*. Not less than 2 calanoids, 24 cyclopoids, and 20 harpacticoid species have been found in the hypogean parts of the Pivka river and the waters along its bed (Brancelj 1987). At least 15 of them are presumably stygobitic.

The large (20-30 mm), predatory, and swimming isopod *Sphaeromides virei* Brian is restricted to a few caves in the "paralittoral" strip of the Dinaric karst. Slow walking *Monolistra spp*. may roll up in a ball when disturbed. Some of the numerous species are smooth, others are warty or have long spines on their backs (e.g. *M. spinosissima* Racovitza). Stenasellids have been found in Slovenia only in slightly thermal springs. It has been suggested, that the proximity of Pleistocene glaciers destroyed other populations of this thermophile group (Sket & Velkovrh 1981). The Asellidae frequent all kinds of hypogean waters. For example, the dwarfish *Proasellus deminutus* (Sket) is widely distributed in interstitial waters, while *P. slovenicus* (Sket) is endemic in one of the karst areas. Very interesting is the widely distributed *Asellus aquaticus* (L.), which penetrates some cave systems and builds differently adapted stygobitic populations. Ecologically similar is the small amphipod *Synurella ambulans* (Fr. Mueller).

The amphipods are represented by a large number of *Niphargus* taxa. Apart from some surface (also surface species are eyeless) waters, the 2 mm to 30 mm long niphargids inhabit all kinds of hypogean ones; they are perhaps the most commonly seen animals there. *N. krameri* Schellenberg occurs in wells in addition to surface streams, the large *N. orcinus* Joseph is common in cave lakes, *N. stygius* (Schioedte) inhabits only percolating waters. The extremely peculiar *Carinurella paradoxa* (Sket), which may roll in a ball, is probably a relative of some upright walking dwarfish interstitial *Niphargus* spp. For the rock crevices inhabiting *Niphargobates orophobata* Sket, the only congeneric has been found on the Mediterranean island of Kriti (Crete).

Beside astacid crayfishes in some sinks, Decapoda are well represented in Slovenian caves by atyid shrimps of the genus *Troglocaris*. Although not yet recognized, recent investigations make clear that the genus consists of a series of independent species.

There are no stygobitic insects in Slovenian caves, but some surface species may penetrate for kilometers along the hypogean parts of the sinking rivers. Such are some Ephemeroptera, Plecoptera, Trichoptera, Diptera. In such waters, the insect larvae may play ecologically an important role. At least the trichopteran *Wormaldia occipitalis* (Pictet) builds locally self-sufficient cave populations.

The very peculiar "handicap" of the extremely rich Dinaric (and European) cave fauna is a total absence of troglobitic fish. But, the only European stygobitic amphibian, *Proteus anguinus* Laurenti, is very common in southern (Dinaric) half of Slovenia.

Although *Proteus* certainly consists of a number of geographical races if not even separate species, their recognition did not succeed up to now. However, a very diverse race was discovered some years ago. The "black proteus" seems still to retain most character states of its surface dwelling ancestor. Its dark - sometimes black - skin, well developed eyes, short legs, make it a probable prototype of the acknowledged cave specialist. One of the biggest surprises in Slovenian biology was the discovery of this unusual population in an extremely restricted area of the comparatively well explored Slovene karst.

The description of the subspecies is currently in print. Biochemical analysis has shown that this population is genetically very close to some white ones.

## The dwellers of the land

Although very rich in general terms, the terrestrial cave fauna of Slovenia does not exhibit such a ralative priority as the aquatic one. This can best be demonstrated by the well investigated group of cave beetles Coleoptera: Bathysciinae. Only 48 taxa of the species category have been found in Slovenia, compared to 149 in Bosnia & Herzegovina (cf. Pretner 1968). It seems that also some other groups are more diversified in central and south-eastern parts of the Dinaric karst than in its Northwest. Unfortunately, the last attempt to summarize the terrestrial fauna was long ago (Gueorguiev 1977) and was not complete.

A terrestrial turbellarian (cf. *Microplana*) was found in one cave but has not been described yet. Snails are well represented in the Dinaric region and in the Alps by some species of the basommatophoran genus *Zospeum*. Their dwarfish shells may regularly be found on wet cave walls.

Since arachnids are mostly predatory, their populations are very poor, but the number of species is important. The most observable are comparatively large and troglomorphic dysderid spiders of the genus *Stalita* which may be found even in "sterile" dripstone caves; they are free hunters without webs. *S. taenaria* Schioedte was the first cave spider known. The genus *Troglohyphantes* contains species of all kinds edaphic and microcavernicolous as well as differently troglomorphic ones. *Meta* spp. are common inhabitants of the entrance parts. Also pseudoscorpions are well represented by some troglomorphic species of the genera *Neobisium* and *Chthonius*, while opilionids are few. The palpigrad *Koenenia austriaca* is usualy found on the surface of puddles; it probably belongs to soil fauna. Crustaceans are represented in caves by a great number of troglomorphic Trichoniscidae, although most of them are, in fact, soil dwellers. Certainly cavernicolous are large species of the genera *Titanethes* and *Alpioniscus (Illyrionethes)*, which are found right up to the borders of the Dinaric karst. All these large trichoniscids are amphibious.

Also many Diplopoda, found previously only in caves, are in fact thought to be edaphobionts. The *Brachydesmus* spp. are very regular inhabitants of caves, particularly of their entrance parts. A number of endemic *Haasia* spp. or their subspecies seem to be troglobitic (Mršić 1992). As in other parts of the Dinaric karst, Chilopoda are seldom seen in caves except for the widely distributed *Lithobius stygius* Latzel, which is not troglomorphic but has not been found outside caves.

Coleoptera are the most diversified group of terrestrial cave dwellers. The trechine *Typhlotrechus bilimeki* Sturm, although troglomorphic, can usually be found near the cave entrances. A high number of taxa represent the genus *Anophthalmus* which does not range far beyond Slovenian borders; inside Slovenia, it inhabits the Dinaric as well as the Alpine karst. Some of them, like *A. hirtus* Sturm can quite readily be found. The range of the highly troglomorphic genus *Aphenopidius* is very restricted in a part of the Alpine karst. The bathysciine beetles are richer and more diversified than the above mentioned group. The tiny and egg-shaped *Bathyscimorphus byssinus* Schioedte and some others do not differ from the soil inhabitants. More troglomorphic are *Aphaobius* and *Oryotus* spp. while *Leptodirus hochenwarti* Schmidt is among the most beautifully transformed beetles in the world; it is enlarged, with very elongated legs and antennae, a neck-like prothorax and a nearly globular abdomen (pseudophysogastry). The similar *Astagobius angustatus* Schmidt has usually been found in Dinaric ice caves.

Other insect groups are represented in Slovenian caves only by trogloxene or troglophile species but they may play a similar, ecologically important role as the nesting colonies of pigeons or bats.

**The origins and distribution of fauna.**

It has been supposed that the karstification in the Slovenian territory began at the end of the Pliocene and continued through the Pleistocene (Melik 1958). The age of the oldest troglobites must be from this age, too(Sket 1970). However, new studies indicate that some highly specialized troglobites, like Proteus, could be of a much younger provenience, maybe even towards the end of the Pleistocene.

Some cave species belong to the genera widely distributed in surface habitats. They are certainly a result of the independent immigration of some species to caves. Examples are the troglobitic pseudoscorpions Neobisium sp. as well as the races of the widely distributed water slater Asellus aquaticus. A southern European distribution (the Pyrenees-Dinarides or Cevennes-Caucasus) is exhibited also by some entirely troglobitic genera: *Zospeum* (terrestrial snails) and *Troglocaris* (aquatic shrimps).

Most troglobitic species and even many genera are endemic in parts of the Dinaric and Alpine (Italo-Dinaric) karst area and some exhibit a holodinaric distribution. Examples are aquatic genera *Monolistra* (Isopoda), *Iglica* (Gastropoda) and the terrestrial isopod genus *Titanethes*, as well as probably unit species *Marifugia cavatica* (Polychaeta) and *Proteus anguinus* (Amphibia). Some other groups belong to the NW-Dinaric region which means that they are absent in its SW counterpart. Such are terrestrial beetle genera *Anophthalmus, Leptodirus,* the aquatic snails *Hadziella*, etc.

The most interesting is the distribution of some aquatic species of snails and crustaceans. Contrary to expectations, their ranges do not follow the recent hydrographical units but the presumed Pliocene ones (Sket 1986). This means that the separate species developed in surface streams before karstification; they immigrated underground and developed there further in a parallel fashion (all of them losing eyes and pigment, elongating appendages, etc.), but after hydrographical changes they have not changed their distribution ranges along the newly established water connections. Of course, there are a number of species which have been found till now in only very restricted areas, or even in unique specimens - for example the highly specialized beetle *Anophthalmus capillatus* Joseph.

*Tab. 1 The richest regions listed by absolute numbers of specialized inhabitants (species and subspecies) in hypogean waters. The code number and the regions' names are used here according to Botosaneanu (1986); Slovenia is also included in the Dinaric region.*

| | area in 1,000 km2 | number of taxa | taxa per 10,000 $km^2$ |
|---|---|---|---|
| (1.7a+b+c+d+f Dinaric region) | (117) | (388) | (33.2) |
| 1.3 Pyrenean-Aguitan. Prov. | 168 | 200 | 11.9 |
| 1.7a Slovenia (W+S+C) | 15 | 170 | 113.3 |
| 8.1 Rhodano-Lothar. Prov. | 141 | 167 | 11.8 |
| 1.4 Apalachian Highlands | 1.101 | 152 | 1.4 |
| 1.7c Dinaro-Dalmatine Distr. | 26 | 106 | 40.8 |
| 1.8b (Yugoslav) Macedonia W | 14 | 100 | 71.4 |
| 1.7b Istra | 3 | 27 | 90.0 |

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# ENDEMIC ANIMALS IN HYPOGEAN HABITATS IN SLOVENIA

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Roughly 120 species and subspecies of aquatic troglobites and 184 species and subspecies of terrestrial troglobiotes are recognized as endemic in Slovenia. Most numerous are Coleoptera with 138, Gastropoda with 44, Malacostraca with 35 and Diplopoda with 27 endemic taxa.

The fauna of Slovenia (and that of the Dinaric karst as a whole) has not yet been studied sufficiently. It is very difficult to list their "troglobitic endemics" at least for two reasons: (1) for many of them, the real distribution ranges have not yet been established with certainty, and (2) for many of the reputed "cave taxa" their presence in surface habitats (particularly in soil) is very likely but not yet proven. On the other hand, a number of not yet recognized species may exist in Slovenia, some of them being also endemic. All of these limit the present list. In general, only those animal taxa (species and additional subspecies) have been listed which distribution area do not go across the political boundaries of the Republik of Slovenia. Exceptions are some taxa which are also present in the Italian part of the Kras (Carso) or some kilometres across the borders in Croatia. Not taken into account are the taxa, occuring also further in Croatian Istra or near Ogulin and/or further eastwards. Stygobitic (= aqatic trobitic) taxa:

Remark: the symbol "PPCS" stands for Postojna-Planina Cave System SSW of Ljubljana; "c." stands for cave (= "jama")

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STYGOBITIC (aquatic troglobitic) TAXA

(CILIATA: PERITRICHA), epizoic on Monolistra spinosissima, the following have not yet been found in any other locality:

1. Scyphidia microlistrae Hadži 1940
2. Vaginicola subcylindrata Hadži 1940
3. Pyxicola psammata Hadži 1940
4. Platycola lageniformis Hadži 1940
5. Platycola callistoma Hadži 1940

SPONGES (PORIFERA)

1. Ephydatia fluviatilis (Linne), a changed population in the PPCS

FLATWORMS (TURBELLARIA: TEMNOCEPHALIDEA) epizoic on Troglocaris spp.

1. Bubalocerus pretneri Matjašič 1958 - Dinaric Slovenia
2. Scutariella maxima Matjašič 1958 - SW Slovenia
3. Troglocaridicola longipenis Matjašič 1990 - Novo mesto - Dobrepolje
4. T. krkensis Matjašič 1958 - Krka - Dobrepolje
5. T. cervaria Matjašič 1958 - Tržaški Kras
6. T. cestodaria Matjašič 1958 - Krka - Dobrepolje
7. T. istriana Matjašič 1958 - Slovene Istra
8. T. vilkae Matjašič 1990 - Slovene Istra

(TURBELLARIA: TRICLADIDA)

1. Planaria torva var. stygia Kenk 1936 - c. Gradišnica (Logatec)
2. Atrioplanaria opisthogona (Kenk 1936) - c. Godobovska jama (Rovte)
3. Dendrocoelum abditum Kenk 1940 - well in Domžale
4. D. puteale Kenk 1930 - well in Maribor
5. D. spelaeum (Kenk 1924) - southern Slovenia
6. D. tubuliferum deBeauchamp 1919 - PPCS

NEMATODA, a very insufficently studied group; following species have not (yet) been found outside Slovenia and outside caves:

1. Desmoscolex aquaedulcis Stammer 1935 - Krška jama
2. Criconema minor (Schneider 1940) - Podpeška jama
3. C. paxi (Schneider 1940) - Podpeška jama
4. C. southerni (Schneider 1940) - Podpeška jama
5. Criconemoides stygia (Schneider 1940) - Podpeška jama
6. Thalassoalaimus aquaedulcis (Schneider 1940) - Podpeška jama
7. Halalaimus stammeri Schneider 1940 - Krška jama
8. Mylonchulus subterraneus (Schneider 1940) - Krška jama

SNAILS (GASTROPODA: PROSOBRANCHIA)

1. Belgrandiella crucis (Kuščer 1928) - Lož region
2. B. globulosa Bole 1979 - Lož region
3. B. schleschi (Kuščer 1932) - Cerknica - Lož
4. B. substricta (Kuščer 1932) - Vrhnika
5. B. superior (Kuščer 1932) - Cerknica
6. Boleana umbilicata (Kuščer 1932) - Vrhnika
7. Erythropomatiana erythropomatia (Hauffen 1856) - NW Slovenia
8. E. verdica Radoman 1978 - Vrhnika
9. Hadziella deminuta Bole 1961 - NE Slovenia
10. H.ephippiostoma Kuščer 1932 - S Slovenia
11. H.krkae Bole 1992 - Krka
12. H.thermalis Bole 1992 - SE Slovenia (also near Zagreb)
13. Hauffenia wagneri (Kuščer 1928) - SE Slovenia
14. Horatia supracarinata Bole & Velkovrh 1986 n.n. - NW Slovenia
15. Iglica aedlaueri (A.J. Wagner 1927) - Kojsko (W Slovenia)
16. I. gracilis (Clessin 1882) - Krka
17. I. hauffeni (Brusina 1885) - NW Slovenia
18. I. luxurians Kuščer 1932 - Ljubljanica system
19. I. robiciana Sajovic 1908 n.n. - NW Slovenia
20. Kerkia kusceri (Bole 1961) - Krka
21. Mervicia eximia Bole 1967 - Ljubljana
22. Neohoratia subpiscinalis (Kuščer 1932) - Ljubljanica - Idrija
23. Paladilhiopsis grobbeni Kuščer 1928 - c. Raja peč (Sevnica)
24. P. kostanjevicae (Schuett 1970) - Kostanjevica
25. P. robiciana (Clessin 1882) - N of Ljubljana
26. P. sublesta Bole & Velkovrh 1986 n.n. - NW Slovenia
27. Sadleriana schmidti (Menke 1849) - SE Slovenia
28. Lanzaiopsis savinica Bole 1992 - Luče (NE Slovenia)

(GASTROPODA: PULMONATA)

29. Z. exiguum Kuščer 1932 - Lož - Cerknica
30. Acroloxus tetensi (Kuščer 1932) - Krka - Ljubljanica

OLIGOCHAETE WORMS (OLIGOCHAETA)

1. Trichodrilus ptujensis Hrabe 1963 - NW Slovenia
2. T. sketi Hrabe 1963 - Ljubljana
3. T. stammeri Hrabe 1936 - SW Slovenia
4. T. tacensis Hrabe 1963 - Ljubljana
5. Tubifex flabellisetosus Hrabe 1966 - PPCS - Timavo (Italy)
6. Psammoryctides hadzii Karaman S. 1974 - PPCS
7. Haber monfalconensis Hrabe 1966 - Divača - Timavo (Italy)

8. Potamothrix postojnae Karaman S. 1974 - PPCS
9. Rhyacodrilus sketi Karaman S. 1974 - PPCS
10. Epirodrilus slovenicus Karaman S. 1974 - PPCS

CLADOCERANS (CLADOCERA)

1. Alona sketi Brancelj 1992 - Slovene Istra

OSTRACODS (OSTRACODA)

1. Cypria reptans stygia Klie 1935 - Krka - Dobrepolje
2. P. cavicola (Klie 1935) - Krka
3. P. pretneri Danielopol 1978 - Cerknica region
4. P. trigonella (Klie 1931) - PPCS
5. P. aemonae (Klie 1934) - Dobrepolje

COPEPODS (COPEPODA: CYCLOPOIDA)

1. Diacycops slovenicus Petkovski 1954 - S Slovenija
2. Metacyclops postojnae Brancelj 1987 - PPCS

(COPEPODA: HARPACTICOIDA)

1. Paramorariopsis anae Brancelj 1992 - Slovene Istra
2. Ceuthonectes rouchi Petkovski 1984 - S Slovenia
3. Elaphoidella franci Petkovski 1983 - PPCS
4. E. jeanneli (Chappuis 1928) - S Slovenia
5. E. kieferi Petkovski & Brancelj 1985 - c. Škocjanske jame (Divača)
6. E. stammeri Chappuis 1936 - S Slovenia
7. Moraria pectinata radovnae Brancelj 1988 - Bled region
8. Nitocrella slovenica Petkovski 1959 - Celje

ANASPIDACEANS (BATHYNELLACEA)

1. Bathynella natans slovenica Karaman 1954 - Ljubljana

ISOPOD CRUSTACEANS (ISOPODA)

1. Monolistra caeca absoloni Racovitza 1910 - S of Ljubljana
2. M. caeca intermedia Sket 1964 - S of Ljubljana
3. M. racovitzai racovitzai Strouhal 1928 - SW Slovenia
4. M. racovitzai conopyge Sket 1964 - Bela Krajina
5. M. racovitzai karamani Sket 1959 - between Krka and Sava
6. M. racovitzai pseudoberica Sket 1964 - Krka
7. M. bolei Sket 1960 - Bela Krajina
8. M. calopyge Sket 1982 - Novo mesto
9. M. spinosa (Racovitza 1929) - Krka
10. M. spinosissima (Racovitza 1929) - Vrhnika - Planina

11. Asellus aquaticus cavernicolus Racovitza 1925 - PPCS - Timavo (Italy)
12. A. aquaticus cyclobranchialis Sket 1965 - Šica - Krka
13. Proasellus deminutus (Sket 1959) - N Slovenia
14. P. vulgaris (Sket 1965) - Ljubljana region
15. P. parvulus (Sket 1960) - Bela Krajina
16. P. pavani orientalis (Sket 1965) - Ljubljana
17. P. slavus histriae (Sket 1963) - Slovene Istra
18. P. styriacus (Sket 1963) - NW Slovenia
19. P. slovenicus (Sket 1957) - Krka - Dobrepolje

AMPHIPODS (AMPHIPODA)

1. Carinurella paradoxa (Sket 1964) - Vipava (- Gorizia, Italy)
2. Niphargobates orophobata Sket 1981 - PPCS
3. Niphargus aberrans Sket 1972 - NE Slovenia
4. M. labacensis Sket 1956 - Ljubljana (- Zagreb, Croatia)
5. M. longiflagellum S. Karaman 1950 - SE Slovenia
6. M. orcinus orcinus Joseph 1869 - SW Slovenia (Carso, Italy)
7. M. puteanus spoeckeri Schellenberg 1933 - PPCS
8. M. rejici rejici Sket 1958 - S of Ljubljana
9. M. stenopus Sket 1960 - Krka
10. M. steueri subtypicus Sket 1960 - Bela Krajina
11. M. stygius stygius (Schioedte 1847) - Postojna
12. M. stygius brachytelson S. Karaman 1952 - Kočevje
13. M. stygius novomestanus S. Karaman 1952 - SE Slovenia
14. M. stygius valvasori S. Karaman 1952 - W Slovenia
15. M. stygius podpecanus S. Karaman 1952 - S Slovenia
16. M. carniolicus Sket 1960 - Novo mesto

SHRIMPS (DECAPODA)

Some, not yet recognized species of the cave shrimp Troglocaris are certainly endemic in Slovenia.

