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Karst in Slovenia

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ABSTRACT

Karst is a type of landscape with special surface, underground and hydrological features and phenomena. Its main characteristic is dissolution of the carbonate rocks by water enriched with CO_2 as the dominant morphological process, removal of the rock in the form of solution and prevalent underground drainage that forms caves. In Slovene language, kras means a rocky, barren surface developed on limestone or dolomite and is also used as a toponym, so the word karst was developed from the name of the Kras plateau, which is a classical, reference site for the karst type of landscape.

Key words: carbonate rocks, landscape, karst, Kras, Slovenia

EL karst en Eslovenia

RESUMEN

El karst es un tipo de paisaje con características y fenómenos hidrológicos especiales tanto en superficie como subterráneos. Su principal característica es la disolución de las rocas carbonatadas por agua enriquecida con CO_2 como proceso morfológico dominante, movilización de la roca en forma de solución y drenaje subterráneo prevalente que forma cuevas. En lengua eslovena, kras significa una superficie rocosa y desnuda que se desarrolla en calizas o dolomías y también se utiliza como un topónimo. Es decir, la palabra karst se ha desarrollado a partir del nombre de la meseta Kras, que es el sitio clásico y de referencia para el paisaje kárstico.

Palabras clave; Eslovenia, karst, Kras, paisaje, rocas carbonatadas.

VERSIÓN ABREVIADA EN CASTELLANO

Historia de la exploración del karst en Eslovenia

Varios fenómenos kársticos ya fueron mencionados en la antigüedad, pero los primeros intentos para describir y comprender la hidrología kárstica los formuló Valvasor en 1689. En el siglo XIX algunos exploradores obtuvieron un gran conocimiento acerca de los fenómenos kársticos. El trabajo básico de espeleología fue realizado por Schmidl (1854) y Kraus (1894), la geomorfología fue estudiada por J. Cvijić en 1893 y otros. En 1929 se estableció en Postojna el primer Instituto de Investigación del Karst. En el instituto se trata el estudio de la geomorfolocgía kárstica, la espeleología, la hidrología y la espeleobiología y se mantiene el registro de cuevas, se edita la revista Acta Carsologica y se organizan reuniones anuales regulares con el título Karstological International School, "Classical Karst".

Características geológicas del karst en Eslovenia

Los terrenos kársticos están localizados en el oeste de Eslovenia en las montañas Dináricas y en la parte sur de los Alpes Calcáreos. El karst se formó principalmente en las extendidas calizas y dolomías mesozoicas. La sucesión carbonatada completa desde el Carbonífero superior al Eoceno excede los 8000 m. La tectónica *está relacionada al movimiento de la micro-placa Adrio-Apuliana que expuso las rocas carbonatadas durante el Oligoceno.*

Áreas kársticas de Eslovenia

El karst en Eslovenia, desarrollado en calizas y dolomías, cubre 8800 km^2 en tres áreas kársticas principales. El paisaje kárstico alpino consiste principalmente en extensas mesetas transformadas y separadas por los valles fluviales. Las altas mesetas son áreas kársticas desnudas casi sin vegetación y suelo, con precipitaciones importantes y potentes cubiertas de nieve. Los más importantes son el macizo Kanin y los Alpes Julianos con una morfología glacio-kárstica y numerosas cuevas profundas, siendo la más profunda la sima Čehi II con más de 1.5 km de profundidad; y el sistema de cuevas más largo es el Col del Erbe con más de 40 km de longitud. El sistema de cuevas esloveno más largo tiene 24 km de largo y 900 m de profundidad y se encuentra en el borde meridional de los Alpes Julianos. Las cuevas se caracterizan por una geometría de rampa escarpada, seguida de pasajes inclinados por donde circula el agua que termina en hundimientos o colectores sifonados.

El karst Alpino también incluye fragmentos de sistemas de cuevas que precedió la elevación tectónica de la montaña. Uno de ellos, Snežna jama tiene unos 1500 metros de altitud y se formó por una corriente de agua que se hunde antes de la elevación principal de la zona, lo que causó la incisión de los valles fluviales en unos 950 m. Los sedimentos de la cueva tienen una edad de entre 2.6 y 6 millones de años.

El Karst Dinárico es el mayor área kárstica de Eslovenia y es el principal tipo de relieve de las montañas dináricas. Esta cordillera consiste en una sucesión de mesetas kársticas de 1000-1700 m de altura. Desde estos relieves desciende desde ambos lados a mesetas kársticas más bajas, a modo de peldaños. La meseta inferior ubicada en el lado litoral, en la frontera con Italia, es el Kras. La superficie de enrrasamiento más baja es Bela krajina a unos 200 m del borde de la cuenca de Panonia. Las estructuras geológicas y las unidades mayores del relieve están conectadas a la evolución tectónica terciaria tardía. Las características más grandes del relieve son extensas superficies enrasadas y levantadas a diferentes alturas, diseccionadas en grado diferente así como un relieve modelado únicamente por procesos kársticos para formar depresiones cerradas y colinas cónicas residuales. Entre las superficies se han desarrollado grandes depresiones cerradas controladas estructuralmente, como los poljes y uvalas. La topografía kárstica de pequeña escala se compone de lapiaz, dolinas de diferentes diámetros y profundidades, grandes dolinas de colapso, las entradas de las cuevas y cuevas destechadas. Características fluviokarsticas como valles ("dells") son frecuentes en dolomías.

La mayor parte del área tiene drenaje subterráneo. Los ríos aparecen solamente en las partes inferiores de poljes, que se sustentan en el nivel alto del agua subterránea. Los ríos alogénicos fluyen desde las rocas no carbonatadas y, o bien se hunden en el límite de karst formando valles ciegos y secos, o bien cruzan el karst a través de cañones. Existen numerosos grandes sistemas de cuevas formadas por ríos que se hunden y que conectan con la superficie a través de pozos vadosos. Son comunes los grandes manantiales en los bordes de las formaciones kársticas y que drenan en pequeños valles.

El Alto Karst Dinárico se compone de mesetas con altitudes comprendidas entre 900 y 1400 m por encima de las cuales algunos picos alcanzan altitudes mayores. Estas montañas reciben una gran cantidad (de 2000 a 3000 mm) de precipitaciones. Tan pronto como el agua penetra en el karst ya no hay ningún flujo superficial. Las características principales de estas zonas son grandes dolinas, algunas de ellas con más de 100 m de diámetro y más de 100 m de profundidad. La cobertura de suelo es delgada y discontinua por lo que las rocas calizas están normalmente expuestas. Durante las glaciaciones del Pleistoceno la línea de nieve estaba en torno a los 1200 m s.n.m., y algunas mesetas estaban cubiertas por glaciares que modificaron ligeramente la topografía kárstica.

Hay muchas cuevas profundas y la más importante tiene 880 m de profundidad, pero no hay cuevas de desarrollo horizontal conocidas. Es característica la surgencia a través de manantiales localizados al pie de las mesetas. Las unidades kársticas más pequeñas son mesetas o superficies enrrasadas que separan o bordean las mesetas kársticas altas. Las más importantes son la meseta Kras, la cuenca de Pivka y el Podolje Notranjsko con varios poljes en su interior. Kras es una meseta caliza baja, de 40 km de longitud y hasta 13 km de anchura y localizada sobre la bahía de Trieste. Las rocas del flysch Eoceno rodean la meseta carbonatada y están a mayor altitud que la meseta en su borde sureste. La mayor parte de la meseta está esencialmente enrasada, aunque ligeramente basculada hacia el noroeste, con numerosas dolinas, cuevas y otras formas kársticas. Hay unas 3490 cuevas conocidas. El área drena hacia los manantiales más importantes de Timava (32 m^3/s) en la costa.

La cueva más importante es Škocjanske jama formada por el hundimiento del río Reka (8 m^3/s) que fluye hacia los manatiales del río Timavo localizados a 35 km. Las características kársticas más antiguas

en el relieve kárstico son cuevas destechadas que están expuestas a la superficie por denudación kárstica. Algunas de ellas están rellenas de sedimentos alogénicos fluviales o coladas calcíticas. Las antiguas direcciones de flujo y la edad de los rellenos de las cuevas fueron datados en torno a 5 Ma. Una de las características más importantes es el hallazgo, en tubos de calcita en las paredes de cueva destechada, de estigobionte Marifugija cavatica y que fue datada como 3.2-4.1 Ma.

La cuenca de Pivka es una gran cuenca intramontañosa en la cual una parte de la superficie se formó sobre el flysch y la otra sobre roca caliza en forma de polje kárstico. Se ha formado una red fluvial en el suelo de la cuenca; el río Pivka desaparece en la cueva de Postojnska jama de 20 km. La cueva de Postojnska jama es turística desde 1819 y es muy importante debido a la gran cantidad de visitantes (500 000 por año) así como desde el punto de vista histórico. El río subterráneo de Postojnska jama reaparece en el borde del polje de Planinsko.

El karst de Notranjska es una superficie enrasada y varios poljes entre las mesetas más altas en la parte central de la cordillera. No hay escorrentía superficial, sólo en los poljes donde los ríos fluyen porque están mantenidos por el agua kárstica. La mayoría de las cuevas accesibles son cuevas en manantiales o cuevas en sumideros en los bordes de los poljes. Todas el agua de la zona pertenecen a la cuenca del río Ljubljanica cuyos manantiales con una descarga media 39 m^3/s ubicados a 300 m s.n.m. El polje más grande de Cerkniško, es una depresión kárstica cerrada con fondo plano en la zona de las oscilaciones del agua subterránea. Esto permite la corrosión y el nivelado de la roca en el fondo del polje.

El karst aislado se desarrolla entre el karst Alpino y el karst Dinárico en altitudes típicamente entre 150 y 800 m, en áreas pequeñas de roca caliza rodeadas de roca impermeable que controla la evolución del karst. Los parches de karst aislado son generalmente áreas de varias decenas de km^2. Su morfología y evolución están generalmente definidos por las condiciones locales de cada zona kárstica y son importantes para la comprensión de la evolución general también de las áreas no kársticas.

La espeleobiología en Eslovenia, con énfasis en el sistema de cuevas de Postojnska y de Planinska jama

El karst en Eslovenia tiene una fauna subterránea rica y taxonómicamente diversa. Las cuevas de Postojnska jama-Planinska jama son las cuevas más ricas y mejor estudiadas con 84 especies trogloditas. Entre estas se encuentra la salamandra de cueva P. anguinus anguinus. Es endémica de las aguas subterráneas del karst Dinarico que fue y es la única cueva encontrada en Europa en la que viven especies de cordados y es el mayor animal troglodita del mundo. El sistema de cuevas es una localidad tipo de muchos otros animales cavernícolas, como pseudoescorpiones, arañas, escarabajos, colémbolos, además de algunos grillos, polillas, los milpiés de cueva y caracoles. Por encima de los pasajes de la cueva se encuentra la rica comunidad del epikarst. Tambien se conocen formas de vida más elementales de la vida del subsuelo, esto es, microorganismos.

Hombre y karst

La falta de cubierta de suelo y el flujo de agua subterránea son las principales características del karst. En el pasado, cuando la mayoría de la gente se ganaba la vida de la agricultura, estos dos factores también fueron los principales limitantes para el asentamiento de población. Para resolver el problema del suelo, los campesinos despejaron la superficie de las piedras y las apilaron o hicieron paredes. Así adquirieron campos pequeños en su mayoría en los fondos de dolinas donde el suelo era un poco más potente; el resto fue utilizado para pastos. En la zonas de karst continental y montañoso los bosques nunca fueron talados. Es por ello que muchos terrenos kársticos están actualmente entre los más boscosos de Eslovenia. En las últimas décadas el abastecimiento de agua se ha solucionado por suministro regional de agua, de modo que los terrenos kársticos encaran un urbanismo e industrialización agresiva debido al bajo precio de la tierra.

Los principales problemas de las zonas kársticas aparecieron en las últimas décadas y están ligados al uso como lugares para la eliminación de residuos, mala calidad y malas ubicaciones de estaciones de depuradoras de aguas residuales y construcción incontrolada de viviendas. Un poco más sostenible ha sido la construcción de autopistas modernas ya que las pautas básicas para la planificación de las rutas del tráfico incluyen la evaluación integral del karst.

Introduction

In Slovene language, kras means a rocky, barren surface developed on limestone or dolomite and is also used as a toponym for small or large rocky and barren areas such as the Kras plateau. Because of the distinctive relief forms, unusual hydrologic phenomena and the considerable amount of early research done there, this region has become a classical, reference site after which the type of landscape formed on soluble carbonate rocks was named.

Karst is a type of landscape with special surface, underground and hydrological features and phenomena. Its main characteristic is dissolution of the carbonate rocks by water enriched with CO_2 as the dominant morphological process, removal of the rock in the form of solution and prevalent underground drainage that forms caves. Karst formed during a wide time span during which other geomorphic processes were also present and influenced the karst morphology.

Similar features may also form in gypsum or salt. As they are formed in a different time scale, by different processes and form different landscapes we have to make a clear distinction between them.

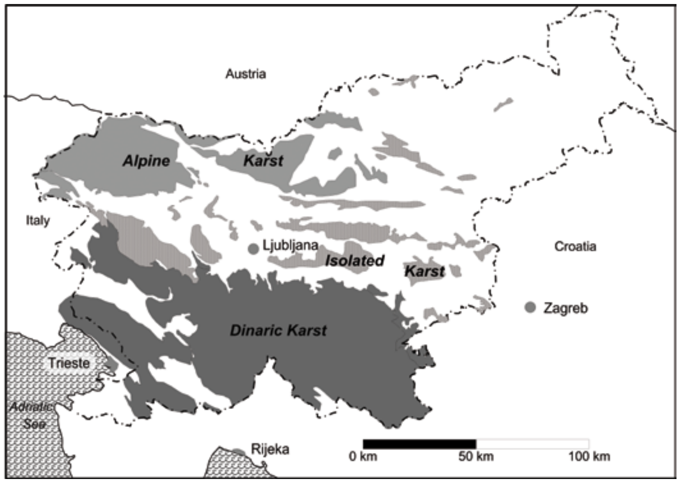

Figure 1: Extension of karst in Slovenia. Marked are the areas with limestone and dolomite and the three main types of karst: Alpine karst, Dinaric karst and Isolated karst.

Figura 1*. Extensión del karst en Eslovenia. Las áreas marcas son áreas calizas y dolomías y se observan los tres tipos principales de karst: karst alpino, karst dinárico y karst aislado.*

History of karst exploration in Slovenia

Several karst phenomena were already mentioned in antiquity and the middle ages, such as large springs, sinking rivers and some caves. Floods and springs on Cerkniško polje were used by Kircher (1678) to illustrate ground water movements. Valvasor (1689) described many caves and especially the karst hydrology of the polje. The explanation was improved by Steinberg (1758) and others. These were the first attempts to describe and understand karst hydrology.

In the first half of 19th century exploration of caves around Postojna, flood regulations related to karst poljes and the exploration of caves for water supply on the Kras plateau above the city of Trieste, collected together a vast knowledge about karst phenomena. Many caves were explored and mapped. Among them were large parts of the Postojnska jama cave and the Abisso di Trebicciano, which was explored to a depth of 320 m in 1840 and was for the next 60 years the deepest known cave in the world (Shaw 1992). Besides caves, springs and sinkholes, other karst relief forms were identified and described: the rocky surfaces, dolines, collapse dolines, karst poljes, uvalas, ponors, karren, blind and pocket valleys.

The basic work on speleology was done by Schmidl (1854) and Kraus (1894). At about same time the geological survey and production of first geologic maps started which facilitated the study of karst. Geomorphology of the area was also studied by Martel (1894), Grund (1914) and A. Penck's student, Cvijić (1893), so the term karst was spread worldwide for the denomination of natural phenomena.

Moreover, the first ideas of karst evolution were formed. Later basic karst evolution concepts followed the main trends in geomorphology, they were upgraded with cyclic theory (Cvijić, 1918; Melik, 1955; Roglič 1957) climatic geomorphology (Radinja 1972) and others. Karst today is a common research subject for various, distinct scientific fields, such as geology, geography, speleology, hydrology, biology, geomorphology, sedimentology and others which have been brought together with the development of measuring techniques and enormous advances in the knowledge of karst have been made.

Postojna was already an important tourist karst site in 1906 and preparation for a special karst research institution started. During the Italian occupation in 1929 the Instituto Italiano di Speleologia was established and in 1947, the Inštitut za raziskovanje krasa within the Slovene Academy of Sciences and Arts continued the research. The institute deals with karst geomorphology, speleology, hydrology and speleobiology.

Together with the institute, the Speleological Association of Slovenia is maintaining a Cave Register with 10500 registered caves which represent the current state of cave research. The institute is editing the Acta Carstologica journal and since 1983 has been organising regular annual meetings with the International Karstological school, "Classical Karst". It also holds a course of karst studies within the University of Nova Gorica. There is also seat of the International Speleological Union in the institute. Karst is also a research topic at the University of Ljubljana and in Nova Gorica.

Geologic characteristics of karst in Slovenia

Geological characteristics of Slovenia to a great extent arise from its geotectonic position between the African and Eurasian plates or the intermediate Adria-Apulian microplate. Here three major geotectonic units meet – the Alps, the Dinarides and the Pannonian basin (Fig. 2) with different characteristics and abundance of carbonate rocks and related karst. The Southern Alps and Dinarides are separated from the Central Alps by a pronounced Periadriatic fault (Fig. 2).