AMPHIBIANS (AMPHIBIA)

1. Proteus anguinus ssp. (= "black proteus") - Bela Krajina. This non-troglomorphic subspecies is at the moment the only subspecific taxon recognized.

TERRESTRIAL TROGLOBITIC ENDEMICS IN SLOVENIA

SNAILS (GASTROPODA, MOLLUSCA)

In Slovenia, 237 terrestrial snail species have been recorded so far. This includes 11 terrestrial troglobiontic species and 5 subspecies, most of them being endemic in Slovenia. The great majority of them belongs to the

Archeopulmonata, and all to the genus Zospeum ; 1 species - Spelaeodiscus - belongs to the Pulmonata and to the Pupillidae family.

order Archeopulmonata

family Carychiidae

1. Zospeum alpestre alpestre (Freyer, 1855) - Savinja Alps
2. Z. alpestre bolei Slapnik, 1991 - Savinja Alps
3. Z. isselianum Pollonera, 1886 - C. and W Slovenia
4. Z. amoenum (Frauenfeld, 1856) - Central and SW Slovenia
5. Z. frauenfeldi (Freyer, 1855) - Dolenjska
6. Z. kusceri (A. J. Wagner, 1912) - Central and SW Slovenia
7. Z. lautum (Frauenfeld, 1854) - Central and SW Slovenia
8. Z. obesum (Frauenfeld, 1854) - Dolenjska
9. Z. spelaeum spelaeum (Rossmaessler, 1839) - Western Slovenia
10. Z. spelaeum schmidti (Frauenfeld, 1854) - Central and SW Slovenia
11. Z. spelaeum costatum (Freyer, 1855) - NW Slovenia
12. Z. spelaeum lamellatum Bole, 1974 - S Slovenia
13. Z. subobesum Bole, 1974 - S Slovenia

order Pulmonata

family Pupillidae

14. Spelaeodiscus hauffeni (F. Schmidt, 1855) - around Ljubljana

WOODLICE (ISOPODA TERRESTRIA, CRUSTACEA)

In the fauna of Slovenia, 72 woodlice species and 52 subspecies have been recorded. Of these, 10 species and 15 subspecies (20 %) are endemic. Of these, however, only 2 species with 3 additional subspecies (4 %) are endemic and troglobiontic.

family Trichoniscidae

1. Androniscus s. stygius Nemec, 1897 - SW Slovenia
2. A. stygius cavernarum Verhoeff, 1908 - SW Slovenia
3. A. s. dentatus Strouhal, 1939 - C. Lubniška jama at Lubnik
4. A. s. scabridus Verhoeff, 1929 - SW Slovenia
5. A. subterraneus nodosus Strouhal, 1939 - SW Slovenia

FALSE SCORPIONS (PSEUDOSCORPIONES)

In the fauna of Slovenia, 25 false scorpion species and subspecies have been recorded so far. Of these, 7 species (28 %) are endemic and troglobiontic.

family Chthoniidae

1. Chthonius cavernarum Ellingsen, 1909 - around Postojna
2. C. ellingseni Beier, 1939 - Dinaric Karst
3. C. raridentatus Hadži, 1930 - around Kočevje

family Neobisiidae
4. Neobisium pusillum Beier, 1939 - around Planina
5. N. reimoseri histricum Beier, 1939 - Primorska
6. N. stygium Beier, 1931 - South Slovenia
7. Roncus stussineri stussineri (Simon, 1881) - around Šmarna Gora

SPIDERS (ARANEAE)

In the fauna of Slovenia, 500 Spider species and subspecies have been recorded so far. Of these, 2 species (0,4 %) are endemic and troglobiontic.

family Linyphiidae
1. Troglohyphantes diabolicus Deeleman-Reinhold, 1978 - around Dobrovlje
2. T. confusus Kratochvil, 1939 - around Rakek and Žirovski vrh

HARWESTMEN (OPILIONES)

In the fauna of Slovenia, 55 Opinion species and subspecies have been recorded so far. Of these, 4 species (7 %) are endemic and troglobiontic.

family Sironidae
1. Siro duricorius (Joseph, 1868) - Western Slovenia

family Travuniidae
2. Peltonychia postumicola (Roewer, 1935) - South Slovenia
3. P. tenuis Roewer, 1935 - Primorska

family Ischyropsalididae
4. Ischyropsalis hadzii Roewer, 1935 - Karavanke and Savinjske Alpe
5. I. muellneri Hamann, 1898 - The suthwestern Slovenia

MILLIPEDES (DIPLOPODA)

In the fauna of Slovenia, 139 Diplopoda species and 30 subspecies have been recorded so far. Of these, 69 species and subspecies (41 %) are endemic. 27 species and subspecies (16 %) are troglobiontic. Strasser (1971) mentioned a number of endemic troglobionts in his Diplopoda catalogue, but later on some species were found at the entrances to the caves and in the soil. The following species are endemic troglobionts for the fauna of diplopods of Slovenia (herewith only their families are stated):

family Glomeridae
1. Strasseria mirabilis Verhoeff, 1929 - around Draga near Ponikve (SW Slovenia)

family Polydesmidae
2. Brachydesmus (Brachydesmus) herzegowinensis septentrionalis Strasser, 1940 - around Ponikve near Št. Vid nad Valdekom
3. B. (B.) inferus concavus Attems, 1898 - Primorska and Kočevje regions
4. B. (B.) incisus Strasser, 1966 - around Dolenji Globodol

family Chamaesomidae

5. Verhoeffeuma spinosum Strasser, 1937 - Triglav mountain chain

family Haaseidae

6. Haasea (Brachybainosoma) pretneri Strasser, 1966 - Podkum

family Anthogonidae

subfamily Haasiinae

7. Haasia (Haasia) troglodytes (Latzel, 1884) - Slovene Karst
8. H. (H.) hadzii (Strasser, 1966) - C. Golobinja near Petelinjsko jezero
9. H. (H.) tridentis (Verhoeff, 1931) - C. Ciganska jama, Črni vrh
10. H. (H.) largescutata largescutata (Strasser, 1935) - C. Velika Pasica near Gornji Ig
11. H. (H.) largescutata parallela (Strasser, 1940) - C. Turkova jama near Petkovec
12. H. (H.) largescutata idriense (Strasser 1966) - C. Jama pod Lešetnicami near Kovačev Rovt
13. H. (H.) falsa (Strasser, 1971) - Vicinity of Postojna
14. H. (H.) carinifera (Strasser, 1935) - of Primorska
15. H. (H.) cornuata cornuata (Strasser, 1940) - around Kočevje
16. H. (H.) cornuata dentigera (Strasser, 1940) - around V. Lašče
17. H. (H.) cornuata paligera (Strasser, 1940) - around Lož

family Attemsiidae

18. Mecogonopodium bohiniense bohiniense Strasser, 1933 - Julian Alps
19. M. bohiniense parvulum Strasser, 1971 - C. Pološka jama near Idrija
20. M. zirianus Mršić 1987 - around Žirovski vrh
21. Coelogonium cavernarum Strasser, 1937 - around Rašica
22. Stiphrogonium attemsi attemsi Strasser, 1937 - around Dobrovlja
23. S. attemsi celeae Mršić, 1987 - C. Ocvirkova jama near Liboje
24. Glomogonium karawankarum karawankarum Strasser, 1965 - region of Mt. Peca
25. G. karawankarum saviniense Mršić, 1987 - C. Mesarska lopa near Mozirje
26. G. karawankarum intermedium Mršić, 1987 - C. Gorooljčna rupa on Mt. Gora Oljka

family Iulidae

27. Typhloiulus (Stygiiulus) illyricus Verhoeff, 1929 - Istra and around Kozina

BEETLES (COLEOPTERA)

In the fauna of Slovenia, 58 endemic and troglobiontic beetle species and 79 subspecies have been recorded.

family Carabidae

subfamily Trechinae

1. Typhlotrechus bilimeki bilimeki (Sturm, 1847) - around Kočevje.

2. T. b. arcuatus Jeannel, 1928 - around Dobrepolje.
3. T. b. cosinensis, G. Mueller, 1926 - around Kozina
4. T. b. frigens Jeannel, 1928 - around Lož
5. T. b. hacqueti (Sturm, 1853) - Borovnica, Kum and Mokrc
6. T. b. hauckei Ganglbauer, 1913 - Črnovrška planota, Logaški rovte, Hrušica, Novi svet and northern Notranjska planota
7. T. b. istrus G. Mueller, 1926 - Slavnik and Podgrajsko podolje
8. T. b. monfalconensis G. Mueller, 1926 - Slovene Karst
9. T. b. tergestinus J. Mueller, 1905 - Slovene Karst
10. Orotrechus muellerianus muellerianus (Schatzmayr, 1907) - around Vojščica (Karst)
11. O. muellerianus primigenius G. Mueller, 1919 - around Ponikve (Štorje, Kobjeglava)
12. O. globulipennis globulipennis Schaum, 1860 - around Škofja Loka and Bohinj
13. O. globulipennis chendai Schatzmayr, 1922 - Mt. Matajur
14. O. lucensis Scheibel, 1935 - C. Trbiška zijalka (Luče, Savinjske Alpe)
15. Anophthalmus scopolii scopolii Schmidt, 1850 - Postojna and Nanos
16. A. s. glacialis G. Mueller, 1931 - C. Ledenica Dol (Predmeja)
17. A. s. hoscheki Scheibel, 1933 - around Železniki and Logaške Rovte
18. A. s. impudicus G. Mueller, 1931 - Kambersko pogorje near Plave
19. A. s. lomensis G. Mueller, 1931 - C. Jama pod Smoganico, Tolminski lom.
20. A. s. matajurensis G. Mueller, 1935 - Mt. Matajur
21. A. s. ternovensis G. Mueller, 1931 - Trnovski gozd
22. A. bohiniensis bohiniensis Ganglbauer, 1903 - around Bohinj
23. A. bohiniensis nonveilleri Scheibel, 1933 - Mt. Lubnik
24. A. kaufmanni kaufmanni Ganglbauer, 1900 - Kočevsko
25. A. kaufmanni uskokensis Scheibel, 1934 - Gorjanci
26. A. episcopalis G. Mueller, 1931 - around Škofja Loka
27. A. labacensis G. Mueller, 1931 - around Škofja Loka
28. A. gobanzi gobanzi Ganglbauer, 1911 - Matkov kot, Savinja Alps
29. A. schaumi schaumi Schaum, 1860 - around Domžale and Moravče
30. A. s. angusticeps Scheibel, 1937 - around Studence near Sevnica
31. A. s. knirschi Winkler, 1912 - Dobrovlje and Čreta
32. A. s. kumensis Fischhuber,1975 - Mt. Kum
33. A. s. leptonotus Jeannel, 1926 - around V. Lašče and Kočevje
34. A. s. macromelus Jeannel, 1926 - around Liboje
35. A. s. orientalis Jeannel, 1926 - around Brestanica and Lastnič
36. A. s. silvicola Jeannel, 1928 - Menina planina
37. A. bernhaueri broderi Daffner, 1992 - around Podljubelj
38. A. schmidti schmidti J. Sturm, 1844 - around Postojna and Hrušica
39. A. s. cordicollis, Motschulsky, 1862 - around Velike Lašče

40. A. s. gspani Reitter, 1918 - Mt. Lubnik and Polhograjski Dolomiti
41. A. s. insignis J. Mueller, 1912 - around Trnovski gozd and Nanos
42. A. s. istriensis J. Mueller, 1912 - around Podgrad, Istria
43. A. s. motschulskyi Schmidt, 1860 - Mt. Krim and Mokrc
44. A. s. trebicianus J. Mueller, 1912 - around Divača
45. A. erebus erebus Krauss, 1906 - Dobrovlje, Menina planina and Savinja Alps
46. A. erebus kraussi Winkler, 1923 - Čreta
47. A. egonis J. Mueller, 1923 - Pokljuka, Pršivec and Viševnik
48. A. mariae Schatzmayr, 1904 - Zgornja Trenta
49. A. micklitzi micklitzi Ganglbauer, 1913 - Mt. Jelovica
50. A. m. alphonsi J. Mueller, 1915 - around Škofja Loka
51. A. m. fallaciosus J. Mueller, 1915 - around Domžale and Moravče
52. A. m. ljubnicensis J. Mueller, 1915 - Mt. Lubnik
53. A. m. staudacheri J. Mueller, 1923 - around Kranj and Naklo
54. A. springeri G. Mueller, 1931 - C. Jama Krasnica, Slap pri Idriji.
55. A. ajdovskanus ajdovskanus Ganglbauer, 1913 - Posavje
56. A. a. concubinus G. Mueller, 1923 - C. Pesjakov buden, Pokljuka
57. A. a. muelleri Jeannel, 1926 - C. Snežna jama, Obranca-Mežaklja
58. A. a. pretneri J. Mueller, 1913 - Mt. Stol
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family Catopidae

subfamily Bathysciinae

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100. A. m. pretneri J. Mueller, 1913 - Mt. Stol
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115. B. khevenhuelleri tergestinus G. Mueller, 1922 - Mt. Slavnik and Podgrajsko podolje

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118. B. byssinus acuminatus (L. Miller, 1855) - Suha Krajina
119. B. byssinus uskokensis (J. Mueller, 1911) - Gorjanci
120. B. glogosus (L. Miller, 1855) - Grosuplje, Suha Krajina and Velike Lašče
121. B. trifurcatus (Jeannel, 1824) - Hrušica and Ravnik near Cerknica
122. Ceuthmonocharis freyeri (L. Miller, 1855) - around Domžale
123. C. netolitzkyi netolitzkyi (J. Mueller, 1908) - Posavje near Sevnica
124. C. netolitzkyi kodrici (G. Mueller, 1932) - Bohor and Kozjansko
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family Staphylindae

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family Curculionidae

137. Troglorhynchus anophthalmus Schmidt, 1854 - Northern Slovenia
138. Troglorhynchus pretneri Solari 1955 - around Rakek and Mt. Snežnik

family Pselaphidae

139. Machaerites subterraneus L. Mueller - N Slovenia

## CONCLUSIONS

The presently recognized status of endemism in Slovenian hypogean habitats (c.s, crevice systems, interstitial waters) is as follows.

| | |
|---|---|
| CILIATA | 5 |
| TURBELLARIA | 4 |
| NEMATODA | 8 |
| GASTROPODA | 30 |
| OLIGOCHAETA | 10 |
| CLADOCERA | 1 |
| OSTRACODA | 5 |
| COPEPODA | 10 |
| BATHYNELLACEA | 1 |
| ISOPODA | 19 |
| AMPHIPODA | 16 |
| AMPHIBIA | 1 |
| or all stygobitic (= aquatic) taxa | 120 |

Most of the known 120 stygobitic endemics are inhabitants of karstic caves in the southern, Dinaric part of Slovenia, although also the interstitial waters in Alpine and Pannonian parts are not without them. However, the political borders of Slovenia differ greatly of biogeographical ones. A more coherent region would be the NW Dinaric Region (Sket 1986), reaching far further into Croatia. And a number of the most interesting troglobites (Proteus anguinus, Marifugia cavatica, Congeria kusceri, Velkovrhia enigmatica) are endemic in the holo-Dinaric region which includes Slovenia. The number of endemics will increase also in Slovenia itself by increasing knowledge of its fauna which is still very insufficient.

The presently recognized status of endemism in Slovenian terrestrial hypogean habitats (caves) is as follows.

| | |
|---|---|
| GASTROPODA | 14 |
| ARANEAE | 2 |
| PSEUDOSCORPIONES | 7 |
| OPILIONES | 4 |
| DIPLOPODA | 27 |
| ISOPODA | 5 |
| COLEOPTERA | 139 |
| or all terrestrial taxa | 198 |

# THE ŠKOCJANSKE JAME CAVES

Andrej Kranjc*

**Astract**

The caves Škocjanske jame (Škocjan Caves) are the most significant speleological object not only of the Classical Karst but also of the whole Slovenian karst territory. The characteristic feature of the 5.5 km long system is an underground canyon with the river at its bottom (having the discharge of up to 400 $m^3 s^{-1}$). The largest chamber is the Martelova dvorana (Martel Hall) (250 x 120 x 140 m). In the caves, highest waters can reach the level of as much as 132 m above the siphon. The natural phenomena, the history of venturing into the Caves, cultural curiosities, natural-science investigations and the history of the tourist development (from the year 1819 on) were the reason why the Škocjanske jame were included in the UNESCO World Natural and Cultural Heritage List in 1986.