In Slovenia, the majority of karstic terrains are located in Dinarides and the Southern Calcareous Alps in the western half of Slovenia (Fig. 2). In Dinarides, carbonate rocks occupy mainly its western and south western part or the fold-and-thrust belt of the External Dinarides, whilst in the Southern Calcareous Alps compose the major part of the Julian Alps, Kamnik-Savinja Alps and Karavanke Mt. or its S to SE verging fold-and-thrust-belt (Fig. 2).

The oldest carbonate rocks that crop out in Slovenia are Lower and Middle Devonian bedded and massive reef limestone in the Southern Karavanke Mt. Of the same age are patches of slightly metamorphosed limestone and marbles in the Slovenian part of the Eastern Alps.

In the Southern Alps, Carboniferous and Permian carbonate sequences that alternate with clastic rocks on metric and decametric scales reflect highly irregular post-Variscan topography of sedimentary basins. In the Upper Permian a unified shallow marine carbonate platform was established over the western part of present day Slovenia and also further towards the south (i.e. the Dinarides in Croatia) and north (i.e. the Italian Southern Alps). Between the Middle Triassic and Lower Jurassic this extended epeiric carbonate platform was dissected and in the area of the central part of the western and central Slovenia, the deeper marine "Slovenian Basin" was formed. It separated the southern Adriatic carbonate platform (AdCP) from the northern Julian carbonate platform (JCP). While the JCP was drowned until the Middle Jurassic, the AdCP, whose deposits are recently presented in the External Dinarides, thrived until the end of the Mesozoic. In the external Dinarides, the Mesozoic shallow marine deposits of AdCP are overlain by Maastrichtian to Eocene shallow to gradually deeper marine limestone of the synorogenic carbonate platform and prograding hemipelagic marl and deep-water clastics (flysch). At the periphery of the foreland basin, carbonate successions of the AdCP are separated from the overlying deposits of the synorogenic carbonate platform by paleokarstic unconformity (Otoničar 2007). In the Slovenian basin, mixed siliciclastic and deeper marine carbonate sediments were deposited during the Mesozoic.

In the Dinarides, the entire Upper Carboniferous to Eocene carbonate succession may exceed thicknesses of 8000 m, whilst the Lower Jurassic (the final stage of the formation of the AdCP) to Eocene from 3500 to 5000m. The most pronounced carbonate formations in the Slovenian part of Southern Calcareous Alps belong to bedded Upper Triassic dolomite (up to 1400m) and "Dachstein" limestone (up to 1700m) (Vlahovič *et al.,* 2005).

Compressional tectonics related to closures of the nearby small oceanic basins of the western extension of the Neo-Tethys dominated the area since the Jurassic/Creatceous boundary culminated in the Upper Cretaceous to Eocene foreland basin formation and especially in the final uplift of Dinaric range during the Oligocene and Miocene. In Slovenia, during this time some intermontane basins had been partly filled by carbonate coarse grained clastics, while in the surroundings forming the extensional Pannonian basin in the Middle Miocene, small cold water carbonate platforms (ramps) with "foramol" communities thrived. Quaternary fluvioglacial coarse grained material deposited in intermontane depressions of NW Slovenia (i.e. the northern part of the Ljubljana Depression) is commonly highly calcareous and indurated in carbonate conglomerates.

The Paleogene to recent thrust belts along the Adria margin (northern part of the Adria-Apulian microplate) include Dinaric thrust systems, the South-Alpine thrust system and Dinaric faults. The Dinaric thrust systems of the External Dinarides are post-Eocene, representing a NW-SE striking fold-and-thrust belt that can be followed from the Istra peninsula towards central Slovenia (Fig. 2). The S to SE verging fold-and-thrust-belt of the Southern Alps formed younger (post-Upper Miocene) than Dinaric and are in part thrusted over it. Dinaric faults cut and displace both Dinaric and South-Alpine fold-and-thrust structures. Many Dinaric faults, including the prominent Idrija Fault (see below), formed as dip-slip normal faults and were only later dextrally reactivated (Vrabec and Fodor, 2006). The tectonics of Slovenia has played an important role in about of the 30° counter-clockwise rotation of the Adria since the late Miocene to Pliocene, based on paleomagnetic data (Márton *et al.,* 2003).

As far as geotectonics is concerned, Slovenia has moderate historic and recent seismicity. According to Poljak *et al.* (2010) several regions of distinct recent tectonic and seismic activity can be delineated for Slovenian territory: 1) the Periadriatic structural

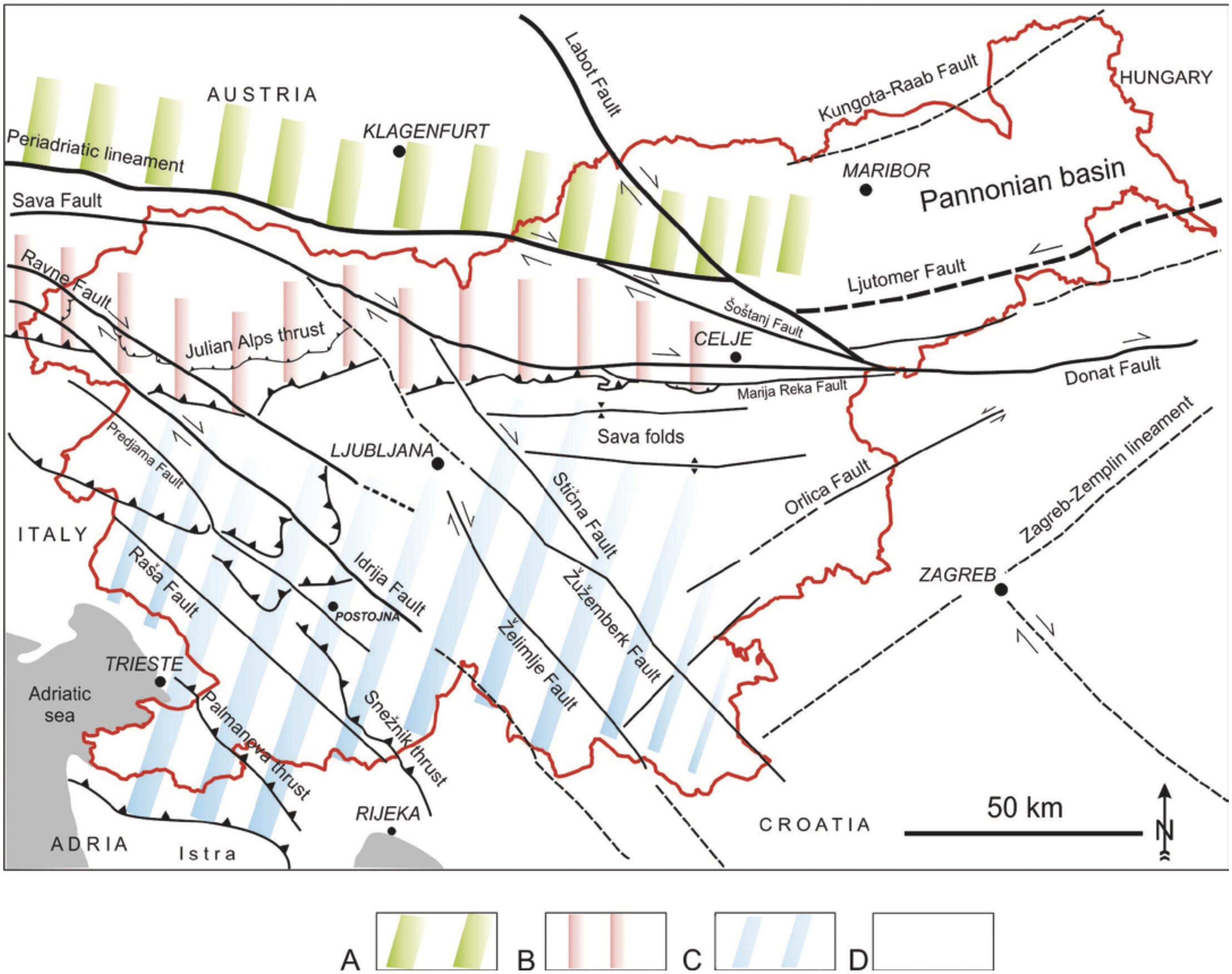

Figure 2: Structural geology of Slovenia. A-Eastern Alps, B-Southern Alps, C-External Dinarides, D-Pannonian basin. Compiled after Placer (2010), Poljak (2000) and Šebela *et al.* (2010).

Figura 2*. Geología estructural de Eslovenia. A-Alpes Orientales, B) Zona sur de los Alpes, C- Dinarides Externos, D- Cuenca de Panonia. Compilado a partir de Placer (2010), Poljak (2000) y Šebela et al. (2010).*

zone of dextral shear, 2) the Dinaric zone of dextral shear and 3) Transdanubian-Middle Hungarian structural zone of sinistral shear. Dinaric shear zone with majority of Slovene karst area corresponds to External Dinarides and includes a wide area between Raša Fault on the SW and Stična Fault on the NE. The zone consists of NW-SE oriented Dinaric faults with right-lateral horizontal displacements. The most prominent structure is the Idrija Fault.

The GPS-based best-fitting angular velocity vector predicts actual convergence in the Dinarides at ≤ 5 mm/year (Weber *et al.,* 2010). Recent seismicity observed in the vicinity of the Raša and Idrija faults is characterized by focal mechanisms that indicate the right-lateral strike-slip or reverse type of faulting (Poljak *et al.,* 2000).

Karst areas of Slovenia

Karst in Slovenia developed only on limestone and dolomite and covers 8800 square kilometres or 43% of the country. According to the general morphological and hydrological conditions and its evolutionary history, it is divided into three principal karst areas: Alpine karst, Isolated karst and Dinaric karst (Fig. 1).

Alpine Karst

Alpine karst landscape dominates the Julian Alps and Kamnik-Savinja Alps, which are both part of the Southern Calcareous Alps. The latter separated from the Dinaric Mountains in the Miocene. The area has been subdued to folding, faulting and uplifting in Tertiary orogeny. The karst is mainly developed in the upper Triassic limestone and dolomites.

Beside tectonic structure and lithology, several other factors influenced the exokarst and endokarst development of the area. Initial planation, especially on the southern side, formed extensive karst plateaus. Uplift and Pleistocene glaciations formed and/or reshaped fluvial valleys, separating karst plateaus with the highest peaks (Triglav 2864 m asl.) so that up to a two-kilometre thick vadose zone developed between them. In the valleys large karst springs are recharging the alpine rivers. The largest are the Soča, Sava, and Savinja. In some places deepening of valleys was faster than the lowering of water flow, therefore many karst springs are situated higher in the slopes and there waterfalls are formed (e.g., the 140 m high Boka waterfall in the Soča valley, and Spring of Savica as one of the springs of the Sava River). Smaller and more densely distributed are springs of fissured aquifers in which the karst network is less developed and groundwater is drained more locally. The Soča River flows towards the Adriatic sea, and the other ones towards the Black sea.

The alpine karst aquifers store important amounts of groundwater. It was assessed on water balance that they can recharge an average outflow of 115 m^3/s (Petrič 2004). For the karst springs, the Alpine nival-pluval regime with the main discharge peak in May or even June (a result of the snow melt) and the secondary peak in October or November (arising from the precipitation maximum) is characteristic.

The alpine karst springs are valuable sources of drinking water. They have high discharges and good water quality. At present they are only partly exploited, mostly because of a low density of population in the high mountains and relatively large distances from the big cities.

The high plateaus are bare karst areas with almost no vegetation and soil, high precipitation (1600 to 3200 mm), long and thick snow cover and highly effective infiltration runoff. Surface streams are rare, formed on less permeable dolomites. Due to the high amount of precipitation and high runoff coefficient, denudation rates are high which can be recognized from up to 10 cm high pedestals of karrentischen (Kunaver 2009).

The Kanin massif is the most well known Alpine karst area in the region. It belongs to the western Julian Alps and extends on the both sides of Slovene-Italian border. It is mainly made up of carbonate rocks that are partly thrusted over flysch rocks of the Bovec basin and is densely intersected by vertical faults which disturb the geometrical arrangement of blocks and largely influence speleogenesis. The massif is divided into several high plateaus with typical glacio-karstic morphology and numerous vertical cave entrances (Gabrovšek 2004). The vertical extent between the highest peaks and the springs in the surrounding valleys reaches almost 2 km. The massif has been intensively explored by local and international caving groups. Currently, there are seven caves deeper than 1 km, the deepest Čehi II (Slovenia) is over 1.5 km deep and the longest cave system, the Sistema Col del Erbe (Italy) is over 40 km long. Five caves, deeper than one kilometre on the Slovene side are characterized by steep pitch-ramp geometry, followed by inclined water passage terminated by breakdowns or siphons. These passages follow the limestone – dolomite boundary in some of these caves, but not in all. A comprehensive review on Kanin mts., with particular focus on the Italian side can be found in the book edited by Muscio *et. al.* (2011).

Since 2012 the longest explored cave system in Slovenia is in the southern rim of the Julian Alps, above the town of Tolmin. Intense exploration during the last 20 years has resulted in a system over 24 km long and 900 m deep with 5 entrances (ICCC 2012). The system is expected to be extended by joining now isolated branches. In no other area of the Julian Alps has a cave deeper than kilometre has been explored, although the speleogenetic setting and potential for deep caves do not differ substantially from Kanin. Therefore, no natural reason exists for the absence of very deep caves elsewhere. In the Kamnik-Savinja Alps, however, one cave is deeper than the kilometre system Zadnikovo brezno-Ledena devica, -1135 m.

Alpine karst also includes fragments of pre-alpine cave systems, mostly of phreatic or epiphreatic origin, which are scattered within the massifs. These are sometimes intersected by younger vertical shafts, or on rare occasions, their entrances are exposed by surface processes (Kunaver and Gabrovšek 2001, Audra *et al.,* 2007). Such a case is the Snežna jama na Raduhi, at an elevation of about 1500 m. The cave is rich in allogenic sediments that were brought in by a sinking stream. They were dated by combined a palaeontologic and palaeomagnetic method to an age of between 2.6 and 6 Ma. They were transported into the cave before the main uplift of the area and /or river valleys incision for about 950 m (Mihevc *et al.,* 2013). On the Kanin mountain paleomagnetic dating of allochthonous sediments in Črnelsko brezno (-1 241 m) proofs of at least 0.78 Ma long speleogenesis (Audra 2000).

Many caves and surface karst features characterize the landscape of forest-vegetated karst plateaus extending at altitudes between 900 and 1 700 m a.s.l at the southern rim of the Julian and Kamnik-Savinja Alps. The geometry of the caves there somewhat differs from those in high mountain karst; several caves with exceptionally large chambers have been explored in Jelovica and Pokljuka plateau. Research on the hypogene features in some of these caves is currently underway.

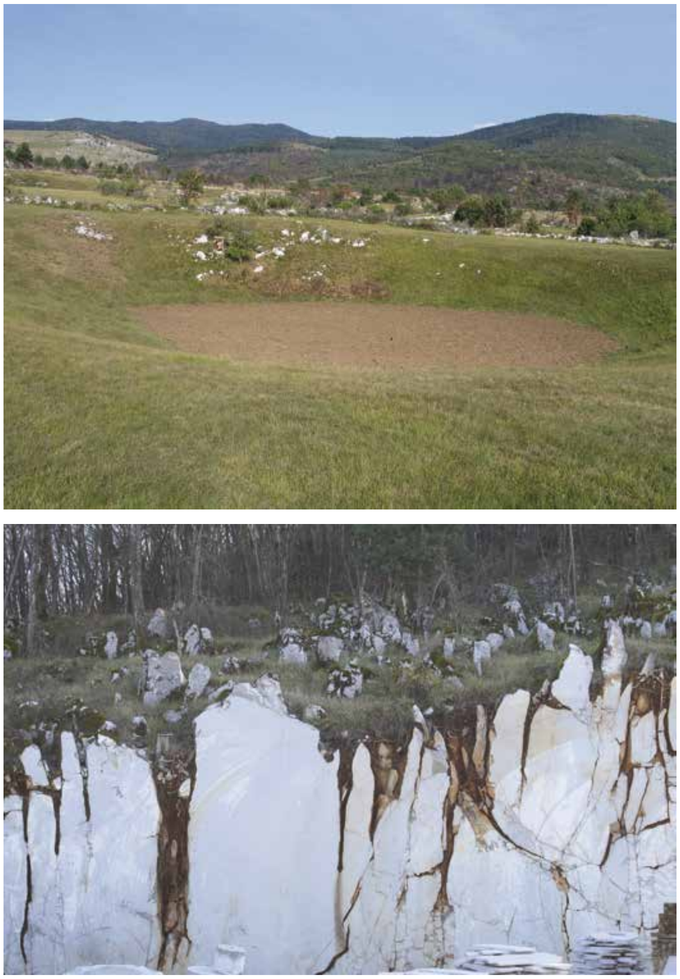

Figure 3: The most common features of the Dinaric karst are rocky surfaces as the soil cover is not continuous and dolines in which some soil is concentrated and were used as small fields. Photo by A. Mihevc.