The caves Škocjanske jame (Škocjan Caves) are the most significant speleological object of the Classical Karst. Man has always been closely attracted to the canyon, where the Reka river disappears underground, and even more to the karst phenomenon itself. The Reka sinking underground beneath the rocky face emerges after some 100 m at the bottom of a deep collapse doline and then ultimately disappears through the dark cave entrance. The remains giving evidence of man's early presence and dwelling in the caves of Škocjan and their immediate vicinity extend from the Mesolithic period through the Iron Age, antiquity and the Middle Ages up to the present days.

In the caves Tominčeva jama (Tominc Cave) and Ozka špilja (Narrow Grotto), being part of the Škocjanske jame system, there are remains from the Mesolithic period. The Tominčeva jama is the largest cave burial site within the entire area of the Eastern Alps. In the vicinity there is the cave Jama na Prevali, an Iron Age cultic site, with the finds of numerous remains of weapons and military-equipment. At the place where the present village of Škocjan (the Caves bearing its name) is situated, there was a Roman fortification.

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*Fig. 1: Part of the map of "Goritiae, Karstii, Chaczeolae, Carniolae, Histriae et Windorium Marchae Descrip(tio) 1561, 1573" by W. Lazius - A. Ortelius, where the course of the Reka, the village of Škocjan "ubi Recca flu, absorbetur, et in Timaui fontibus erumpit", and the name Karst are drawn.*

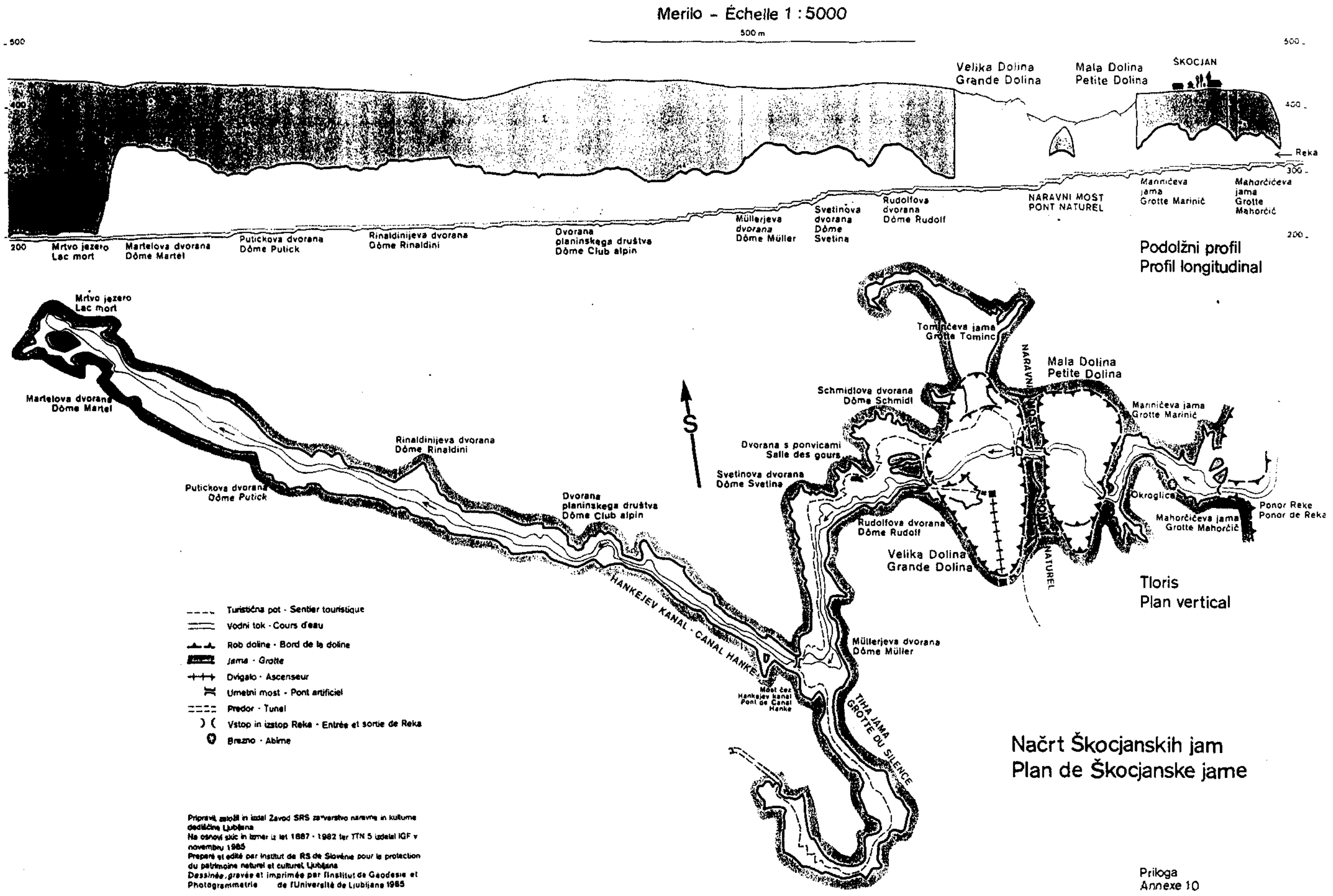


*Fig. 2: The map of the Škocjanske jame (according to the Škocjan Caves - Natural and Cultural Monument, 1985).*

The first written sources of the Škocjanske jame are from the antiquity times: "The River Timavus springs in the mountain, flows into a pothole (i.e. Škocjanske jame), reappears after the distance of 130 stadia, and flows into the sea," was written by Posidonios from Apamea (135-50 B.C.), who was researching one of the Timavo springs. The Škocjanske jame were presented on the oldest printed maps (Lazius - Ortelius 1561; Mercator's *Novus Atlas* from 1637). Father F. Imperato found out during his numerous experiments (by using water tracers such as floaters and suspended material) that the Reka reappears in the springs of the River Timavo. In his descriptions of the Reka, J. W. Valvasor (1689) referred to Posidonios and Cluverius (1624). Valvasor included in his history book an illustration of the Reka ponor, but the first paintings were created by the French painter F. Cassas in the year 1782. The Škocjanske jame were further described by J. A. Nagel in his manuscript from 1748, and by T. Gruber in his book from 1781. The Caves became a curiosity in the 19th century; beside the caves of Postojnska jama (Postojna Cave), Jama pri Predjami and Vilenica, they were being mentioned in all significant articles on the Classical Karst region. In 1823, the Škocjanske jame were described by Agapito as a tourist attraction, and were also dealt with by A. Schmidl in his articles.

One of the reasons why the Škocjanske jame were included in the UNESCO World Heritage List was that the Caves had been closely linked with the Karst as well as with the development of karstology and speleology (together with their history) and the international term "karst".

The 19th century was the time of "great discoveries" in speleology. In the year 1818, the interior parts of the Postojnska jama were discovered, explorers penetrated into the caves Planinska jama (Planina Cave) and Karlovice on Lake Cerknica, in 1824 the cave Križna jama was being explored by means of a special boat, and even in the region of Gorenjsko ("Upper Carniola") the cave Jama pod Babjim zobom was opened to the public in 1861. The main stimulus to explore the Karst region was searching for drinking-water supplies for the area of Trieste. The connection Škocjanske jame - Timavo was already discovered, and at that time it was already known that underground streams were very deep below ground. That was the reason why the exploration of deep potholes was tackled on one hand, and on the other that of the sinking rivers. Under the lead of Svetina the explorers started penetrating into the Škocjanske jame downstream the Reka, and under Lindner they undertook the research of deep potholes. The practical results concerning water supplies could not be considered a great achievement, but they were inestimable for speleology and the knowledge of karst. In the year 1839, the bottom of the 226 m deep cave Jama na Hudem letu was reached; in 1841, the 329 m deep Labodnica cave (as long as 60 years considered to be the deepest in the world!); and in 1889, the 200 m deep entrance shaft of the Kačna jama was successfully negotiated.

A new scientific study, i.e. study of caves or speleology, developed most closely related to the research of Slovenian caves and the Slovenian karst. It was particularly the Slovenian caves, which were being studied by F. Kraus, the initiator for one of the oldest speleological societies Verein für Höhlenkunde, founded in Vienna in 1879. Therefore, the Škocjanske jame and their significance should undoubtedly take part in the birth of speleology.

Besides, the Škocjanske jame are a significant natural phenomenon. The Reka river flows from the springs below Mt. Sneénik along the 47 km long course as a superficial stream. After its contact with limestones, the river does not erode only mechanically, it also deepens its bed by means of corrosion. In the first section, the Reka flows along a 4 km long canyon at which end a mighty entrance opens to the Škocjanske jame. A little further beyond the ponor section the cave ceiling collapsed; the consequence is the present collapse dolines Velika dolina ("Great Doline"; under 200 m deep) and Mala dolina ("Little Doline"), divided by a natural arch which is the only remaining part between them. Over the cave and between the ponor and perpendicular walls in the Mala dolina, the village of Škocjan calmly rests. Close to the houses, there is another entrance to the underground world, the 60 m deep pothole Okroglica, which finds its end underground by the Reka river. In the Velika dolina, the Reka ultimately disappears underground and emerges on the surface as far as 34 km away in the Timavo springs. Between the last ponor and the siphon in the caves (and according to the lattest investigations beyond it), the Reka runs along an underground canyon which is 10-60 m wide and up to 140 m high. In some places, the canyon enlarges into exstensive underground rooms, the largest of which is the Martelova dvorana (Martel Hall), 250 m long, 120 m wide and 140 m high. The underground canyon reaches almost 2 km of length.

There is a series of collapse dolines and abandoned blind valleys proving that the Reka has not always disappeared underground at the same place as being the case at present. The Reka was cutting its bed deeper and deeper - in this way the underground canyon formed, in places the channels were being abandoned and the new ones were being formed. The former channels are today abandoned dry passages and lateral caves all situated at higher levels. Some of the caves probably result from the action of the former underground Reka tributaries.

An event which happened 10 years ago gives evidence that the karstification process and the incision of the Reka into its bed are still being in progress. In the year 1982, a 5 x 10 m big and 27 m deep hole opened in the river-bed of the Reka, at the beginning of the limestone section. The opening was engulfing the whole water amount of the Reka. The river-bed beyond the collapse, extending further through the Škocjanske jame, was dry. It was not earlier than after the autumn rains, which swole the Reka to such an extent that the inflow was larger than the quantity which was being engulfed by the collapse, that the stream in the Škocjanske jame was able to run further along the entire length of the Reka bed.

That proves that the limestone beneath the bed of the Reka as well as beneath the Caves is karstified and cavernous; but the limestone is mainly flooded and inaccessible. The majority of the fissures in the river-bed opening up to the surface is covered by alluvium.

Two of the reasons why the caves of Škocjan are such as they are, i.e. unique in the Slovenian karst, are their location at the contact of impermeable flysch rocks and limestone, and the fact that the large river flows from the impermeable territory. The Reka is not significant for its length of 47 km, but for the quantity of its waters which is at times considerably enlarged. Its mean annual discharge is 9 $m^3 s^{-1}$, and the maximum can reach about 400 $m^3$. That is an explanation for large cave dimensions: a tube letting through some 100 $m^3$ of water in a second can by no means be a thin one.

The cave ceiling lowers at the end of the underground canyon, the channel turns down and forms a siphon which is a bottleneck for high waters stagnating and rising before they reach it. During the highest recorded flooding (in 1826), the water-level reached the height of 132 m above the siphon, and in the year 1965, when the participants in the 4th International Speleological Congress should visit the cave, the water-level reached 106 m. Floods in the Škocjanske jame are rather turbulent; the water in 1965 was rising at a velocity of 5 m $s^{-1}$. So it is not surprising that the Reka in the Mahorčičeva jama (Mahorčič Cave), right after the ponor, deposits even 30-40 cm large boulders on the tourist pathway.

Most trouble during the exploration of the caves of Škocjan was caused by water; it took over 60 years before the explorers finally suceeded in negotiating the cave section between the ponor in the Velika dolina and the Mrtvo jezero ("Dead Lake"), situated at the end of the underground canyon. Another 100 years were needed before the cave divers (in 1991) penetrated through the siphon; beyond they discovered passages of similar dimensions than the ones situated in the upper section of siphon. Techniques used in the Škocjanske jame for exploration are unique in the history of speleology, and should be given a detailed description, as they are one of the reasons why the Caves deserve world's attention.

On the basis of the old sources, e.g. Cassas's paintings, it can be concluded that at least occasionally, people used to visit the entrance parts to the caves, the Velika dolina and Mala dolina like tourists. The beginning of cave tourism and intense investigations of Škocjanske jame may be the year 1819 with the introduction of a book for visitors. In 1823, a tourist walkway leading into the Velika dolina as far as the Tominčeva jama (Tominc Cave) was completed. In 1839, the master well-sinker J. Svetina from Trieste ventured along the underground Reka by means of a raft, and penetrated downstream as far as the 3rd Waterfall, about 120 m deep into the underground. Svetina frequently attempted to penetrate even deeper, but the stream full of rapids and waterfalls as well as the constant danger that water would rise abruptly due to the high rainfall and that return would be impossible, were an obstacle too large to be surmounted. In 1851, a group of miners and the locals from the Karst, who were under the lead of A. Schmidl, penetrated downstream the Reka and managed to reach the underground length of 500 m. Their boats were swept away by the high waters, so they were prevented from any further investigations.

The turning point for the exploration of the Škocjanske jame came in the year 1884, when the Littoral Section of the German-Austrian Alpine Club from Trieste founded its Caving Section. In the same year, the Section took a lease of the Škocjanske jame together with the surrounding land. The motive power in further investigations as well as in the tourist development was the "caving triumvirate" Hanke - Marinitsch - Müller. In the very first year of their research, they negotiated the 6th Waterfall - the main problem for further investigations. In 1887, the 14th Waterfall in the Hankejev kanal (Hanke Channel) was reached, and in 1890, the Martelova dvorana - the end section of Hankejev kanal, and the Mrtvo jezero together with the siphon. The last major achievement in that period of research was the discovery of the Tiha jama in 1904 - it was climbed into via the 60 m high wall of the Müllerjeva dvorana (Müller Hall) by four locals. After the long period of unsuccessful attempts, the continuation of the Škocjanske jame was discovered in 1991, when the cave divers from Koper and Trieste penetrated through the 22 m deep and 60 m long siphon before the Mrtvo jezero. Beyond the siphon, there are new passages, partly researched, but most of them still awaiting new discoveries (Morel 1992, Sancin 1992).

A contribution to the significance of the Škocjanske jame is presented by exploring techniques. The major obstacle of cave exploring was the wild underground river with waterfalls and rapids, constantly threatening with an abrupt 100 m rise of water. The perpendicular walls of the canyon of outstanding dimensions prevented from the proceeding on foot by the river. The underground Reka was being ventured by means of various "boating techniques", i.e. wooden rafts and boats, paddles, poles, anchors, hooks, ropes and pulleys. But the danger of an abrupt rise of water still remained a constant threat. For such occasions the defined lengths of "rescue trail", leading from the bed of the, Reka more or less vertically upwards to a level which could not be reached by water during a mean flooding, were being cut into the rock in appropriate places. In case of flooding when the Reka would rise to such an extent that upstream proceeding would be impossible, the explorers would use a "rescue trail" to proceed up to the cave ceiling where they could wait for the retreat of flood waters. In some cases it really occured that the explorers had to use such a *Rettungsweg* (rescue trail). Adequate techniques, the precaution and good organization contributed to the fact that there was not a single serious accident during the whole period of cave exploration which took many decades.

The other kind of exploring, which was used for wall traversing and ascents to the open side passages on top of the walls as well as in the walls, was enabled by using the techniques of the then mountain tracks in the Alps. The leading members of the Caving Section were searching for caverns and new leads, they were exploring and surveying, and the locals from the neighbouring villages were permanently employed "cave workmen", who were, mostly during the winter, cutting and constructing the trails in designated sections of the caves. Stone ledges, bends and other appropriate places in the walls were being used for the new trails; the pitches and stairways were being cut into the bedrock; iron pitons for pitches and holds were being hammered into the rock; new iron fences were being fastened for security; bridges, footbridges and "swinging paths" were being built by means of stones, planks and beams. That was a slow work, but in the course of some decades, all the caves were being crossed over by such walkways; there was no opening or ledge in a wall without a pathway leading up straight to it. In this way the Dvorana ponvic ("Bowls Hall" - the chamber with rimstone pools) was discoverd, and as the last the Tiha jama. Some of the pathways are undoubtedly topmost technical masterpieces of the kind. A good example is the Visoka pot ("High Trail"), carved into the walls of the Hankejev kanal, which made it possible to reach the siphon without a boat even at high waters. A supplement to this trail, i.e. a predecessor of the present Hankejev most (Hanke Bridge), was the fear-respected "Mačja brv" ("Cat's Walk"), which was spanning the Hankejev kanal directly under the ceiling, about 90 m above the river.

These pathways, some of them improved and widened, served not only as paths for explorers but also as tourist paths for "underground visitors". A written record from those times saying that the hand of such a visitor as well as the foot should be strong and that he should not feel dizzy, is definitely no exaggeration. In the same way as the research pathways, the tourist walkways were being developed. As has already been mentioned, the first tourist footpath leading into the cave was made in 1823, but the first "mountain tourist tracks" were not built before 1884. During the time of the development of the pathways in the Caves, the footpaths, resting places and viewpoints were being built in the surroundings, in both collapse dolines and on the edge of the gorge, and pine trees were being planted. Under Italian rule (between World War I and II), particularly tourist facilities were being extended and improved. Most significant achievements were the artificial tunnel connecting the collapse doline Globočak and the cave section Tiha jama, and the Hankejev most (as called at present).

Today there are kilometres of tourist trail in the caves; at many places, the old research trails are still well preserved and can even be used. There are five firm bridges over the Reka, a tunnel from the Globočak into the Tiha jama, a lift service in the Velika dolina, and electricity illuminating the tourist section of the Caves.

By further investing and care, three activities, i.e. three most attractive features of the karst underground world: caving, tourism and preservation of the natural and cultural heritage, might ideally be united in the Škocjanske jame.

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# KARST WATERS AND HOW THEY ARE ENDANGERED

Janja Kogovšek*

**Astract**

The paper deals with the kinds of water percolation in the karst as well as the corrosion which increases the permeability of waterways, i.e. karst permeability. Two examples of corrosion observed in detail are mentioned here. Special emphasis is laid on the quality of karst waters. There are many particular examples of pollution being spread all over the karst.

Pure drinking water is one of the most important raw materials on the Earth, but man has not been entirely aware of this fact, and if yes, then he has not endeavoured seriously enough to preserve as much as possible of it. Man's universal activities produce more and more waste materials and waste waters and thus endangers the human environment as well as the sources of pure water.