***Figura 3**. Las formas más comunes de karst Dinárico son superficies rocosas debido a que la cobertura del suelo no es continua y existen dolinas donde se ha concentrado parte del suelo que se utilizaron como campos pequeños. Foto por A. Mihevc.*

Dinaric karst

Dinaric Karst is the major karst area of Slovenia and is the main type of relief of the Dinaric mountains. This mountain range stretches from the south-western part of the Alps towards the SE. The central part of the mountains consists of a row of 1 000–1 700 m high karst plateaus. From them step-like low karst plateaus and planation surfaces descend onboth sides. The lowest plateau is on the littoral side, on the border to Italy is the Kras. The lowest inland planation surface is the Bela krajina at about 200 m on the edge of the Panonian basin (Habič 1992, Mihevc *et al.,* 2010).

The geologic structures and major relief units are connected with late Tertiary tectonic evolution. The larger relief features are extensive levelled surfaces uplifted to different elevations dissected to different degrees with closed depressions and residual conical hills. Among the surfaces are structurally controlled large, closed depressions such as poljes and uvalas. The small scale karst topography consists of karren, dolines of various diametres and depths, extensive collapse dolines, cave entrances and unroofed caves. Fluviokarst features like dells are common on dolomites (Gams 2004).

Limestone and dolomite of Mesozoic age form well permeable aquifers with karst and fissured porosity. The whole area has relatively high specific runoffs from 10 $l/s/km^2$ in the south-western part up to 50 $l/s/km^2$ in the north-western part are characteristic, and the runoff coefficients range from 40 to 75 (Frantar, 2008). Some larger patches of dolomite act as slightly less permeable aquifers with fissured porosity. Rivers appear only in the bottoms of karst poljes, where they are supported by a high level of karst water. Allogenic rivers flowing from non-carbonate rocks either sink at the karst boundary, forming blind and dry valleys, or cross the karst in canyons. In the Dinaric karst almost 200 tracer tests with artificial tracers were carried out which revealed the characteristics of the groundwater flow.

There are numerous extensive cave systems formed by sinking rivers and also connected with the surface by vadose shafts. Large karst springs with in pocket valleys are common on the edges of the karst.

The high Dinaric Karst consists of plateaux in elevations between 900 and 1 400 m above which some higher peaks reach that are higher. The plateaux are Javorniki, Nanos, Trnovski gozd, Kočevski Rog, Snežnik (1 796 m) and others. These mountains receive a large amount (2 000 – 3 000 mm) of precipitation. As they immediately penetrate into the karst

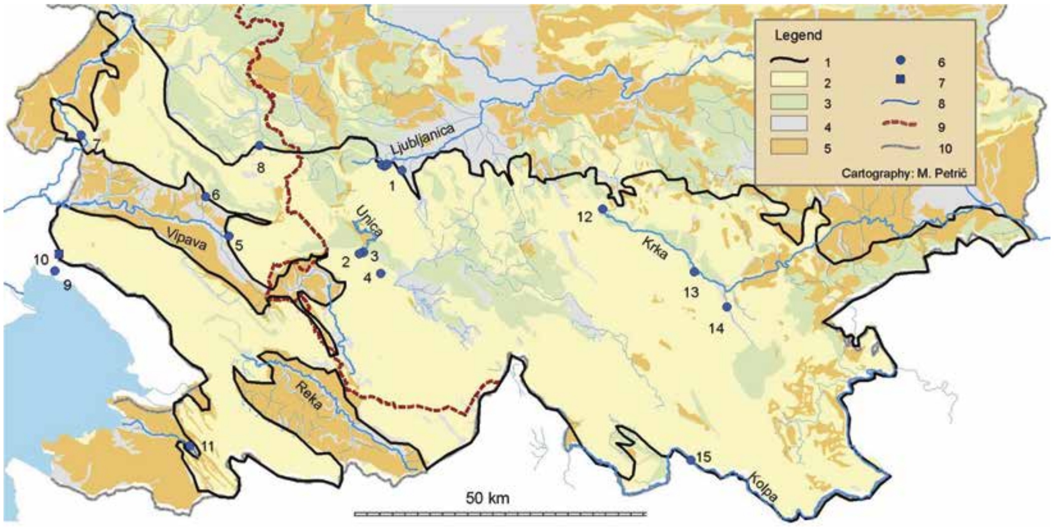

Figure 4: Hydrogeological map of the Dinaric karst in Slovenia. Legend: 1. Boundary of the Dinaric karst, 2. Karst aquifer, 3. Fissured aquifer, 4. Porous aquifer, 5. Very poorly permeable rock, 6. Important karst springs mentioned in text and a table, 7. Pumping station, 8. Surface stream, 9. Adriatic-Black Sea watershed, 10. State border. (Source: Basic geological map 1:100 000, Geological Survey of Slovenia).
Figura. 4: *Mapa hidrogeológico del karst Dinárico en Eslovenia. Leyenda: 1. Límite del karst Dinárico, 2. Acuíferos kársticos, 3. Acuíferos fisurados, 4. Acuíferos porosos, 5. Roca muy poco permeable, 6. Importantes manantiales kársticos mencionadas en la tabla, 7. Estación de bombeo, 8. Corriente superficial, 9. Cuenca del mar Adriático-Negro, 10. Frontera estatal. (Mapa geológico simplificado: 1:100 000, Geological Survey de Eslovenia).*

there is no surface flow. Karst water level is generally several 100 m below the surface. On plateaux only the karst morphology is developed. The main features are large dolines and some of them are several 100 m wide and over 100 m deep. Among there are residual conical hills. The soil cover is thin and not continuous so limestone rocks are exposed. Because of high humidity, mosses and snow cover their surface which is smooth and rounded.

There are many deep caves; the deepest are the 880 m deep Belo Brezno, and the 850 m deep and more than 6 km long Ledena jama v Paradani, both on the Trnovski gozd plateau. On the high karst plateaus no horizontal caves are known, only in lowest part of Ledena jama v Paradani where there are some horizontal passages which are flooded by high water. Springs are located at the foot of the plateaux. For the area of Trnovski gozd and Nanos high karst plateaux in the north-western part, groundwater flow with outflow through springs in the valleys at the foothills of the plateaux is characteristic. The most important among them are Mrzlek (No. 7), Hubelj (No. 6), Vipava (No. 5) and Podroteja/Divjejezero (No. 8) springs. All of them are captured for water supply.

During Pleistocene glaciations the snow line was about 1 200 m a.s.l., so some of the plateaus were glaciated and glaciers slightly modified the karst topography. Today the plateaux are covered with forests.

No. on **Fig. 1**	Spring	Qmin./Qmax. m^3/s
1	Ljubljanica	4.3/132
2	Unica	0.2/80
3	Malenščica	1.1/11.2
5	Vipava	0.7/70
6	Hubelj	0.2/59
7	Mrzlek	0.5/ 40 (est.)
8	Podroteja/Divje jezero	0.2/40 (est.)
9	Timava	9.1/127
11	Rižana	0.3/80
12	Krka	0.8/80
13	Tominčev studenec	0.5/10
14	Radeščica	0.35/40 (est.)

Table 1: Characteristic discharges of some important springs in the Dinaric karst of Slovenia. (Frantar, 2008; Gospodarič and Habič, 1976; Kranjc, 1997; Novak 1992).
Tabla 1. *Descargas características de algunos manantiales importantes en el karst dinárico de Eslovenia. (Frantar, 2008; Gospodarič y Habič, 1976; Kranjc, 1997; Novak, 1992*).

Figure 5: High karst plateau Snežnik in elevation about 1500 m. Conical hills and large closed depressions, large dolines are typical relief forms. Photo by N. Zupan Hajna.

Figura 5*. Karst alpino del la meseta Snežnik con elevación cercana a los 1500 m. Cerros cónicos, grandes depresiones cerradas y grandes dolinas son las formas típicas del relieve. Foto de N. Zupan Hajna.*

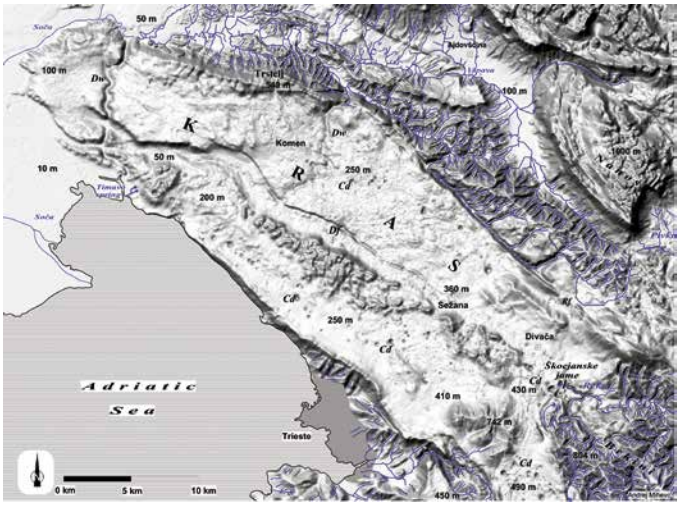

Figure 6: The Kras Plateau. Levelled karst surface cut two relict, now dry valleys (Dw), and trench along the Divača fault (Df). The Reka river flows to Kras from flysch rocks on SE and sinks at Škocjanske jame. It springs out at about a distance of 35 km in springs of the Timavo river. Collapse dolines mark the flow corridor where the main waters of the Reka flow.

Figura 6*: Meseta Kras. Superficie de karst nivelada y cortada dos valles relictos, ahora valles secos (Dw) y zanja a lo largo de la falla de Divača (Df). El río Reka fluye hacia Kras desde las rocas del flysch al SE y se encaja en Škocjanske jame. Los manantiales afloran a unos 35 km de distancia del de río Timavo. Las dolinas de colapso están marcando el corredor por donde fluyen las aguas principales de Reka.*

Lower karst units are plateaux or levelled surfaces separating or encircling the high karst plateaus. The most important are the Kras plateau and the Matarsko podolje karst, Pivka basin and Notranjsko podolje, with several karst poljes.

The Kras is a low, 40 km long and up to 13 km wide, NW–SE-trending limestone plateau lying above Trieste bay. It belongs to the Adriatic–Dinaric Carbonate Platform of the External Dinarides, composed of shallow marine fossil-bearing Cretaceous and Palaeogene carbonates. Eocene flysch rocks encircle the carbonate plateau and are higher than plateau on its SE side. The area of Kras in the south-western part is drained toward the springs in the Trieste bay in Italy. The biggest among them, with a mean discharge of 32 m^3/s, is the Timava spring (No. 9). In the hinterland of the Slovene Littoral the most important is the Rižana spring (No. 11).

The climate is sub-Mediterranean with an average yearly precipitation from 1400 to 1650 mm. The main part of the plateau is essentially levelled, but slightly tilted towards the north-west, with numerous dolines, caves and other karst features. About 3490 caves are known on the plateau.

The longest caves are: the Kačna jama (15181 m), the Škocjanske jame (5800m), the Lipiška jama (1400 m), the Vilenica (841m) and the Divaška jama (672 m). The deepest caves are: the Kačna jama (280 m), the Škocjanske jame (250 m), the Lipiška jama (250 m), the Lipiško brezno (210m) and the Vilenica (190 m). The Grotta di Trebiciano cave, located beyond the border, in Italy, is even deeper (319 m). Relatively short and shallow caves are more common. The average length of the known caves in the Classical Karst is 86m, whereas their average depth is 30m. The length of all the passages is almost 65km.

The most important cave is the Škocjanske jame. The cave was formed by the Reka river which has mean annual discharge 8.26 m^3/s. At low waters it sinks before it enters the cave, floods usually reach up to 30 m, the greatest known floods have raised the water table level to about 150 m.

The Škocjanske jame caves are composed of phreatic tunnels and gravitational or paragenetic reshaped galleries. The largest chambers are the Martelova dvorana, with a volume of 2100000 m^3. Some of big chambers collapsed, forming the collapse dolines. Because of its large dimensions the cave is on the UNESCO world heritage list.

From the terminal sump in the cave underground river flows toward 35 km distant springs of theTimavo river between 200 and 300 m below the surface of the plateau. We can reach the underground river in 7 other caves together with 21 km of passages. Above the underground flow of Reka are numerous collapse dolines. Large chambers and collapses are

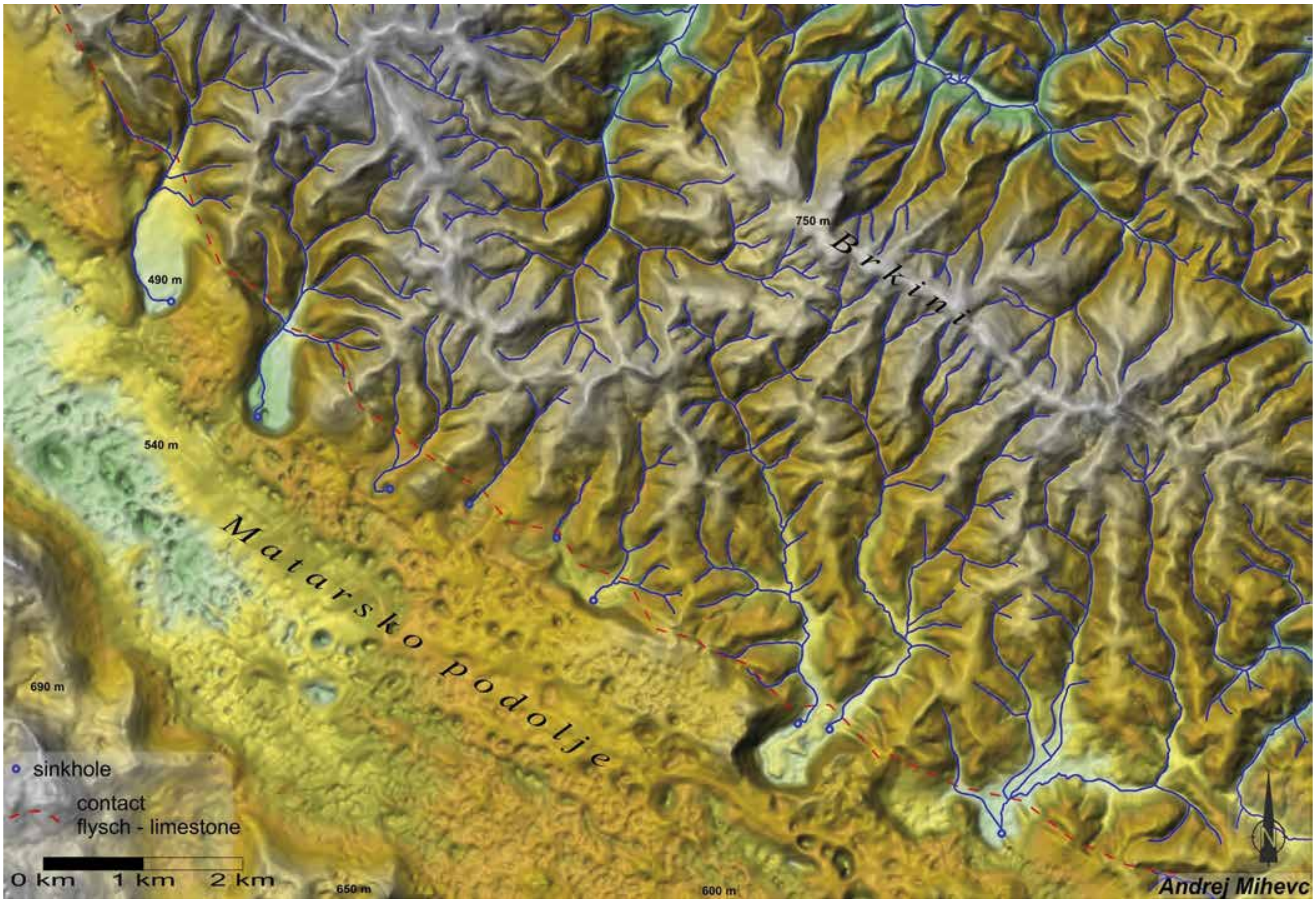

Figura. 7: Contact karst of Matarsko podolje with a row of blind valleys. Notice the difference between fluvial and karst relief dissected by hundreds of dolines and some larger collapse dolines. DEM drawings are on base of 12.5 m grid, Survey and Mapping Authority of the Republic of Slovenia.

Figura 7*: Contacto del Karst de Matarsko podolje con una fila de valles ciegos. Atención a la diferencia entre el relieve fluvial y el relieve de karst diseccionado por cientos de dolinas y grandes dolinas de colapso. El MDE tine una resolution de pixel de 12.5 m, Survey and Mapping Authority of the Republic of Slovenia.*

most likely genetically connected with oscillations of the underground Reka.

The oldest karst features in the karst relief are unroofed caves that are exposed to the surface by karst denudation (Mihevc and Zupan, 1996, Mihevc 2001, Zupan *et al.,* 2008). Some of them are filled with sediments, allogenic fluvial sediments or flowstone. From some, sediments were washed away or were never filled. On the surface, they are expressed as elongated depressions. Fills exposed on the present day surface include speleothems and cave fluvial deposits. The ancient directions of flow and the age of cave fills was calculated from denudation rates and thickness of missing overburden or were dated by paleontological and paleomagnetic datations of sediments to about 5 Ma (Zupan et.al. 2010, Mihevc, 2007).