One part of waste materials can be used again, such recycling process demands that waste materials should be sorted out (which is being gradually introduced into Slovenia) and their processed. The result of such an activity is above all minor quantities of waste materials at the disposal sites. The rest of the wastes which cannot be used again and which present more or less hazardous, dangerous and poisonous solid substances, are being dumped ~~ed~~ at waste disposal sites. All dumping grounds are exposed to precipitations washing away the soluble substances and thus alter into a waste water. This water together with other waste waters should be purified by a purification plant. Waters purified up to an appropriate level are suitable to be let out into waterways.

On the impermeable ground, waste waters are being drained off into a sewage system where they can be controlled. Due to its permeability, the situation is worse in the karst where waters immediately disappear underground and percolate more or less directly through the karst rocks as far as underground water streams. In this way the sources of drinking water are being endangered. Beside the activities demanding another use of waste materials and beside the

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searching for suitable localities for waste disposal sites which should be built according to the contemporary demands, the knowledge of underground streams and their courses is very important. Despite the recent intense research in this field, not everything has been investigated yet. Various polluted waters join the sinking streams along their superficial flow, but the underground influxes of waste waters are still unknown. There are certainly self-purifying processes of superficial as well as underground river streams, but that all is restricted by the kind and quantity of pollution. The ponor water of a sinking stream emerges in a resurgence. The quality of the spring water depends on the pollution before the ponor, the pollution effect can be diminished by the self-purifying effect between the ponor and the spring.

## Some investigations of karst waters

More or less vertical percolation of precipitations from the surface straight through a carbonate massif demands the knowledge of dynamics and corrosional processes as well as the processes concerning the degradation of the pollution during the percolation of polluted waters. Such percolating waters collect in underground water streams which run below ground in different directions and emerge as resurgences which are often used for water supplies. It is of vital importance to designate catchment areas of the springs as well as their underground connections, for this purpose numerous tracing methods are being used at present. A very signigicant contribution is the knowledge of water stream qualities, particularly under critical circumstances with low discharges and high temperatures, the knowledge of potential pollutants as well as the consequences of abrupt and unexpected pollutions of the streamways, at the same time it is also important to consider the most efficient measures needed in such circumstances.

According to the programme of the Institute of Karst Research, vertical water percolation has been observed for many years in numerous karst caves: Postojnska jama, Planinska jama, Pivka jama, Divaška jama, Taborska jama, Škocjanske jame and Vilenica. Particularly oscillations of the corrosion of percolating waters have been measured during the year as well as flowstone deposition in the caves. In case of polluted percolation waters, the corrosion oscillations have been observed and it has been attempted to designate the significance of self-purification processes during the percolation. Subsequently, the rainwater composition has been observed at Postojna, as precipitations are often polluted by many hazardous emissions of industry and communications. The pollution of this kind is transmitted by means of air currents even at a distance of 100 km or more.

The Pivka river, which is an example of a karst sinking stream, was already investigated by N. Preka and N. Lipold-Preka (1976), and later by B. Sket and F. Velkovrh (1981). Our team has observed the quality of the Pivka river in the section before the ponor to the Postojnska jama under various circumstances, as well as the changing of its quality during its further flow underground as far as the caves Pivka jama and Planinska jama. On that occasion we observed the quality of its surface-flowing tributaries as well as that of some brooks which probably join the Pivka underground (J. Kogovšek 1991).

The quality of the waters running from the Babno Polje over the Loé Polje as far as the Cerknica Polje has been observed, as well as that of the waters of Gabranca, Mrzlek and Ribnica. Some investigations have been carried out in order to determine the influence of the polluted water, coming out from the meat-packing plant of the Poultry Farm of Pivka na Kalu, on the Reka quality.

All those detailed observations, periodical measurements and analyses of other karst waters have indicated their quality and various permeability rates of karst rocks, which was demonstrated by the concrete values of the penetration rate of precipitations into the karst in some areas observed in detail. At the same time some possible critical situations which may cause large pollutions in the karst have occured.

## Vertical percolation

It has been found out that the rate of corrosion of vertically percolating waters differs according to particular territories. Carbonate hardnesses of percolating waters in the Karst and the cave Taborska jama in Dolenjsko have thus reached the values of up to 330 mg $CaCO_3$ $l^{-1}$, and in the Notranjsko region only up to 260 mg $CaCO_3$ $l^{-1}$. For percolation waters it has been found out that corrosion depends particularly on the water quantity, which had already been established for horizontal water streams. The increase of a discharge during a water pulse with a smaller or larger delay is followed by the decrease of hardnesses, but discharge oscillations are far larger than oscillations of the rate of corrosion or hardnesses, the corrosion being the result of both of them. During the year, the corrosion oscillates to a great extent. During the periods of large changes with abundant precipitations, the corrosion is more intense; these periods are followed by the periods with little precipitation, i.e. the periods of a constant run-off with minimal discharges and minimal corrosion. Particularly the periods with abundant precipitations (spring and autumn rainfalls) contribute to the annual corrosion of trickles, i.e. to the annual corrosion of vertically percolating waters. In the cave Planinska jama, a trickle with the annual water discharge of about 2,000 $m^3$ dissolves on its way over 400 kg of carbonates, which amounts to 0.21 kg of carbonates/$m^3$.

In underground caves there are mainly oversaturated trickles depositing flowstone, i.e. carbonates dissolved by water in the cave ceiling, hence an appropriate deficit of the mass (and spreading of conductors). Very rarely it occurs that percolation water which does not deposit flowstone or is even slightly aggressive can be encountered. The majority of such drippings (in many cases the drippings are slow) has been recorded in the passage Pisani rov in the cave Postojnska jama. In places, the aggressive water hollowed up to half a metre and sometimes even deeper corrosion cavities into the rocks. Similar features have been recorded in the Lepe jame, the section of Postojnska jama, with many dripstone formations on the floor, after an inspection considered to be artificially "placed". Here it is evident that the maintenance service were disturbed by the deficit in the otherwise intensely flowstone decorated cave.

Observations of trickle reactions to superficial precipitations have shown reaction times of trickles in the caves. A major difference has been observed between the drippings and more abundant trickles; crucial for trickles are the circumstances and the intensity of precipitation. During long summer as well as winter droughts when the catchment area of the trickles is rather emptied, even frequent precipitations (altogether 70 mm) have not released trickle reactions in the caves, whereas during wet periods they start reacting after an hour to some hours. This is of great significance when the karstic surface is polluted. The way of rainwaters seepeing from the surface into the karst underground can at the same time be the way of polluted waters. Larger is the permeability (dependent upon the intensity of corrosion in the past and today), faster can the pollution penetrate into the karst underground. In the last few years while observing percolating waters, it has been found out again and again that many waters are polluted. In places there are even signs of pollution in some underground caves. Such an example of pollution in the Kristalni rov was reported by the cavers; further the polluted waters have been determined in the caves Pivka jama, Ponikovska Draga, Mahorčičeva jama, and the increased rate of nitrates from a trickle has been observed in the caves Škocjanske jame immediately beyond the Paradiž. In all the cases, major pollution can be connected with man's influence from the surface.

In order to get a detailed insight into the transmition of the pollution from the surface into the karst underground, the seeping of waste waters coming from the sewer system in a camp which is situated above the Pivka jama was followed for many years (the waters were seeping through the 40 m thick cave ceiling (J. Kogovšek 1987). In the cave, the percolated water was caught from many trickles of different sizes or from the drippings. The polluted water flowing off from many points on the surface appeared in the cave within an extensive section with the diameter of 30 m.

During slow percolation or low discharges, the content of chlorides and phosphates decreased by 50% after the percolation. Chemical oxygen demand (COD) decreased by 95% and more, but the determination of biochemical oxygen demand ($BOD_5$) gave even better results, which was evident from good aeration of the cave ceiling. This was also confirmed by ammonia and nitrate measurements of the waste waters of the cesspit and in percolated water. During actinic oxygen processes in the cave ceiling, nitrates are formed from ammonia. Different rates of purification were recorded in individual trickles, which is to be explained by various kinds of percolation. A poorer purification of the percolation through the cave ceiling occured during large discharges when the organic suspense, which deposited at the bottom of the cesspit, was washed away, but the case was different during low discharges. The suspense in the percolated water largely increased COD and $BOD_5$ as well as the content of other measured parameters; the purification effect in this case was distinctly worse.

A karstified carbonate massif is needed for self-purification actinic oxygen processes which are confined to enough low pollution and slow percolation through the massif. When solid impurities are being sedimented at the bottom or in case of appropriate low pollution according to the quantity and composition, the fissured carbonate massif behaves like an effective purification plant. Its effectiveness depends to a great deal on the discharge and a kind of percolation which is dependent upon the karstification rate of carbonate rocks. The results prove that multi-chest cesspits in the karst are reasonable when the residue is regularly emptied.

At Postojna, it was observed from 1986 to 1988 that precipitation is not a pure distilled water. The mean pH value amounted to 4.5. Summer precipitations, i.e. showers, reached a higher mean value of pH than those in the period of more abundant precipitations, the minimum recorded value was 3.1. The measurements indicated a very complex composition of rainfall. On one hand, the concentrations of nitrates, sulphates and chlorides were augmented and on the other those of calcium and magnesium, which resulted in the moderate pH, though its pollution was rather large. The presence of these ions was reflected in the specific electrical conductibility (SEC) which reached the values between 5 and 285 uS $cm^{-1}$. The largest precipitation pollution is evident during the time of drizzling (there is no dilution) and in the beginning of longer precipitation cycles (here the composition was rather changing in the course of time). Aggressive rain is often neutralized by carbonate particles from the air, but normally when it reaches the carbonate ground. It has not been found out yet what is its influence upon the washing away of various components into the karstic water (J. Kogovšek & A. Kranjc 1989).

## Underground watercourses

The knowledge of spring catchment areas which are had or planned for the captures of drinking water, is necessary. Every pollution on the surface can influence water quality. The tracing of karstic waters is thus so important and enables the insight into the underground percolation of water. It is very complex as there are considerable differences in percolation according to different water levels. Systematic investigations by means of natural indicators and artificial tracers would be necessary. The international association for the development of tracing methods and using of appropriate tracers - the Association of Tracer Hydrology (ATH) - has so far organized six symposiums. Slovenia as one of the members of the Association has a reach tradition.

In Slovenia, first water tracing attempts for establishing the underground connections carried out in the period before the year 1945, were collected and summarized by A. Šerko (1946). Twenty-eight sinking streams were dyed, some of them for several times. First successful tracings were carried out before the First World War in the tributary area of the river Timavo while searching for the drinking-water supplies for Trieste. The subsequent investigations until 1965 were collected and summarized by I. Gams (1965). The connections in the river basin of the karst river Ljubljanica were evidenced, and several tracing attempts were carried out in the river basin of the river Krka as well as the first tracing in the Julian Alps. The apparent underground water velocities were oscillating between 1 and 5 cm $s^{-1}$.

In the third period after the year 1965, there were 90 tracing attempts in Slovenia (R. Gospodarič et al. 1988). The connections of all main sinking streams of the Slovene Dinaric karst were established (P. Habič 1989). Tracing attempts were carried out mainly by the Geological Survey, Hydrometeorological Survey and Institute of Karst Research. The major combined tracing attempt, where 13 different dye tracers were used, was carried out in the catchment area of the Ljubljanica springs in the framework of the research carried out for the Third Symposium of Undergroung Water Tracing (3th SUWT). The tracing of the Pivka river near Trnje demonstrated that its water partly runs off beneath the flysch of the Pivka Basin in the direction to Vipava; the tracer, poured into the brook Sajevški potok, emerged in the 40 km (air line) distant spring of Timavo. In the catchment area of the Rižana, the protected area of the spring was determined by a series of tracing attempts (P. Krivic et al. 1987, 1989). The Geological Survey also carried out the tracing of the sinking stream near the settlement Klinja vas, into which the effluents from the pig farm are being spilt. It established the connection with the Tominčev studenec and the Radeščica which was confirmed by the tracing of the Željnski potok (P. Habič et al. 1990). This example gives a clear evidence of the establishing of underground connections particularly in the catchment area of the springs which are captured for the provision of the inhabitants or were planned for it. Extensive tracings in the catchment area of the Dobličica demonstrated that its catchment area extends only into the narrow region of Poljanska gora, and that there were no direct connections with the polluted waters of Kočevje. Water tracings in the karst catchment area of the Krupa (P. Habič & J. Kogovšek 1992) provided important new results of investigations of the water percolation in the limestone dolomitic aquifer of the area.

## Sinking streams

In case of sinking streams there might come to corrosional effects, too. An example is the corrosion of the brook Predvratnica, which runs from the non-carbonate territory and sinks into the carbonate massif (J. Kogovšek & A. Kranjc 1992). The corrosion intensity gradually decreases according to the distance from the ponor, which could be an explanation for the form of the cave Vratnica. The annual corrosion from the ponor into the Vratnica to the resurgence in Peči (1150 m air distance) amounts to 74 t of rock, i.e. 0.18 kg of carbonats/m$^3$ of water. In the case of the brook Predvratnica, and similarly in that of the vertical percolation, there is a dominant influence of the discharge or water quantity upon the large amount of corrosion in comparison to the rate of corrosion.

Karst sinking streams along their superficial flow are the receivers of waste waters from the nearby settlements. Purification plants are slowly developing only near the major industrial settlements, so the inspection of the quality of sinking streams is necessary as the analyses demonstrate the real state of the quality of these waters. As we rely too much on the self-purification of streamways, it should be found out which are their capabilities, but only during the critical conditions of low water levels.

With regard to large quantities of waste waters from the Pivka Poultry Combine, which were collecting rather unpolluted in a doline behind the factory after the purification, there was a possibility for the pollution of the nearby springs and the river Reka. The measurements proved that the waste waters do not pollute the observed waters and that they evidently seep into the karst inaccessible underground water which is being endangered despite the dilution and self-purification processes (P. Habič & R. Gospodarič & J. Kogovšek 1984).

The observation of the water quality from the Babno Polje over the Lož Polje and the Cerknica Polje, which are part of the catchment area of the Malni spring, has shown that the spring waters were pretty pure with regard of the chemical parameters, and the bacteriological investigations have shown a frequently opposable water. The ponor water in the Babno Polje was at a low water level rather polluted, whereas the Loški Obrh near Dane was only slightly polluted. Some minor springs were polluted to a larger extent, the reason is commonly the settling.

B. Sket (1970) established on the basis of the chemical analyses in the years 1965 and 1966 that the superficial Pivka was only slightly polluted and oversaturated by oxygen in the winter, and in the summer it was quite polluted by a faint deficit of oxygen. After the confluence of the Unica river with the Rak in the cave Planinska jama, the Unica was flowing as a clear oligosaprobic river. The results were also confirmed by N. Preka and N. Lipold-Preka (1976) who were establishing that the Pivka was improving quickly on its downstream flow and that the level of self-purification under the given circumstances was 62.1%. The condition of the Pivka and its tributaries was followed by R. Gospodarič and P. Habič (1985).

Before the Pivka sinks into the Postojnska jama, the river flows superficially for 15 km and receives the effluents from the majority of small settlements the main occupation of which is farming and the timber-manufacturing industry. The largest settlement (10,000 inhabitants) is Postojna with the metal, timber-manufacturing and food-processing industries, the transport enterprise and forestry with its own driving park and several military objects.

Since 1984 a worse water quality of the Pivka has been observed at the ponor, as the COD has rarely been below 5 mg $O_2$ $l^{-1}$, at low waters during the summer it reached the values of up to 40 mg $O_2$ $l^{-1}$, and the content of the dissolved oxygen has been decreased by up to 20% of saturation, which was only 2 mg $O_2$ $l^{-1}$. The phosphates and chlorides have been increasing, too. Similar critical situations occur also during winter droughts when at low water levels water partly freezes and the impurities concentrate in the liquid stage. After the introduction of waste water purification by means of a purification plant at Postojna, the Pivka water-quality has improved.

Beside the critical annual periods, there are extreme changes for the worse already at night or during the day, during the summer low waters. The river vegetation abundantly provides the Pivka with oxygen during the day, and during the night when photosynthesis is replaced by assimilation there comes to strong deficits of oxygen, which endangers the animal species living in the Pivka. But as it has been found out, such conditions last only some hours.

During the further underground flow of the Pivka, the brook Črni potok flows into it; the brook was very polluted and had an increased content of sulphates and nitrates, and particularly that of chlorides and o-phosphates, and as much as 0.65 mg $l^{-1}$ of detergents. The Pivka has always been saturated with oxygen in the cave Pivka jama and has generally shown the improvement of its quality, but in the years 1989-90 there were periodical major deviations, which is to be ascribed to the Črni potok. It has been unknown how many and what kind of tributary the Pivka gains during its further flow. It is possible that the polluted water of the Ponikve flows into it from the direction of Studeno.

In the cave Planinska jama, the Pivka is saturated with oxygen also during the summer months, which is the consequence of the cooling in the underground, and it probably gains the tributaries of pure water. The Pivka in the Planinska jama was up to 1990 still in the first quality class. In January 1990 and March 1991, it was noticed that its quality was worse, and that there was foam on the water level.

The brook Nanoščica, which during the summer dry months when the Pivka gradually sinks higher upstream, flows into the Pivka before the ponor and improves its quality. However, coincidentally many unpleasant things can happen, which was also the case with the spillage of liquid manure from the cattle breeding farm near Hruševje in July 1987, when 2,000 $m^3$ of spilled liquid manure percolated into the Nanoščica, which was saved by an instant isolation of the liquid manure. Some 3 km lower, the content of the dissolved oxygen did not drop under 3 mg $O_2$ $l^{-1}$ because of the pure tributaries Korentan and Šmihelski potok; the content of the dissolved oxygen was satisfactory after another 8 km downstream. It has been found out that the pollution did not effect the Pivka quality before the ponor into the Postojnska jama (J. Kogovšek 1992). At the beginning of August there were 135 mm of rainfall which caused the mixing and extreme dilution as well as running off of the isolated polluted water.

In any case, the knowledge of the qualities of sinking rivers and their tributaries is necessary, as also minor polluted inflows can cause major deteriorations of the qualities of sinking rivers which sink into the karst terrain.

Underground streams are sooner or later joined by more or less polluted waters sinking directly from the surface into permeable karst rocks. An example would be the rainwater draining the roads. The analyses of such waters from a section of the highway near Postojna have shown that the pollution here is not negligible (J. Kogovšek 1993). From October to April these waters have a high content of chlorides (up to 19.3 g $Cl^-$ $l^{-1}$) due to the winter salting of roads. Precipitation water from the roads washes away also tiny solid particles which cause a major turbidity of the draining water, particularly after longer periods of drought, as well as the parallelly higher COD and $BOD_5$ which indicate organic pollution. For COD the values from 21 to 2,500 mg $O_2$ $l^{-1}$ have been measured, and for $BOD_5$ the values from 2.3 to 84 mg $O_2$ $l^{-1}$. In all the cases, the COD has been much larger (up to 30 x) than the $BOD_5$, which indicates a considerably larger part of hardly decompositing and incompositing organic matters in comparison with the decompositing ones. For orientation I mention the standards for purification plants. By law, the upper level of the COD for the outlets from purification plants, where streamways are diluted, is 160 mg $O_2$ $l^{-1}$. However, it was suggested that the value should be lowered for the karst territory. The sulphate content of the water from the highway is not negligible either; up to 1.1 mg Pb $l^{-1}$ and 0.034 mg Cd $l^{-1}$ has been determined.

## Conclusion

Water percolation in the karst is a very complex process. A gradual insight into individual minor segments gradually enables better knowledge of the complete activity of water percolation in the karst. As pure drinking water is needed now and will be in the future, it is necessary to try to protect sufficient quantities of that natural wealth. It leads to the establishing of the catchment areas of springs, to the gaining the insight into the percolation water dynamics as well as to the establishing of self-purification processes, in order to protect the chosen sources from numerous pollutants.

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# CAVE DIVING

√ Ciril Mlinar*

**Astract**

Cave diving in Slovenia took root in the period before World War I, when explorers made diving attempts in the springs of the river Ljubljanica by means of very simple equipment, but still achieved great success. After the War, this kind of karst underground exploration expanded and modernized. At present there are several cave diving groups and tens of cave divers in Slovenia.

*The recent survey proved little public knowledge of cave diving and cave divers. Not many people have been acquainted with this activity so far. Public opinion is: "Cave diving is a very hazardous sport, in fact the real Russian roulette. The fools involved play with their lives."*

Cave divers certainly disagree with the above mentioned statement. Regular training, faultless double equipment, medical control, and safety factors make our activity less dangerous than that of driving a car, for instance.

For superficial public knowledge of cave diving, cave divers could be blamed themselves. It is apparent that the activity has not been properly popularized as well as our achievements not properly represented in mass communications. With my article I would like to fill up the gap and somehow illuminate the obscurity in which we - cave divers - are swimming.

Cave diving is one of the most demanding kinds of diving. It differs from open-water diving in that a cave diver has the cave roof above himself all the time of the dive. He is prevented from swimming freely towards the surface at any time of the dive, so he has to swim the whole way back again. In the cave, there are complete darkness, many a time a very cold water, and sometimes the water current or poor visibility. For safe negotiating, a cave diver has to have a lot of knowledge of diving and caving, much experience, has to master cave diving techniques and has to use faultless equipment. Beside the physical strain, a cave diver is constantly exposed to psychical pressures. Darkness, shadows, chill and depth make contribution to all

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that. A diver has to be extremely concentrated and focused on his aim, and cannot give his fantasy a free hand. Air consumption in bottles has to be controlled as well as the consumption of electrical energy in the lamps, the depth and time of the dive and besides, the route through the underwater passage has to be found. Every dive into a new passage or an unexplored siphon is a real adventure for a diver, as he never knows in advance, what are the length and the depth of a passage, which are the obstacles awaiting him...

The first recorded cave-diving attempt is English (the cave Peak Cavern) from the year 1777. One of the cavers called Day simply held a deep breath and tried to negotiate the siphon. The attempt was unsuccessful, and the man was saved unconscious from the water.

The breathing apparatus for cave diving was first used by the Italian Cavolini in 1785. He was diving by means of a simple "hard-hat" apparatus in the sea caves near Sorrento on the Bay of Naples. Later on, there were many more recorded cave-diving attempts, the majority of which by using of various kinds of breathing apparatus. The beginning of modern underwater speleology was in the year 1946. While exploring the spring Fontaine de Vaucluse in France, revolutionary aqualungs for cave diving were used by the Cousteau team for the very first time. At the same time the first special organization for systematic research of underground caves, British Cave Diving Group, was founded.

In Slovenia, cave diving activities started pretty early. As early as the 1920s, the Institute of Postojna Cave (Zavod "Postojnska jama") bought a diving suit in order to explore karst caves , but as its weight was too large, the suit did not prove to be the most appropriate one for that kind of diving.

In 1939, Kuščer's team achieved the first great success in the springs of the Ljubljanica river. In the resurgence Malo okence ("Little Window") one of the divers passed through the tight entrance part to the siphon eight metres deep; in the resurgence Veliko okence ("Great Window") he swam through the four-metre-deep and 10-metre long siphon. The diving was practised in a very original manner by means of the home-made equipment. For breathing the divers used a hand air pump (it is slightly larger but very similar to that used for pumping car tyres), and 15 metres of rubber tube. One side of the tube was fastened to the pump, and a diver had to put the other side simply in his mouth. This kind of diving was at that time a great achievement not only in our country but also in the whole world. Unfortunately, the two attempts remained the only ones as the diving party did not proceed with cave-diving activities.

In Slovenia, further caving and diving exploration was not tackled before 1954. In order to research the unexplored world between the caves Pivka jama and Planinska jama, the Society for Cave Exploration (DZRJ), the Management of the Karst Caves and the Institute of Karst Research (IZRK) employed professional bottom-walking divers from Šibenik (brothers Ljubo and Ivo Gović, members of the enterprise "Spužva"), and from Pula (the naval officer Krsto

Garma). On 16th September 1954, L. Gović found an opening beneath the wall. He passed through and proceeded for 13 metres. On the next day, I. Gović said that at the depth of 16 metres the passage had narrowed to such an extent that any further continuation had been prevented. Today, as the siphon is negotiated, it extends 30 metres deep and then abruptly ascends as far as the water level.

In the following year, a section for underwater cave research was founded by the Society for Cave Exploration of Slovenia (DZRJS). The diving section could set to work thanks to the English Underwater Cave Research Association, which gave them two complete diving suits made of impregnated linen.

In 1955, the diving section again started to investigate Veliko okence. The explorers were diving in pairs; the only link with the outside world was the telephone.

The Veliko okence dives were repeated by twos. During the two attempts the divers penetrated 10 metres deep and 25 metres far through the passage, and carried out the first underwater surveys.

The dives were proceeded in the resurgence Žerovniščnica near Lake Cerknica by J. Štirn, M. Drašler and J. Mušič. Thirty-five years later, Mušič individually sailed around the world, which was the first Slovenian attempt. He remembers:

*We were diving by means of a diving suit which had to be pumped manually. Štirn and I passed through a narrow rift straight into the siphon and again reached the air after 10 metres. We were enthusiastic. In the cave I took several pictures with my "Zorki" photocamera which I kept right under my diving suit.*

In Idrija, a diving group was founded in 1957, and on 26th July 1957 the first underwater exploration of the lake Divje jezero ("Wild Lake") was performed. Boris Rupnik and Milan Štraus dived individually one after the other, for 10 minutes each. During that time they found a large entrance to the underwater passage situated at the deepest point of the lake. They penetrated eight to 10 metres deep into the passage.

On 7th September 1957, Rupnik was diving in the cave Ukovnik und successfully negotiated the 40-metre-long siphon. In order to train for more arduous undertakings, the dive into the known siphon of Ukovnik was repeated on 16th Septembre. Štraus swam through the siphon, where he lost the lifeline, so he could not find his way back. With his breathing apparatus empty he returned to the cavern beyond the siphon. As his apparatus was the only one in the cave, he could not be followed by the others. An extensive rescue operation was released. Firemen were trying to pump the water out from the siphon, but they only managed to lower the water-level for one metre. Then Rupnik made a decision to dive with the Dräger apparatus, which was being used in dry conditions by firemen for rescuing from the rooms poisoned with gas. Six hours after Štraus's dive both of them safely reached the surface. That was, as is known, the first cave diving accident in Slovenia, fortunately with the happy end. The group did not proceed with further investigations.

After the longer period of standstill, a new diving group was founded in 1966 by the Institute of Postojna Cave and the IZRK. On Saturday, 7th August 1966, Milan O. Adamič and Ugo Fonda negotiated the 12-metre-long siphon between the caves Pivka and Črna jama, both within the system of Postojnska jama. At that time, the only possible way from one cave into the other was through an artificial tunnel. They were diving in drysuits and used compressed air bottles made by AGA from Switzerland.

In 1967, a cave diving course was organized at Piran. Six of the participants passed the course - three of them from Postojna and the other three from Ljubljana. The course was realized by means of the aqualungs borrowed from the Society for Fishing and Underwater Activities of Piran and the IZRK from Postojna. Fonda, who was beside Orožen a leader of the course, dived alone in the cave Matijeva jama with the task to research drinking-water supplies. He described his experience as following:

*I was swimming through a horizontal passage some 30 metres far. The profile of the 180-centimetre-high passage was almost rounded. I can remember there were thousands of proteus (Proteus anguinus) in the passage. The water was very clear and wherever I directed my lamp, its beam captured some twenty of them at the same time.*

Unfortunately, that was his last underground cave-diving attempt (later he got professional and is still active today).

In 1969, the diving section of the DZRJS revived under the lead of Anton Praprotnik, and since the underwater cave research has uninterruptedly been performed, which was the turning point for cave diving in Slovenia. In the same year, Praprotnik, Di Batista and Krivic dived into the spring of Divje jezero and penetrated 90 metres far reaching the depth of 36 metres. The majority of cave dives were carried out in Divje jezero during the seventies, so the spring became a popular training site for cave divers. As early as 1972, Krivic and Praprotnik penetrated 50 metres deep and 130 metres far into the passage, which was for that time the largest depth reached by the cave divers of former Yugoslavia. After two years, on 23th August 1974, the cavers and public were shocked by the news of the first accident in our country with a dreadful end. Janko Petkovšek, an excellent caver, had started to practice cave diving, too. Until the moment of the fatal dive into the siphon of the cave Tkalca jama, he managed to gain rather little experience. The sad event was described by Peter Habič:

*He was well prepared and equipped and he rapidly dived into the siphon. After five minutes we pulled the empty lifeline, which got stuck a little shortly before, out of the water. Janko untied himself for an unknown reason and swam deeper into the siphon, from where he did not come back again.*

Right after the accident there was a huge organized rescue operation. Divers were systematically searching the siphon and on this occasion dived it through for the very first time. The accident in this way unintentionally contributed to the great achievement, at that time the longest and deepest dived-through siphon with its 26 metres of depth and 147 metres of length. Among a great number of cave divers taking part in the rescue, the "party" Sket - Praprotnik was the first that managed to reach the other side of the siphon. Beyond, the dry section of cave was inspected too, but apparently without success - the unlucky Janko has not been found since.

The fatal event slightly braked the material help coming from many institutions. The cave divers nevertheless carried on with their work, as their desire for new discoveries was stronger. The very next year, two achievements were carried out at the same time. On 4th October 1975, P. Krivic and M. Vogrič climbed as far as the Boka Waterfall, dived into the pool of the spring and swam through the 102 metre-long and 25 metre-deep siphon in a very cold water. B. Sket and M. Krašovec finally managed to penetrate through the "many times attempted" outlet siphon in the cave Pivka jama. They reached the depth of 30 metres and the length of 170 metres.

By the end of the seventies, the members of the section of the Speleological Association of Slovenia (JZS) achieved another great success. In the cave Tkalca jama, they penetraded as much as 1,800 metres far into a dry passage beyond the researched siphon and dived through the second siphon of a shorter length. That strenuous operation took as long as 12 hours.

At the end of the decade, the lack of equipment and various interests brought to the separation of the divers who founded two new cave diving groups: a section of the Ljubljana Society for Cave Exploration (DZRJL), and the Cave Diving Club "Proteus" (DJP "Proteus") in Ljubljana.

The divers of the DZRJL focused on further investigations of Divje jezero, where in 1981 Krivic and Praprotnik reached the record-breaking depth of 83 metres 200 metres from the entrance. They found out that the passage was proceeding even deeper. The largest underwater dived distance in Slovenia, 280 metres, was reached in Veliko okence during the systematic dives, but distance is still not ultimate. To illustrate the significance of the achievement, the following comparison can be made: a party of French divers who negotiated many kilometres of siphon all over the world, stopped after 225 metres of Veliko okence, characterized by silt and bad visibility, saying that was the task too demanding for them to proceed.

In the meantime, the DJP Proteus performed further investigations in the Postojnska jama system, and at the same time undertook underwater filming. During the winter of 1982-83, M. Krašovec and C. Mlinar shot the first Slovenian film of the siphons in the karst underground world. There they shot the first picture of a proteus in its natural underwater environment.

At the International Festival of Spéléological Film (7ème Festival International du Film de Speleologie "La Chapelle en Vercors"), the film won a special prize of the jury for the quality of underwater filming, and later a gold medal at the International Festival of Underwater Film "Hans Hass Medaille 1986" at Linz.

On 16th August 1983, M. Krašovec and C. Mlinar dived through the two siphons following the outlet siphon in the Pivka jama, and surveyed about 700 metres of passage. The DJP Proteus expanded its exploration activities to Herzegovina, Dalmatia and Montenegro, where they were particularly successful in 1984.

The activities during the following years remained vivid. The members took part in international camps of cave diving in different countries where they gained new experience. Beside the above mentioned clubs, there were many other cave diving groups founded within the already exsisting caving clubs in the eighties:

the Dimnice Caving Society (JD Dimnice), the Caving Society of the Slovenian Alpine Club from Trieste (JD SPD Trst), and the section of the Železničar Caving Club (JK Železničar) in Ljubljana. At present there are over 30 cave divers in Slovenia, diving occasionaly, and only ten of them are active divers. Their work has been coordinated by the Cave Diving Commission (KJP) within the Diving and Speleological Associations of Slovenia; at the same time the divers are connected with the International Cave Diving Commission.

Lately, many cave-diving investigations have been performed, as new sources of drinking water have to be found and the existing ones protected in case of ecological catastrophes. Some of the divers started to tackle the problem professionally. Cave diving outgrew the initial amateur- and sportlike approach to the activity and developed into a real research activity the results of which are being used by many institutions.

# SURVEY OF PUBLISHED FLOWSTONE DATATIONS FROM SLOVENIA

Nadja Zupan Hajna*

The studies of cave sediments in Slovenia started in the last century in the Postojna Cave. Karstic caves are commonly filled with: clastic material carried in the caves by water from the outside into the caves, collapsed blocks and chemically deposited calcite. Speleothems can give us the absolute age of their formations. And if the age of speleothem formations is known, then the age of other processes which are presented in the cave is known, too.

The first absolute age of a speleothem from Slovenia is known from 1971. Most of the speleothem samples have been analysed by Radiocarbon dating, some of them by U series dating, and just a few by the ESR method. $^{14}C$ analyses were made at the Radiokohlenstoff und Tritiumlaboratorium des Niedersachsischen Landesamts für Bodenforschung in Hannover, and at the Institute Bosković Rudjer in Zagreb. ESR analyses were made in Japan. By the U/Th method all samples were dated at McMaster University in Hamilton, Canada.

Here the number and the results of absolute dating analyses which were made in Slovenia are represented. Locations of all the caves which are represented in this article are shown in Figure 1. All the results have already been published.

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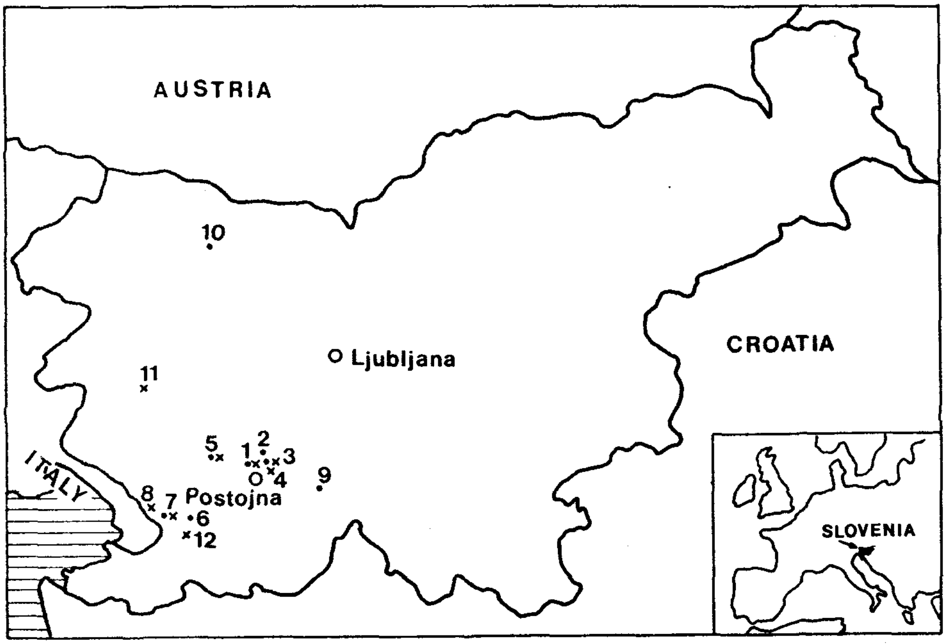


*Figure 1: Locations of caves: 1. Postojna Cave, 2. Planina Cave, 3.Zelše Caves, 4.Small Natural Arch, 5. Fiženca, 6. Škocjan Caves, 7.Vilenica, 8. Lipica Cave, 9. Križna Cave, 10. Babji zob Cave, 11.Paradana, 12. Mejame; x - U / Th analyses, . - other analyses*

The results of all the published datations are presented in this table. It can be seen that the flowstones, recently analysed by the U/Th method, are older than those, dated by $^{14}C$. It is true that the $^{14}C$ method enables the datation of up to 40,000 years only. Maybe, as the authors realized the limits of the method, they have chosen stratigraphically younger flowstones for datation, but also it is evidenced that the results, obtained by $^{14}C$ are not reliable for the flowstones older than 37,000 years and that in fact they are older. From analyses by U/Th it appears that many samples are older than 350,000 years, which is the limit of the method, that is why it would be necessary to date them by the ESR method, too.