The finding of fossilized, attached calcite tubes of stigobiont *Marifugija cavatica* on the wall of the unroofed cave was important. It was dated to 3.2-4.1 Ma (Mihevc, 2000, Zupan *et al.,* 2008). They indicate was that since that time karst evolution in the area was never interrupted and also proves the existence of karst long before that, because the animal species needed time to adapt to life in a cave environment.

On the SE part the Kras continues to the Matarsko podolje, which borders with Eocene non-carbonate flysh hills. From here 17 streams flow to limestone and created a row of blind valleys Gams 1981). The depth of the height of the valley bottoms was controlled by the karst water level but they are much deeper because of neotectonic uplift and tilting of the area in the part which was uplifted most.

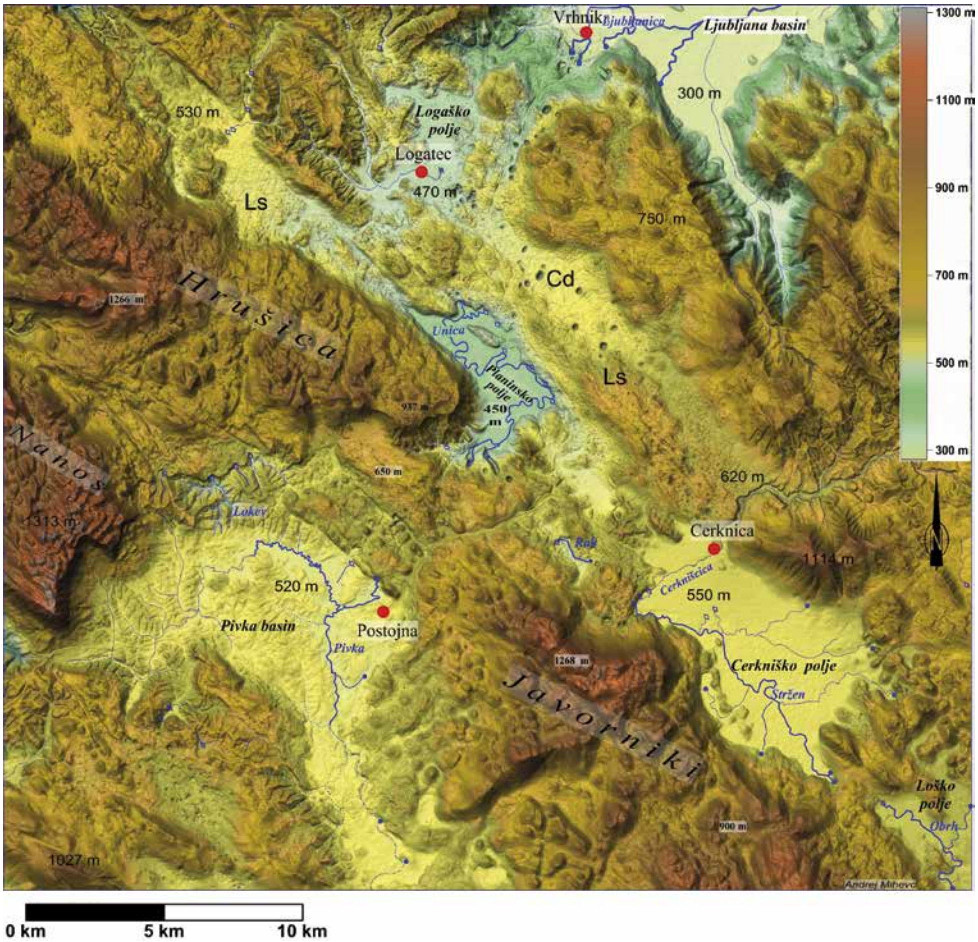

Figure 8: High karst plateaus Nanos, Hrušica, Javorniki and others in the central part of Dinaric mountains. Among them are lower relief units. The Pivka basin with some noncarbonate rocks and several sinking rivers. The largest, the Pivka is a tributary of the Unica river and flows through the Postojnska jama to the Planinsko polje. Poljes: Loško, Cerkniško, Planinsko and levelled surfaces (Ls) are part of stripe of lower relief called Notranjsko podolje, which developed along Idria fault zone. On levelled surfaces collapse dolines (one of them is marked Cd) show the main karst flow corridors between poljes towards springs of Ljubljanica river at the edge of Ljubljana tectonic basin. DEM drawings are on base of 12.5 m grid, Survey and Mapping Authority of the Republic of Slovenia.

***Figura 8:** Karst alpino de las mesetas Nanos, Hrušica, Javorniki y otros en la parte central de las Montañas Dináricas. Entre ellos se encuentran unidades bajas de relieve. La cuenca del Pivka con algunas rocas no carbonatadas y varios ríos sumergidos. El río Pivka es tributario del río Unica y fluye a través de Postojnska jama Planinsko polje. Poljes: Loško, Cerkniško, Planinsko y superficie nivelada (Ls) forman parte de la franja de menor relieve llamado Notranjsko podolje, que se desarrolló a lo largo de la zona de falla de Idria. En las superficies niveladas las dolinas de colapso (una de ellos está marcada Cd) muestran los principales flujos de karst fluyendo entre poljes hacia muelles del río Ljubljanica en el borde de la cuenca tectónica de Ljubljana. El MDE tine una resolution de píxel de 12.5. Survey and Mapping Authority of the Republic of Slovenia.*

Pivka basin is large intermountain basin in which part of the surface is formed on flysch and part on limestone as a karst polje. A river network has formed on the floor of the basin; the water flows into the border limestone going to different river basins.

The Pivka mean flow is 6 m^3/s, and is the largest sinking river in the basin. It sinks into the 20 km long Postojnska jama cave about 511 m a.s.l. The cave has several levels, the main level being between 520 and 477 m a.s.l. The Postojnska jama has been tourist sight since 1819, when the inner parts of the cave were discovered. It is important because of the large number of visitors (500 000 per a year) and from a historical point of view. The underground river from Postojnska jama reappears after 2.5 km in the 8.5 km long Planinska jama at 460 m a.s.l. on the edge of the Planinsko polje.

Notranjsko polje is a levelled surface between high karst plateaus in the central part of the mountain ridge. It developed in the important regional Idrija fault on Mesozoic limestone and dolomite in elevation between 470 and 650 m. The surface was formed

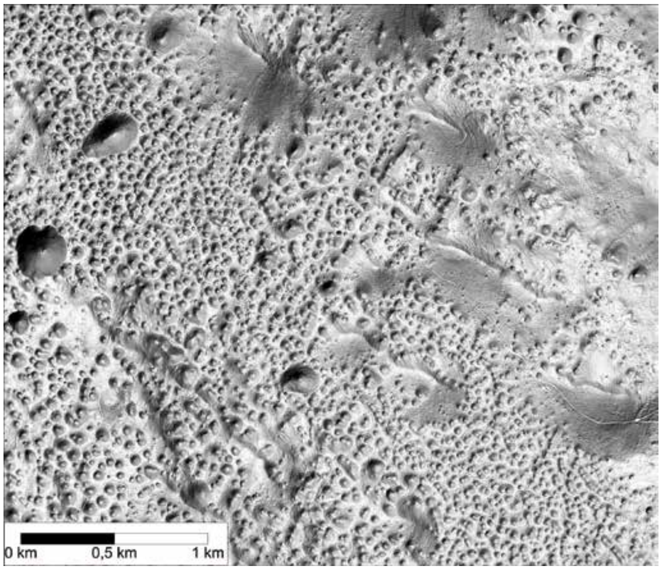

Figure 9: Planation surface East of Planinsko polje. Among dolines are some much larger collapsed dolines and conical residual hills. DEM is based on 1 m grid LIDAR interpolation method by Kobler *et al.* (2007).

***Figura 9**. Superficie de aplanación al este de Planinsko polje. Entre las dolinas algunas son grandes dolinas de colapso y colinas cónicas residuales. El MDE esta basado en una malla LIDAR de 1 m e interpolado por el método by Kobler et al. (2007).*

in the level of the karst water as a large polje. Later the whole area was uplifted and tilted. With this the water level dropped so the surface was dissected by the formation of dolines and collapsed dolines.

During this evolution of the area some parts of levelled surface remain in lower position and are still under the impact of karst waters so they are still active poljes being formed. There is no surface runoff, the rivers flow only on the poljes because they are supported by the karst water. There are many caves, mostly they are vadose shafts but there are also large caves, part of relict or active cave systems. Most of the accessible caves are springs or ponor caves on the edges of the karst poljes (Prelovšek *et al.,* 2008).