As an example, two adjoining stalactites from the Pisani rov in the Postojna Cave were analysed by two different dating methods. In the Pisani rov, at 532 m above sea level, several stalactites hang down from the cave roof, some of them have fallen off and their bases are left on the roof. The flowstone generations with interlayered flood loams are well seen. Stalactites are about 1 m long. In the middle of each stalactite there is a reddish-brown nucleus, which was eroded, and eroded remains of brown flowstone. Around these two layers there is a thicker ring of brown-white rather porous flowstone. This flowstone is encircled by brown

*Table: Results of all published datations in Slovenia*

| Location/ method | | sample | age | |
|---|---|---|---|---|
| **Postojna Cave** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1972, 1977) | | | |
| | 1.brown flowstone | | 39,060 | ±3,820 |
| | 2.brown flowstone | | 39,440 | ±2,660 |
| | 3.broken stalagmite | top | 39,060 | ±3,820 |
| | 4.white stalagmite | | 20,740 | ±860 |
| | 5.white stalagmite | | 17,000 | ±250 |
| | 6.white stalagmite (on the broken one) | | 10,200 | ±200 |
| | 7.white stalagmite (on the broken one) | top | 10,250 | ±290 |
| | 8.white stalagmite (on the broken one) | | 7,470 | ±100 |
| | 9.stalagmite, 30 cm: | base | 14,222 | ±185 |
| | | top | 12,310 | ±175 |
| | 10.stalagmite,120 cm: | base | 42,900 | |
| | | top | 39,175 | ±1,205 |
| | 11.stalactite | middle | 37,050 | ±3,560 |
| | 12.stalagmite: | base | 13,365 | ±260 |
| | | middle | 7,960 | ±185 |
| | 13.stalagmite | | 8,640 | ±140 |
| | 14.stalagmite | | 8,685 | ±140 |
| ESR: | (IKEYA,MIKI& GOSPODARIČ, 1983) | | | |
| | 15.stalactite: | base | 530,000 | |
| | | middle | 280,000 | |
| | | top | 125,000 | |
| | 16.stalactite | | 190,000 | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 17. stalactite: | Po 1/1 | >350,000 | |
| | | Po 1/2 | 269,400 | +130,300 -80,000 |
| | | Po 1/3 | 76,000 | +24,900 -21,900 |
| | 18.stalactite | Po 2, top | >350,000 | |
| | 19.stalagmite | Po 3, base | 19,900 | +25.200 -24,700 |
| **Planina Cave** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.stalagmite: | top | 30,715 | |
| | | outside layer | 9,735 | ±285 |
| | 2.stalagmite | top | 32,875 | ±1,810 |
| | 3.stalagmite: | base | 49,900 | |
| | | top 1 | 45,265 | |
| | | top 2 | 45,780 | |
| | 4.stalagmite: | base | 45,610 | |
| | | top | 32,225 | ±1,450 |
| | 5.flowstone | | 44,240 | ±2,125 |
| | 6.flowstone | | 8,205 | ±355 |
| | 7.flowstone | | 3,630 | ±260 |
| | 8.red flowstone | | 44,635 | |
| | 9.flowstone | | 46,025 | |
| U/Th: | | | | |
| | 4.repeated | base | 79,700 | |
| | 10.flowstone | | 77,800 | |
| **Zelše Caves** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.flowstone | | 9,000 | |
| | 2.flowstone | | 4,500 | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 3.stalagmite | top, Z1 | 350,000 | |
| **S. Natural Arch** | | | | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 1.flowstone | MNM | 35,000 | +13,100 -12,400 |
| **Predjama Caves system** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.stalagmite | top | 34,925 | |
| | 2.stalagmite | base | 9,490 | |
| | (20 cm) | top | 2,380 | |
| | 3.stalagmite: | base | 10,425 | |
| | (82 cm) | top | 3,585 | |
| | 4.stalagmite: | base | 6,380 | |
| | | top | 2,200 | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 5.flowstone | F1 | 153,900 | +23,700 -94,600 |
| **Škocjan Caves** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.broken stalagmite | | 11,325 | ±145 |
| | 2.stalagmite: | base | 8,905 | ±155 |
| | (40 cm) | top | 1,495 | ±115 |
| | 3.stalagmite: | base | 12,245 | ±155 |
| | (22 cm) | top | 10,300 | ±175 |
| **Vilenica** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.stalagmite | | 36,000 | |
| | 2.stalagmite: | base | 29,333 | |
| | | top | 18,865 | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 3.flowstone | V1 | 80,200 | +56,900 -44,400 |
| **Lipica Cave** | | | | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 1.flowstone | L2 | 350,000 | |
| | 2.stalagmite, base | L3 | 160,400 | +116,900 -61,300 |
| **Mejame** | | | | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 1.flowstone | Me1 | 42,100 | +29,900 -28,000 |
| **Križna Cave** | | | | |
| U/Th: | (FORD, GOSPODARIČ, 1989) | | | |
| | 1.YUGK 1A | | 198,000 | |
| | 2.YUGK 2A | | 146,000 | |
| | 3.YUG K22: | top | 126,000 | |
| | | middle | 132,000 | |
| | | base | 146,000 | |
| | 4.YUG K4: | top | 146,000 | |
| | | middle | 173,000 | |
| | | base | 251,000 | |
| | 5.KYU 2: | top | 218,000 | |
| | | middle | 350,000 | |
| | | base | 150,000 | |
| | 6.KYU 4S | base | 133,000 | |
| | 7.KYU 6 | base | 190,000 | |
| **Paradana** | | | | |
| U/Th: | (ZUPAN, 1991) | | | |
| | 1.flowstone | Pa1 | >350,000 | |
| **Babji zob Cave** | | | | |
| $^{14}$C: | (GOSPODARIČ, 1977) | | | |
| | 1.stalagmite | | 42,500 | |
| | 2.stalagmite | top | 23,745 | |
| | 3.stalagmite: | base | 43,050 | |
| | (17 cm) | top | 32,850 | |
| | 4.calcite | | 40,335 | |
| | 5.stalagmite: | base | 37,930 | |
| | (21 cm) | top | 32,510 | |

flood loam, some millimetres thick. The following ring is white pure flowstone, encircled by the second layer of flood loam, followed by another set of white flowstone and loam, finally covered by the external belt of pure white flowstone.

The samples from one of the mentioned stalactites were taken some years ago for ESR dating (IKEYA, MIKI & GOSPODARIČ 1983). From the table it is seen that the red nucleus was dated to 530,000 years, the next layer on 280,000 and the top of the stalactite on 125,000 years. Particulary the first two results are comparable to the results which were obtained by the U/Th method from the samples on the other stalactite (ZUPAN 1991). Cross-section of the stalactite which was dated by the U/Th method is shown in Figure 2. The reddish-brown nucleus was not dated because it surpasses 350,000 years, which is the limit of the method. The established age for brown flowstone is 269,400 years and for the brown-white 76,000 years. The age for three external rings of white flowstone was not established due to too low Uranium content.

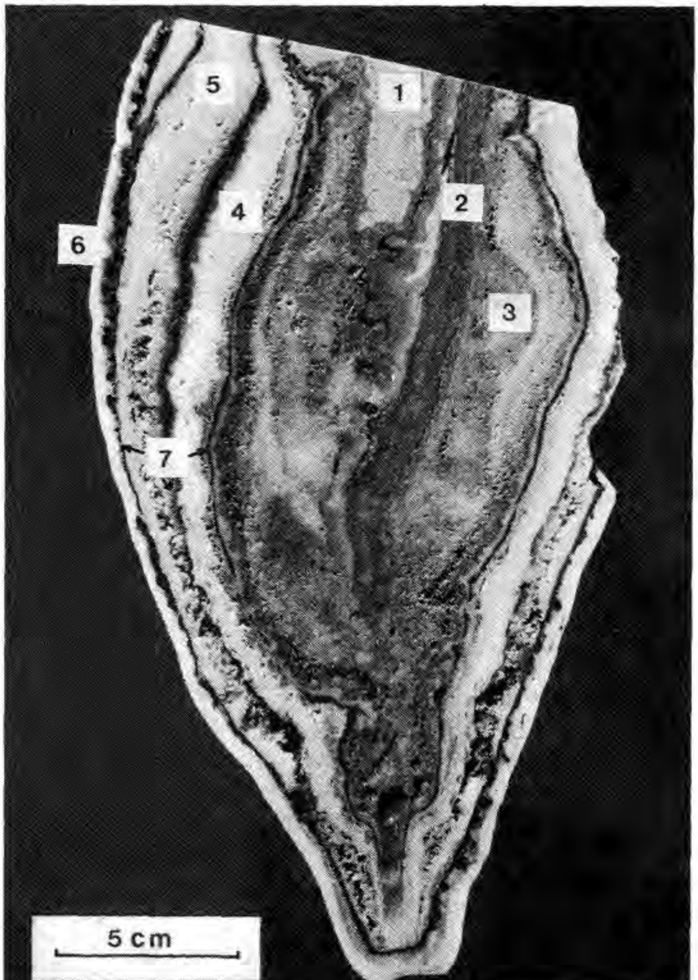


*Figure 2: Cross-section of stalactite from Pisani rov, Postojna Cave, dated by the U/Th method*

From the previous data and from data of the other methods, the possible events can be reconstructed. The red flowstone probably grew in one of the Mindel Interglacials and was eroded in the Mindel already. Brown flowstone near the red one belongs to the Mindel-Riss Interglacial and was probably eroded in the Riss, as the following white flowstone belongs to the Riss-Würm Interglacial. This flowstone is rather porous and contains a lot of loamy material which gives evidence of the intermediary periodical floods. Around this flowstone there is a belt of flood loam, about 2 mm thick, which was probably deposited in the Late Würm. The following three belts of white flowstones, which could not be dated because of the too low content of Uranium, belong according to alternation of flood loams and flowstones to the Würm Interglacials, the belts of flood loams to the Middle and Early Würm. The last flowstone belt was probably deposited after the last glaciation. It would be convenient to date the last three flowstone belts by $^{14}C$ and check these suppositions.

The results of all the datations show that the flowstones, which have been recently analysed, are older than those, dated by $^{14}C$. Also it was evidenced that the results, obtained by $^{14}C$ are not reliable for the flowstones older than 37,000 years and that in fact they are older. Some of the samples are even older than 350,000 years, that is why it would be necessary to date them by the ESR method.

The systematic flowstone datations have to be continued for better understanding of the karst development in Slovenia.

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1. reddish-brown nucleus
2. brown flowstone
3. brown-white porous flowstone
4. white flowstone
5. white flowstone
6. white flowstone
7. brown flood loam

# JOHANN WEICHARD VALVASOR

Aleš Lajovic*

Baron J. W. Valvasor (1641-1693), who lived in the Austrian province of Carniola (Kranjsko; today part of Slovenia), was a great patriot and also by conviction a Carniolan (Kranjec). He was the owner of the estates and castles of Bogenšperk, Lihtenberk and Črni potok near Litija;

he was the Captain of the Carniolan States for the region of Lower Carniola (Dolenjsko) and a member of the London Royal Society.

He published many books and papers, the most remarkable of which was the book written in German - *Die Ehre Deß Hertzogthums Crain* (*The Glory of the Duchy of Carniola* - henceforward *GDC*), Nürnberg 1689. The manuscripts of his other works, among which was a large map of the Duchy of Carniola**, were already in type, but were never published because of his financial breakdown and poor health.

The year 1993 is noted for the 300th anniversary of the death of that distinguished Carniolan, an exceptional man almost without comparison in the world, whose activities reached many different spheres of interest. His opus is enormous and varied to such an extent that one can hardly comprehend the width of Valvasor's intellect. He was a military expert and a commander, which made him extremely proud (his only portrait represents him in his battle gear). In the art of foundry he reached perfection, he wrote, drew and published more books than anyone in Carniola before and after his lifetime (his book the *GDC* has 3532 pages, 528 illustrations and 24 annexes). His interest in extraordinary things took him also into the underground world. He visited as many caves as hardly anyone in the period of the following two centuries after his death. Therefore he can justly be regarded as the first caver or even speleologist not only in Carniola but also in the whole world.

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** *The Dutchy of Carniola (Vojvodina Kranjska) extended during Valvasor's lifetime approximately over the same territory as the present Republic of Slovenia, (except for Štajerska (Styria), Prekmurje and the Goriško region), over the part of Istria as far as Rijeka and over the whole region of Gorjanci - in short, it occupied the major part of Slovenia, where the karst and karstic phenomena can be encountered.*

*Fig. 1 J. W. Valvasor (1641-1693), Captain of the infantry in his battle gear. Today he is known as a polymath, a distinguished founder and a speleologist, but he was very proud of his military service and functions, which is the reason why he is portrayed in his armour. The copper engraving was given to him by his collaborators.*

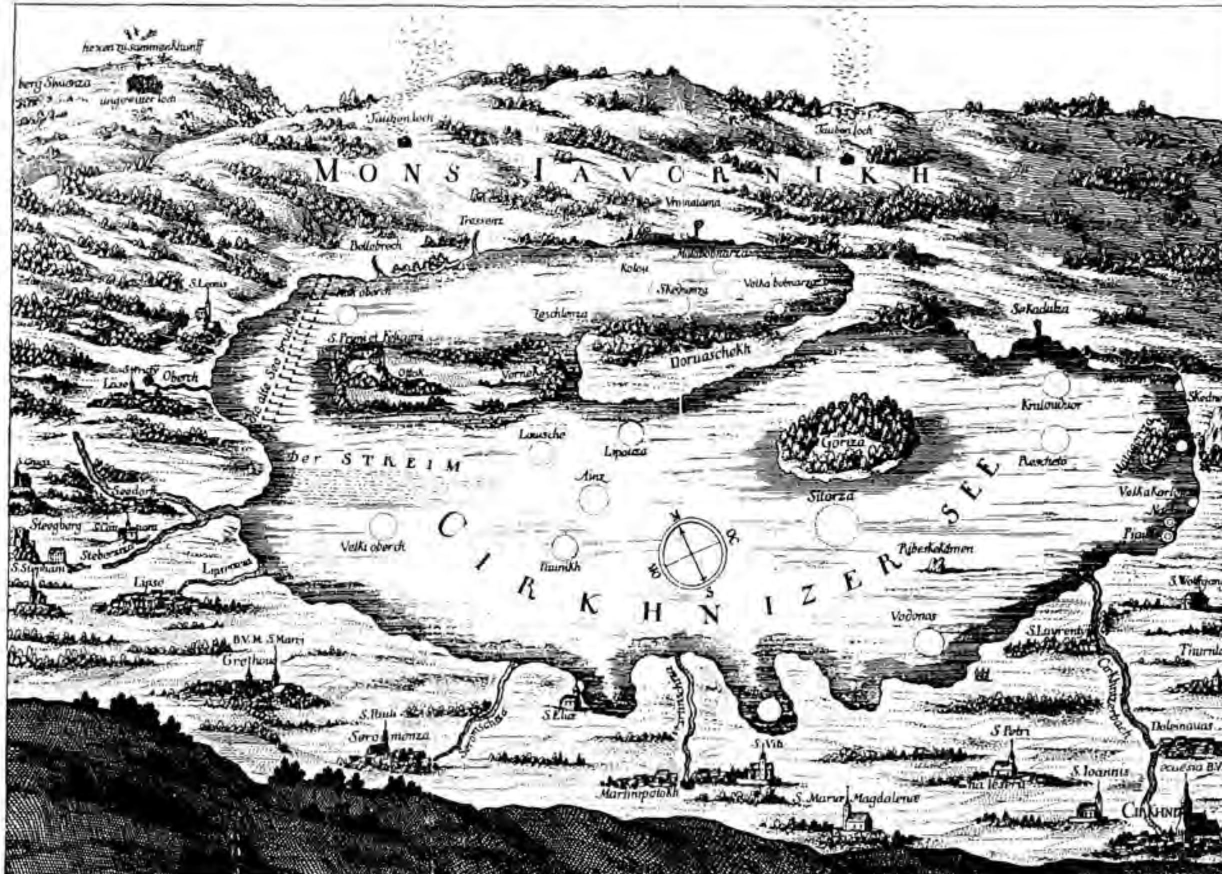


Fig. 2 The perspective map (as it was called by Valvasor) of Lake Cerknica. It was elaborated as the annex to the paper on Lake Cerknica, on the basis of which he entered the Royal Society.

In his youth he seemed rather unprospective although he was on his mother's side a descendant of the Ravbar family from the castle of Krumperk near Domžale. The Ravbars were namely an old noble family whose men were renowned for their cleverness and extreme strenght as well as height. In Ljubljana, he completed *studia inferiora* (the Jesuite junior school). After that he, as was the custom among the sons of noble families, went on a few-year journey around the world. It seemed that he was interested in everything by little, which he carefully noted down into his diary. He travelled around the most part of Europe (present Austia, Germany, France, Denmark, Holland, Spain and Italy), and the northern part of Afrika. In France, he served in the Swiss infantry regiment, where he perfected his military knowledge. He was attracted by everything that was extraordinary, as for instance the underground world of caves. That fondness of his will be from now on of our special interest.

He visited a great number of caves, it seems that all which he was told about, e.g. the Baumann Cave near Brauschweig (280 metres long, at that time renowned as a dripstone decorated cave), Grotte de la Sainte Baume (or Grotte de Sainte Madelaine) near Marseilles and some caves situated in the vicinity of Tours in France. He also visited some of the African caves which names and localities he does not mention (presumably the caves of the present Tunis). He mentions the visit to Kofel Castle in the Tyrol (today in ruins), which locality is similar to that of Predjama Castle in Slovenia; about the latter he says it is undoubtedly worthier visiting. These are presumably not all the caves that he visited abroad. The fact that the caves of Carniola, beside all other curiosities in the country, far surpassed the things that he saw abroad, was undoubtedly one of the motives for the creation of his monumental work - the *GDC*. Beside all other reasons, this extensive work developed from his wish to present to the largest possible number of readers an exhaustive description of the Carniola of his time. Valvasor was angered by the fact that his country was so little known in the world, the country of so many natural wonders worth visiting, e.g. the mine of Idrija, the intermittent Lake Cerknica, Predjama Castle, the Postojna Cave, etc. As the book was mainly intended for the readers abroad (today they would be called tourists), it was written in the German language and not in Latin, as was customary for the books of that period, or even in Carniolan.

Valvasor's words about himself were:

> *I admit without any vain thirst for glory and without conceit that I - the lover of all free and natural arts - have always been stimulated by my inquisitive nature and my eager for knowledge to explore natural curiosities or misteries. Wherever I could hear about a man anxious to learn, there I was bound for, and no path would take too long, no danger would be too large and no effort too hard; the hope that I might learn something extraordinary and learn about extraordinary things was healing all my pain. My bare passion for knowledge was leading me not only around Europe but for some years also around the distant Afrika, where I was longing for natural sciences.*

Whenever he heard about the thing that excited his curiosity, he took the shortest way to reach it - if necessary or worth visiting even for many times. In this way he often travelled around Carniola and crossed the territory from one corner to the other. In the meantime he was steadily drawing, surveying (for this purpose he even constucted his own device which, like many other Valvasor's inventions, has not been preserved), and taking notes. Whenever he had time, he visited and examined the things or places himself.

At first, Valvasor used to visit caves only out of curiosity, but later they became the places where he could confirm his own theories in connection with underground waters, which finally resulted in the first cave map in our land, i.e. the map of the cave Podpeška jama at Dobrepolje. He himself visited some tens of the caves, and also mentioned some tens of the others, particularly potholes, in various chapters and volumes of the *GDC* in different connections (e.g. as "blessed" caves). He describes how he crawled into a cave with a rather steep passage, where he was looking for the fossils (the so-called snakes' tongues) with healing effects. But deep in the cave his candle went out, so he had to crawl out of the cave feeling the whole distance back. In the karst valley Rakov Škocjan, he visited a cave by using a rowing boat. He describes a dripstone group reminding of a weaver bent over a loom. Similarly, his visits to the caves Podpeška jama and Kompoljska jama are described. He knew very well the lower levels of the Predjama system, except for the passage Erazmov rov which he had not visited yet. He writes about its length only what he had heard from the others, i.e. that the passage was tremendously long. The Predjama seemed to him an exceptional creation of nature, and he considered the castle to be without comparison.

He was convinced that the Postojnska jama was the most magnificent and marvellous cave ever seen. He compares it to some artificial formations, i.e. the rocky theatre in Salzburg and Hellbrunn Castle in the vicinity of that town. He often visited the Postojnska jama, on some occasions he was even a tourist guide for foreign visitors.

Beside the mentioned caves, there are some others described in the *GDC*: the Jama (Cave) beneath Socerb Castle (or Sveta jama - "Holy Cave" - which he compares to the cave Grotte de la Sainte-Baume in France), Planinska jama (or Malograjska jama), and some others. He knew the Škocjanske jame as well, but evidently he did not dare the descent into the caves.

Valvasor was mostly dedicated to hydrology. For this purpose he provided himself with all available instuments, some of which he even invented himself (*metropas geometricum*). His instuments were considered by his contemporaries to belong to the most extensive collections of this kind in the whole Europe. These were particularly geodetic instuments (he surveyed Carniola from the corner to the corner); he was surveying altitudes, water levels, etc. The most significant work from this field is the paper on the lake Cerkniško jezero (Lake Cerknica). How it is formed is to be found out in Valvasor's letter to the Secretary of the

Royal Society of London, where he states that he read most surprised in one of the periodicals (issued by the Society) about Lake Cerknica and the mine of Idrija. But to Valvasor the description was much too superficial, so he offered his help to describe the lake himself. It is interesting that in his letter Valvasor mentions some other curiosities of Carniola (caves and underground lakes, etc.) as well. Valvasor's paper on Lake Cerknica was read at the meeting of the Royal Society on 14th December 1687 (the first part); later, the world's famous astronomer Halley (who used to prepare all the experiments needed for the meetings of the Society) constructed a model according to Valvasor's sketch, and thus demonstrated to the present members of the Society the water-flow of Lake Cerknica. The demonstration was sucessful and Valvasor was elected a member of the Royal Society.

Valvasor was intensely engaged in his hydrographical model of Lake Cerknica, but he was also looking for the confirmation of his theory elsewhere. For this purpose he measured the water-level in the caves Kompoljska jama and Podpeška jama. About the latter he says:

> *This cave is my shield and protection against all who judge the matter though they do not understand it and against all who doubt about the activities of Lake Cerknica as described from my point of view, as well as about the possibility that in the underground there are many natural lakes, channels and siphons which function in such a way.*

In order to present the functions and hydrology of Lake Cerknica even better, Valvasor included some sketches in his paper, above all the ground-plan of Podpeška jama, which is considered to be the second cave map in the world and the first within the Slovenian territory*.

The majority of Valvasor's cave descriptions was published in the *GDC*, where exaggeration can often be encountered, particularly as far as the length is concerned. It has to be explained how this monumental work was being created.

As has already been mentioned, the book was written in German. Valvasor did not feel capable enough of writing it in contemporary and fluent German himself, so he engaged Erasmum Francisci, the scholar and writer from Nürnberg, i.e. the place where the *GDC* was printed. Francisci was allowed to form the text freely, so he even wrote some volumes of the *GDC* himself and when necessary added and explained many a thing himself. Valvasor mainly lived in

* *The first published map of a karst cave is today believed to be Collins's plan of the cave Pen Park Hole (Gloucestershire, England) from the year 1683, which was published in Philosophical Transactions (no. 13) by the Royal Society. Four years later, Valvasor's article on the instillation of thin-walled statues (no. 186) was issued in the same periodical, and at the end of 1687 the article on Lake Cerknica (no. 191). The latter was also published in Acta Eruditorum, Leipzig, in 1689.*
*The plan of the cave Podpeška jama (copper engraving) with an English inscription from the year 1686 was added to the article on Lake Cerknica. Later, the same plan was published in the GDC, but with a German inscription.*

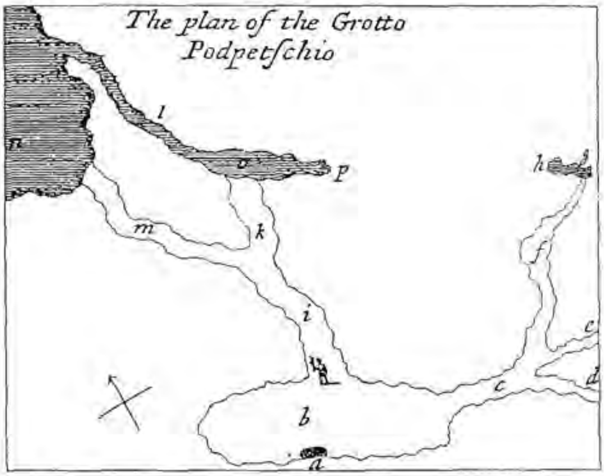


Fig. 3 *Valvasor's sketch plan of the cave Podpeška jama. The copper engraving was made in 1686. In 1687 it was published in Philosophical Transactions (no. 191), the periodical issued by the London Royal Society, in 1689 in Acta Eruditorum (Leipzig) and in 1689 in Valvasor's Die Ehre Deß Hertzogthums Crain (The Glory of the Duchy of Carniola). It was completed as the annex to Valvasor's paper on Lake Cerknica. It is unknown if Valvasor knew Collins's plan of the cave Pen Park Hole, which was also published in Philosophical Transactions (1683), and if that map influenced the elaboration of the map of Podpeška jama. All that is known is that Valvasor was given some issues of the publication by the Royal Society.*

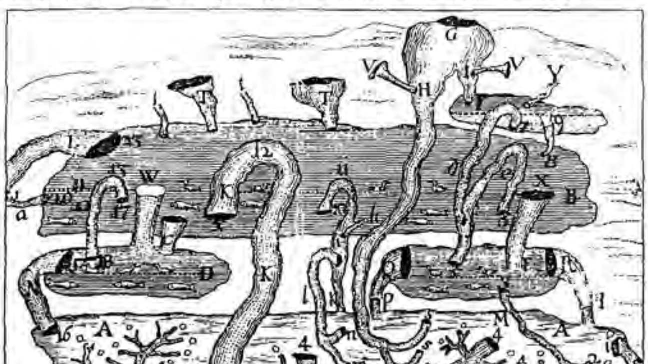

Fig. 4 *The schematic illustration of Lake Cerknica with its underground lakes in the tributary area, connected with a complex system of channels which partly operate as siphons. On the basis of the plan and descriptions, the astronomer Halley, at that time Secretary of the Royal Society, prepared a model for Valvasor's demostration of water-flow directions in Lake Cerknica at the meeting of the Society members.The demonstration succeeded and Valvasor was elected as a member of that distinguished institution.*

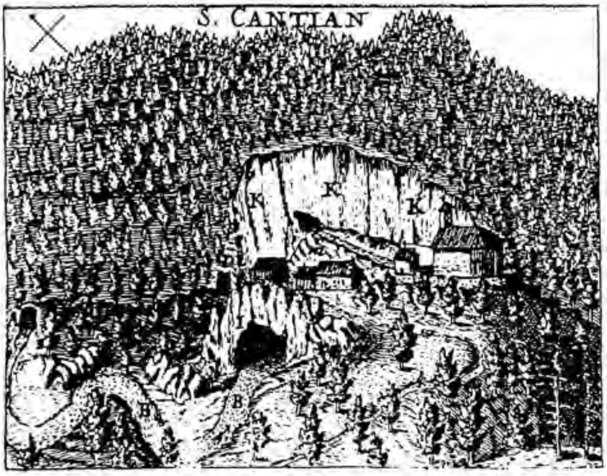


*Fig. 5 Veliki naravni most ("Great Natural Arch") in the karst valley Rakov Škocjan is a great curiosity of the Slovenian karst. Once there were the Church of St. Canzianus (the patron giving protection against the devil and evil spirits), the Church of St. Benedictus, and the house of parish clerks, all of them situated on the natural arch. Unfortunately, there is everything in ruins today, otherwise the buildings would represent an exceptional curiosity, as the constuctions situated in this kind of environment have not been discovered yet. On 7th June 1678, Valvasor passed under the "Great Natural Arch" (I) in a fishing boat and proceeded into the cave Tkalca jama (K) as far as the first waterfall underground. This is the date of the first known exploration attempt in a cave within the territory of the present*

*Fig. 6 An illustration of dripstone formations decorating the cave Postojnska jama (from The Glory of the Duchy of Carniola). Valvasor was convinced that the cave was the most beautiful of all known caves in that period, and shared his opinion with all who he accompanied into the cave.*

Carniola and Francisci in Germany, so the most part of the *GDC* was put in print before Valvasor could see the finished manuscript.

It certainly could not be said that Valvasor was not superstitious or devoted to mysticism at all. In his letter to the Secretary of the Royal Society he wrote about the "openings (i.e. caves) where the fog, clouds, lightning and thunder were coming from", but whenever possible he tried to get to the root of the matter and explain things according to the laws of nature. Only when no reasonable explanation could be found, he gave in. And then Erasmum Francisci appeared with his interpolations, additions, etc., which ruined Valvasor's reputation among the scientists. But an attentive reader can distinguish between Francisci's superstitious lumber and the original text written by Valvasor, as Valvasor's writing was objective enough whereas Francisci's texts were sophisticated and full of verbal acrobatics.

A good example is the intermittent spring Lintvern. It was generally known that there was a dragon in the hill causing the rate of the water-flow change during the day. The evidence was a dragon's young (*Proteus anguinus*) shown to Valvasor. But Valvasor did not find the explanation satisfactory, so he had the landslide, which clogged the former spring, dug through. He did not discover anything new, but he still firmly insisted on his belief that hydrodynamics in the tributary area of the spring* was the real reason for the behaviour of the spring.

A special and notable part of the *GDC* and some other books written by Valvasor are the illustrations of castles and significant places. Today they seem rather clumsy and at times even funny. The disproportions are disturbing, particularly those of the landscapes around the objects (but certainly there are some exceptions). The reson for that is the style of Valvasor's work and the act of choosing his collaborators. Valvasor himself sketched proposals according to which copper engravings were being carved in Bogenšperk Castle by his collaborators, who usually did not even see the original objects they were working on. The author of those realistic and otherwise good proposals was mainly travelling around the country. A contribution to all that was the manner in which the artistic work was created at that time, which was probably the reason why many a detail that could be interesting even today was neglected. Unfortunately, Valvasor himself was subjected to the graphic-art design trend of his collaborators, but his graphic art is even today represented as invaluable creation.

Valvasor was aware of the fact there were many more places in Carniola worth exploring. In connection with the cave Podpeška jama he mentions that it would be of value to investigate the Dobrepolje underground lakes by boat, so he stated:

* *Here it has to be added that Valvasor used to experiment a lot, which is evidenced by his hydrodynamic model of Lake Cerknica. His plan was to publish a book with one chapter dedicated to hydraulics and his experiments, already carried out in this field.*

*I would have enough interest and pleasure if only time and circumstances would allow it, and if certain obstacles would not prevent me from exploring not only these but also many other curiosities of my country; and to my firm belief there are many more natural curiosities to be discovered. I indicated the way and have done in this field even more than anyone before me. If anybody would have discovered more, then I would have had a reason to thank him for that.*

Poor technical possibilities did not prevent him from venturing underground lakes by boat; what scared him more was time. If anyone then Valvasor should be believed; though it seems unincredible today, he had enough will-power and energy to collect and put in order enormous amounts of data. Besides, Valvasor had to take part in campaigns against the Turks and in confidential military missions, as his military knowledge was highly appreciated in those days.

And finally, one would ask himself what is Valvasor's significance in speleology today. Despite the distant period he lived in, i.e. the period completely different from the present as it was full of superstition and restricted technical possibilities, one can find out that Valvasor's visits to the caves were completely without prejudice being so typical of that period, they were similar to the visits of an average speleologist today. Presumably, he was interested in caves already in his childhood, which is the only explanation why he visited so many of them on his journeys around the world in his early years. And presumably he visited all the caves he had heard about. Probably he was the first who understood the significance of the caves in Carniola, surpasing those in Europe and partly those in Afrika. He is supposed to be the greatest expert in caves of his time, and he visited more than any average Slovenian caver or speleologist. His enormous knowledge including that of hydraulics made it possible for him to tackle serious problems of hydrology (without mysticism). He was far ahead in that field (unfortunately, far ahead even before many a scientist today). He provided himself with all attainable instruments and constructed the models which should confirm his hypotheses.

He was interested in the growth of dripstone formations and discussed this topic:

*Fossils of various kinds can be found here, in Carniola, in several caves and underground chambers in a great number. They are nothing but the play of nature; fossils form neither from the devil's breath nor by an earthquake, but in the course of time by means of dripping water. I observed this process in the cave named Jama (Cave)*, where nature displays many formations by means of dripping water. This cave is visited by a great number of travellers and many of them sign their names on these stony statues; the names which were incised with the point of a knife 70 or 80 years ago can be read even today, though they are constantly being soaked by dripping water. I presume that nature needed more than 300 or 400 years for the creation of the stony objects, as in 70 or 80 years the formations can reach the thickness of a knife. But I do*

* *Postojnska jama*

*not deny the fact I have not observed that at some of the places, stones of this kind (growing by means of dripping water) almost reached the thickness of the human finger already after the period of 20 years. The stones are mostly white, solid and sometimes translucent like alabaster. I have made an experiment with a stone which I put into the boiling fresh water. The stone remained solid, and the same occured in the water mixed with salt; but when I added some ammonium chloride it softened a little. In the well heated spirits it was soft and fragile, ashy-grey and it glistened on its edges.*

Evidently, the method of experiment was not unknown to Valvasor!

There are many things we can learn from his descriptions and illustrations, which remained the only sources of the preserved material, e.g. that Lake Cerknica does not fill up in the same way it used to, that the stream of the Radulja beneath the castle of Klevevž is probably more or less artificial, that the stream through the cave Podpeška jama runs in other directions but also returns back into its old water channels), etc. Thanks to Valvasor, many an old name of a cave as well as many religious or superstitious rituals are preserved, particularly in connection with potholes. Such data are interesting even today (e.g. the data of the caves from which the warm cave air was rising during the periods of the increased amounts of water), though the situation has probably changed since his visits to the caves.

Valvasor is undoubtedly the author of the first cave map in our country and the author of probably the first illustration of the underground world, i.e. a dripstone-decorated chamber in the cave Postojnska jama (the latter having no artistic value).

He remains the author of the remarkable paper on Lake Cerknica, which raised him up to the society of the greatest geniuses already during his lifetime, and at the same time inspired many subsequent researchers of that presumably the greatest Slovenian curiosity as well as aroused interest in our country and the karst territory, which won world's fame.

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# ACTIVITIES OF THE TECHNICAL COMMISSION AFTER WORLD WAR II

Tomaž Planina*
France Šušteršič**

1. After World War II, our caving was left without any technical means, and as the borders were closed, the situation actually prevented any contacts with foreign countries for as long as fifteen years. At that time only the windlass and ladders were being used, which dictated the expedition-like manner of negotiating the pitches.

The after-war generation of "young cavers" tried to improve caving techniques and thus encourage the exploration of potholes. Negotiating of potholes by means of ladders, relay groups over each major section and the military wireless telephone (used for the coordination of the team work), was time-consuming and very laborious. An example of such an exploration is Jazben, which demanded three operations: the fixing of ladders and the telephone down to the depth of 200 m, the exploration down to the depth of 334 m (it took 50 hours uninterruptedly), and the evacuation from -173 up to the surface.

2. Hands could be for the first time freely used in 1955, when I. Gams and T. Planina mounted the small carbide lamp to the helmet. During the period of 1954-56, the young cavers made several attempts to negotiate potholes only by means of rope (Prussig knot) and the pulley tug, but the technique was not widely accepted. This activity was supported later, in 1960, when the Commission for Caving Equipment was founded. The Commission's first concern were caving ladders, but on the other hand the members devoted themselves to the development of rescue techniques; the victim was placed in the Graminger rucksack of the rescuer who was lifted by means of the wire rope, the home-made jamming device (made by Aleš Kunaver) and the pulley-tug (the Pivka jama cave,

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1963). Two rescue groups were founded - one at Ljubljana and the other at Postojna. A special sit-harness was made of a thinner rope by France Avčin. Ivan Gams and his collaborators published the manual *Jamarski priročnik* (*Caving Manual*). Following the example of the mountain rescue service (the technique was presented at the Fourth International Congress of Speleology (UIS), at Rakov Škocjan 1965), it was attempted to pull up the victim by a rescuer using the wire rope and the "Tirolia" windlass.

The introduction of electric rechargeable miners' lamps in the 1960s was unsuccessful, as cave chambers are generally too extenxive.

3. The properly organized activity of "depth checking" and venturing underground considerably diminished the strain of exploration, although single-rope techniques (SRT) were still not used at that time. The 1968 exploration of the 345 m deep Žankana jama took individual groups 15, 24, and 18 hours of work, and in 1969, 18, 10 and 30 hours were needed with 12 hours of sleep. The next operations were in Jazben (334 m) and Gotovž (320 m), the latter negotiated by a small group without major problems.

In the same year, the school on the techniques of deep-pothole exploration was carried out by the Commission in Domžale. The telephone was developed further - in the form of a receiver which operated by means of two wires. In 1972, the Commission published *Jamarska tehnika* (*Caving Techniques*), written by Jože Pirnat, who beside other techniques deals with the correct usage of ladders; but in that book SRT was still not mentioned.

In the next year, the basic SRT were introduced and closely examined. Due to the outwear of rope, spindle safety-brakes were being recommended. The pothole Brezno pri gamsovi glavici was still explored by means of ladders, but the organization was better, so the cavers reached the depth of 440 m. Various kinds of SRT, which permitted explorations to the depth of 800 m, were being introduced to more and more cavers. The Technical Commission developed the safety rope brake (the abrasion of rope was negligible). Loam usually increases the outwear of rope, so it is recommended to use the ropes as clean as possible. The Commission further collected the data about caving accidents in Slovenia, analysed the reasons and kinds of rescue, and decided upon the safety standards. Exploration techniques were being dealt with at many meetings of the Technical Commission, the techniques were properly recommended and popularized (at Kranj 1975, Kamniška Bistrica 1977, Šmarna gora 1979). A school for instuctors was organized (at Domžale 1979) and "comradeship" rescue techniques were demonstrated (in the caves Škocjanske jame, 1980).

Free-climbing in chimneys (chimneying) developed in the late 1960s as an obvious element of caving techniques. The cave Pološka jama held a record in chimneying with the obrained 380 m.

4. The karst collection of the Postojna Museum opened the exhibition of caving techniques. At the international meeting of rescuers (Saint Michel en Vercors, 1982), a new type of knot for intermediate belays (between-knot - Noed Papillon Yougoslav by Tomaž Planina) was represented together with its advantages. The Technical Commission further developed the double-spindle safety brake and checked the safety of rope techniques. In 1983, *Vrvna tehnika* (*Rope Techniques*) was published. That is a complex description of the recommended SRT. During the next few years, the caving knots were being tested as well as the aging of rope and its impregnation. SRT security factors were also being dealt with. Jammers and rope brakes as well as home-made rope (UIAA tested) were tested by the dropping of weight. Cavers cooperated with the civil defense in rescuing people from high skyscrapers and cable railways. In 1989 the Technical Commission published *Jamarstvo* (*Caving*). Recently, the primary technical group expanded into the safety-technical, educational and rescue service.

The construction of a special drill composed of elements, which enabled drilling transversally on a wall in very narrow squeezes, was a large step forward in cave undermining.

5. For the last thirty years, the members of the Technical Commission (with many years of experience and testing) have recommended several measurements:

I. A satisfactory degree of the SRT safety can be assured only when all the caving activities can be organized properly. Safety referees in the caving are in charge of the appropriate usage of techniques as well as the satisfactory quality of rope and all other SRT devices. Both the Technical Commission as well as the Cave Rescue Commission of the Speleological Association of Slovenia regularly introduce contemporary techniques which should ensure enough security for safe cave exploration. Instructors and leaderships of caving groups should transmit experience and skills to all the cavers. The system of education ensures that the cavers regularly obtain new information.

II. Wearing out of ropes (the consequence of which is the deminution of the rupture strenght of rope) is not affected by the state of rope, i.e. rope being whether dry or wet (the fibres of the outer layer of rope are worn out more intensely when the rope is dry); the content of quartz in this case is of no essential significance as well as the wearing out of aluminium spindles of the rope brake. When the rope is affected by dirt containing sharply angular particles, i.e. quartz and calcite crystals, the rate of wearing out of ropes in this case is considerably increased in comparison to a clean and wet rope. In order not to increase the wearing out of ropes, clean ropes should be used.

III. Ropes of various makers and constructions are variously firm. The rope loses its declaration strength by one third while being fixed. The wearing out as well as dirtiness of rope diminish its strength. For security, the strength of ropes is over 10 kN. When worn out they should be eliminated. Ropes should be used as clean as possible and should be impregnated. It is recommended to impregnate rope in the 10-15% solution of paraffin wax and petrol.

IV. The strength diminution of tested rope is negligible in case of rope aging (while being storaged) in comparison to the strength diminution due to its wearing out while being used.

V. The "double-loop figure-eight transversal" is firmer than the "between-knot transversal", the "figure-nine transversal" and the "figure-eight transversal". The double loop on the karabiner represents the double strength of a single rope on the karabiner - for that reason additional stirrups do not have to be used. The "tripple-rope figure-eight longitudinal" is firmer than the "double-fisherman's knot" or the "knot for lenghtening". It is the same as the "figure-nine" or "figure-eight longitudinal". It is recommended by the Technical Commission that before the descent, in the end of the rope, the "secure double-rope figure-eight", into which another rope can easily be interwoven, should be done; the new loop serves for protection when the rope break is transferred to the lower rope. SRT demands for the main and intermediate belay points the "double-loop figure-eight", and for the lenghtening of static rope the "tripple-rope figure-eight longitudinal", i.e. interwoven.

VI. The "reciprocally reversed clove knot" is by 5.7% firmer than the "clove knot". The "reversed half-clove knot" takes over during the lining with the dinamic rope once as large force as the "half-clove knot" - here it loads the belay point for 1.2 times and demands 0.76 times less rope.

VII. During the tests for the SRT devices, the Technical Commission found out that:

The break is usable for ropes thicker than inclusively 9 mm. Spindles made of aluminium alloy brake the rope three times as much as steel hardened spindles. Ropes slide at twice as large force when muddy and wet than when dry and clean. The brake is firm enough to resist the load of the out-rope, i.e. the load increased during the rescue. The brake resisted ten main tests of falling one after the other and was not damaged. During the fall, the brake slid down the rope and did not considerably damage it. The weakest point of the brake is in the opening at the side and not in some other parts of the device that are of vital importance - and this occurs only at the force of above 20 kN.

The jammer slides up the rope at a considerably low force. The device successfully passed the main test of falling and was not damaged. In case of a fall it removes the outer layer of rope. At a force of 8 kN, the jammer damages the outer layer of rope but the device itself remains undamaged.

The small pulley resists the force of 20 kN.

VIII. Cave photography should be extra organized.

During the research caving trips, the photographer has to adjust to the aims and technical possibilities of the trip. He should shoot pictures particularly of the research objects and features as well as climbing techniques. The photographer should take part in the work of the research team the members of which should in turn help him when needed. Research activities are at least limited when the photographer uses a "free-hand" technique of taking shots, i.e. without tripods, by means of the electronic flashgun or several flashbulbs operating at the same time. Here it is advised to use more sensitive normal photo material and subminiature cameras with the adjustable focus.

Cave surveying techniques up to the 1960s were based on the usage of the tourist compass and home-made clinometers. Later the Brunton compasses were being introduced and in the late 1970s the SUUNTO compasses. In the early 1980s, an extensive testing of such compasses was carried out; it was found out that their horizontal accuracy amounted to +/-2 degrees. At the same time, the standarized mapping scales (1:100, 1:250, 1:500) were introduced, and the BCRA grading of accuracy was first used.

Optical telemeters are useless in Slovenian caves due to the mud, instead measuring tapes are being used in all cases.

During the '70s and '80s, the new methods were developed in order to establish indirectly the position of inaccesible points and set the polygon in crawlways, turning shafts, etc. In the '80, the software for main and detailed surveys was elaborated, and recently the programme for the net-like adjustment of polygons.

In the 1980s, the method for surveying and rapid calculating of cavern volumes was developed. The software was made for the PC Spectrum, i.e. for the working unit. The method was represented at the World Congress of Speleology at Bowling Green, but was not being extensively used (probably the cavers are not sufficiently motivated for volume surveying).

In the 1990s, a new system of polygons is being developed, the polygon here does not follow the axis of the passage but that of the walls. The accuracy here increases approximately by .5 degrees according to BCRA grades. Experiments are still being made.

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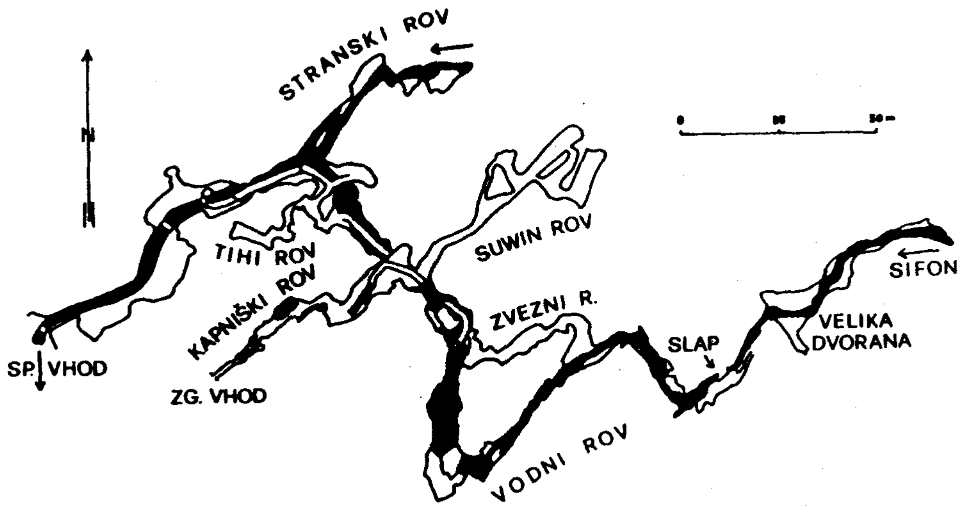
## International speleological and karstological events in Slovenia between 1965 and 1993

1. Fourth International Congress of Speleology, Ljubljana-Postojna 1965
   During the congress, the International Union of Speleology (UIS) was founded
2. International Youth Research Camp (speleological group), Cerknica 1972
3. Third International Symposium on Underground Water Tracing (3th SUWT), Postojna 1976
4. Symposium on Scientific and Tourist Significance of Postojnska jama, Postojna 1979
5. Symposium - Karst Protection (160th anniversary of the tourist development of Škocjanske jame), Lipica 1982
6. Symposium on Karstlands, Postojna 1985
7. Man's Impact in Dinaric Karst (IGU Study Group "Man's Impact in Karst"), Postojna 1987
8. Cave Tourism, Postojna 1988
9. 100th Anniversary of the Speleological Association of Slovenia, Postojna 1989
10. French-Slovenian Round Table on the Karst in the Hilly Regions and Mediterranean, Postojna 1991
11. Minerals and Karst Caves, Postojna 1992
12. International School of Karstology, Postojna 1993
13. Symposium - Man on Karst, Postojna 1993
14. Round Table on Martel's Investigations in Slovenia, Postojna 1993

## JAMA PEKEL (CAVE PEKEL)

**Šempeter in Savinjska dolina**
**Slovenia**

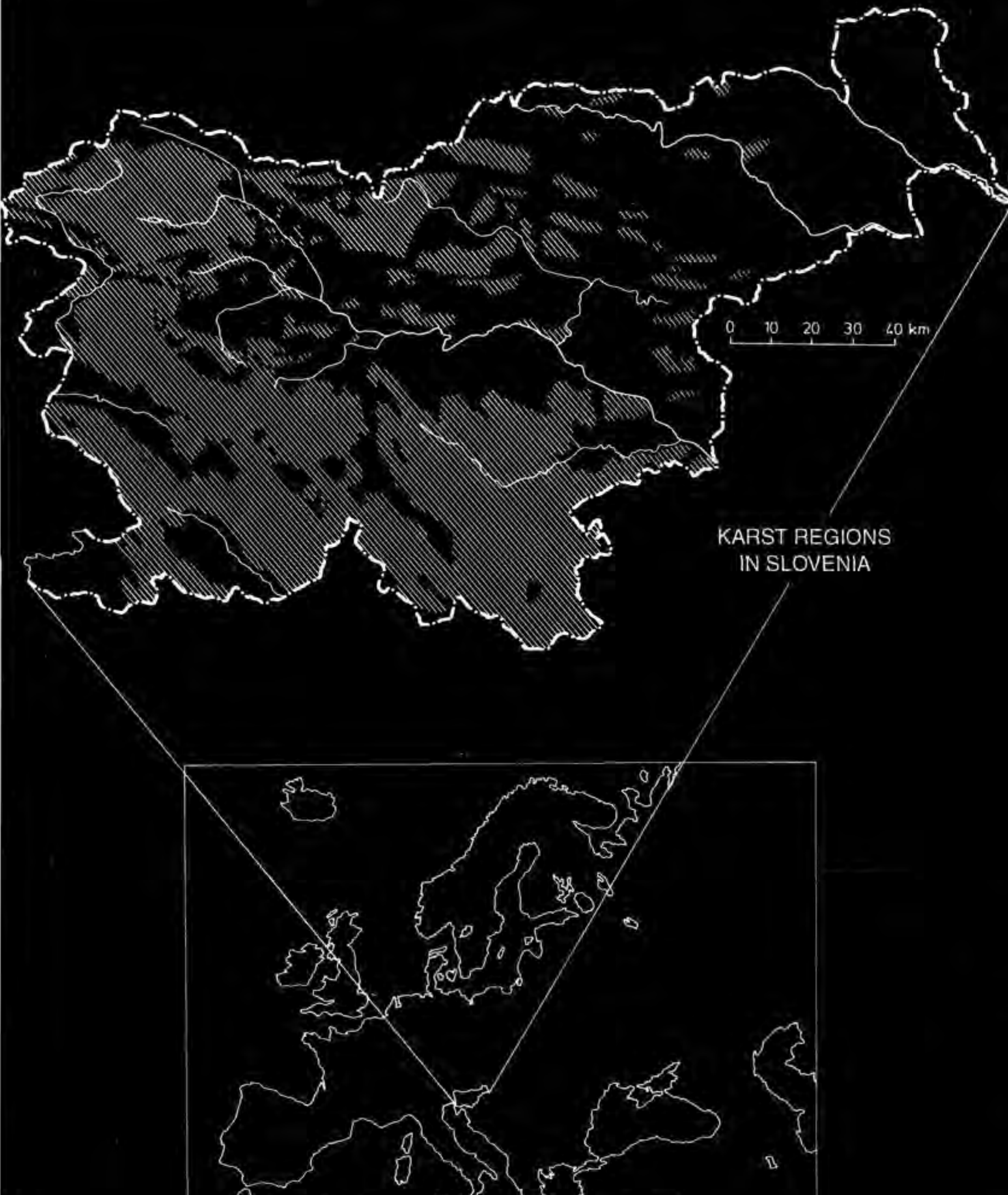



**INFORMATION:** Turistično društvo Šempeter, Savinjska dolina, 63311

Šempeter, tel.: (063) 701-215
**CAVE LENGTH:** 1,500 m; tourist section 400 m
**LENGTH OF VISIT:** 45 min
**VISITS:** 1st March - 31th October; 8 a.m. - 6 p.m.

Pathway and electricity arranged.
Car-park, kiosks, souvenirs, catering service.

Po mnenju Ministrstva za informiranje št. 23/519-92, z dne 29. 12. 1992, šteje publikacija med proizvode za katere se plačuje davek od prometa proizvodov po stopnji 5%.

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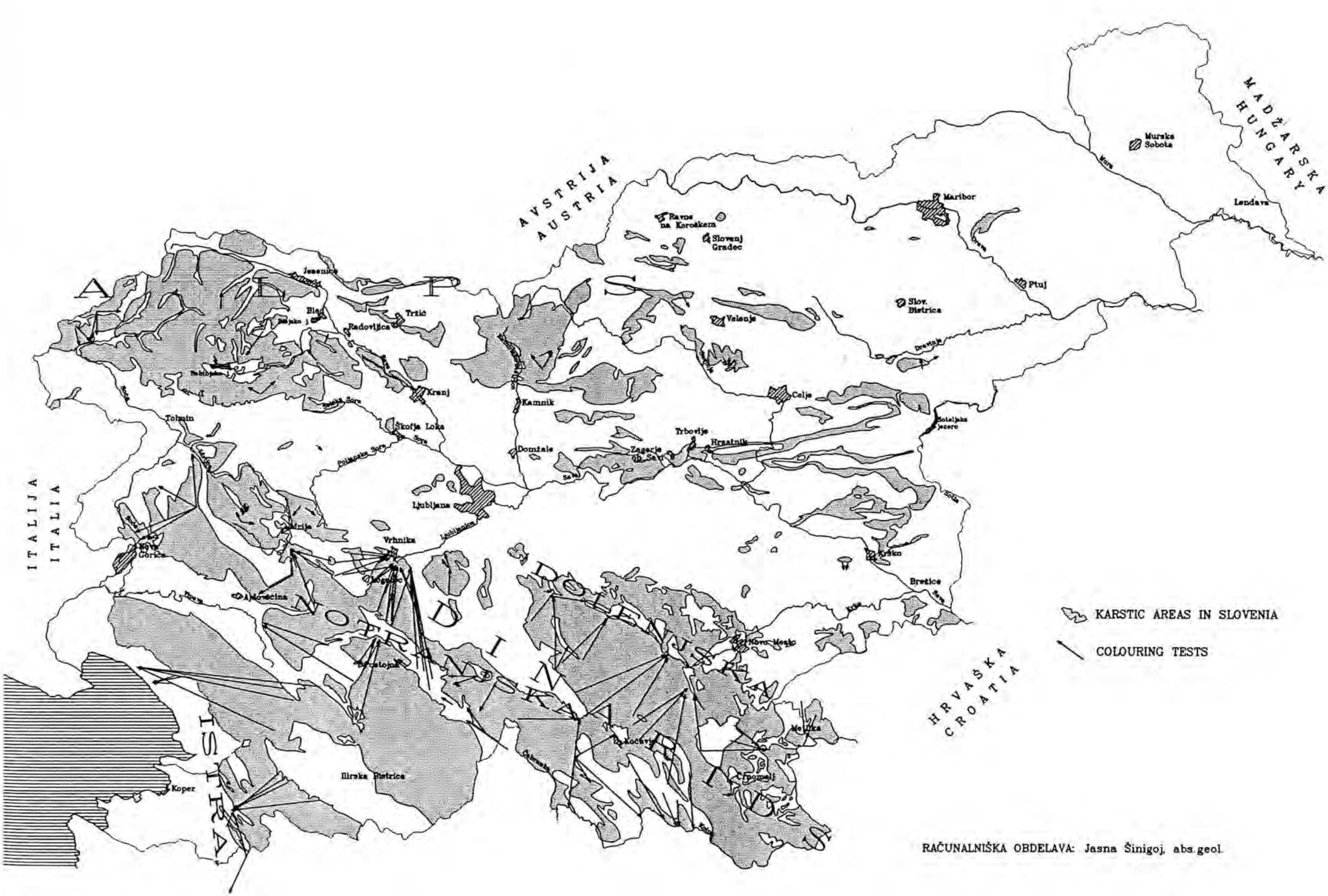
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