The largest is the Cerkniško polje which is a large closed karst depression covering 38 km^2. The flat bottom of the polje lies in an elevation of about 550 m in the zone of oscillations of the karst water. This enables corrosion and levelling of the rock bottom of the polje. The sediments on the bottom of the polje are only few metres thick

Inflows to the polje are from karst springs on the eastern and southern sides and some small superficial tributaries from dolomite. At lower waters the rivers are sinking mostly in marginal swallow holes

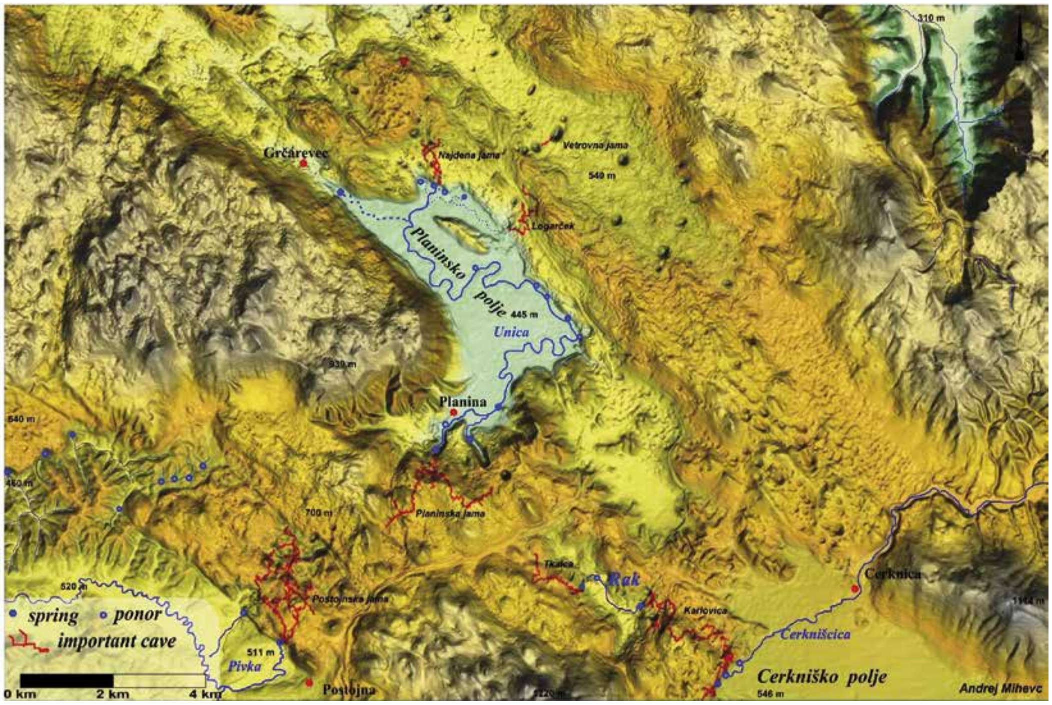

Figura. 10: The Planinsko polje and the main caves and rivers of the Cerkniško polje and Pivka basin. Main relief features between poljes are dolines and collapse dolines and residual conical hills. DEM is base of 12.5 m grid, Survey and Mapping Authority of the Republic of Slovenia.

***Figure. 10**: Polje Planinsko y las cuevas y ríos principales del polje Cerkniško y la cuenca de Pivka. Las formas del relieve principal entre poljes son las dolinas y las dolinas de colapso y las colinas cónicas residuales. El MDE tine una resolution de píxel de 12.5 m, Survey and Mapping Authority of the Republic of Slovenia.*

Figure. 11. Spring of river Unica from a cave on the edge of the Planinsko polje. Photo by A. Mihevc.
Figura 11*. Manantial del río Unica a partir de una cueva en el borde del polje Planinsko. Foto tomada por A. Mihevc.*

and in numerous grounds swallow holes. Higher waters cross the polje and sink into caves at the NW edge of the polje in ponor caves with more than 7 km of passable channels. The bottom of Cerkniško polje is regularly flooded for about 6 months in autumn winter and spring time.

Along the same fault zone other poljes have also developed, the Babno polje (750 m), the Loško polje (600 m) and below the Planinsko polje (450 m). On all the poljes there are springs of water that come from higher poljes or high karst plateaus. They cross poljes at higher waters and sink again. Rivers form more than 70 km of accessible passages but the rest of the cave passages are below water level. All the water from the area belongs to the catchment area of the Ljubljanica river, with springs with a mean discharge of 39 m^3/s are at 300 m a.s.l..

East of the main crest of Dinaric mountains are due to lower relief amplitude and less morphologically expressed tectonics interlacing the system of karst poljes with the biggest Ribniško and Kočevsko polje with deep vadose zone continues eastwards where shallow karst prevails. At the transition towards the Prealpine hills and Panonian there are more dolomites so fluvial processes gradually prevail and overlap with karst processes in a kind of fluviokarst relief that is characteristic for the E and NE part. In these areas, part of the water flows underground and the rest superficially, especially during intensive precipitation. Karst drains mainly underground SE towards the Krka and Kolpa rivers.

In lower karst relief soils are up to a few metres thick and in places enhance subsoil karren formation (Knez and Slabe 2006). Due to thick soil, suffosion dolines as a result of soil collapsing are common. Thick soil with high soil pCO_2 results in high water hardness and tufa formation downstream of small dolomite springs and along the Krka and Kolpa rivers, which are recharged by numerous karst springs, the biggest among them are the Krka spring (No. 12), Tominčev studenec (No. 13) and Radeščica spring (No. 14) in the Krka valley and the Bilpa spring (No. 15) in the Kolpa valley.

The caves of the Dolenjska region are rather shallow and short and do not exceed 3.5 km. The main obstacles for exploration are sumps and breakdowns. The longest caves are formed in different hydrological settings but always close to the regional water level as epiphreatic stream caves: (a) as ponor caves from impervious rocks (cave Podstenska jama, 3.4 km; cave system Željnske jame, 1.6 km), (b) hydrological connection between poljes and valleys in karst (cave Viršnica, 2.4 km, as a part of Grosuplje polje-Krka spring connection) or (c) spring caves (Kostanjeviška jama, 1.9 km; Jelovička jama, 1.8 km; Bilpa, 1.2 km). The depth of the deepest shafts is rather small (Čaganka, currently explored to -350 m). Several ponor caves in the Dolenjska region were modified at the end of 19th century to reduce the impact of floods.

Isolated karst areas

Isolated karst is developed between Alpine and Dinaric karst at the altitudes typically between 150 and 800 m as small limestone areas surrounded by impermeable rock that controlled the evolution of the encircled patches of karst. Patches of isolated karst are generally several tens of km^2 wide areas. Usually these small areas are under the influence of allogenic recharge and the outflow points defined by impervious rocks at the lower edge of each karst unit. Their morphology and evolution are generally defined by local conditions of each karst area and are also important for the understanding of the general evolution of non-karst areas.

Rather long stream caves with several levels are common and palaeo-geographically important at local scale such as in the spring Huda luknja cave (2.3 km). In the cave there are three levels of passages and there are three more separated caves above the cave, clearly illustrating the down cutting of the river valley. In Tajna jama (1.3 km), reversed polarity in investigated profile (Zupan *et.al.,* 2008) proof that sediments are 0.78 Ma or up to 4.2 Ma old. Phreatic morphology and location near springs with sulphate-rich waters suggest hypogene speleogenesis for some caves. Due to peculiarity in generally fluvial relief, caves of isolated karst were important in the Palaeolithic as shelters (i.e., Matjaževe kamre, Špehovka, Jama pod Herkovimi pečmi) and have been important even from the end of 19th century as show caves (Huda luknja, Železna jama, Pekel).

Speleobiology in Slovenia with an emphasis on the Postojnska and Planinska jama Cave System

Slovenia holds a special place in karst studies because it has the karst areas with the richest subterranean fauna in the world. This richness means that of more than 500 registered species of stygobionts and of almost 800 species of troglobionts in western Europe, there are respectively 207 and 166 of these species in Slovenia. There are 120 endemic taxa in Slovenia.

The subterranean fauna is both rich and taxonomically diverse and it contributes to the global biodiversity. There are only seven caves in the world where more than 25 terrestrial species limited to caves—troglobionts are known and Postojnska jama and Planinska jama caves (PPCS) is the richest among them. With aquatic species the Dinaric karst is even more dominant – five of eight caves with more than 25 stygobiotic species are in the Dinaric karst and again PPCS has the highest number of stygobionts (Culver and Pipan, 2013).

The Postojnska jama-Planinska jama Caves are one of the best-studied and richest caves in the world, with 84 obligate cave dwelling species. Among the 48 stygobionts is the European cave salamander *P. anguinus anguinus*. There are 8 snail species and 16 crustacean species. Some of the stygobiotic species, hydrozoan *Velkovrhia enigmatica* and the cirolanid isopod *Monolistra racovitzae racovitzae* have marine origin. Three species of the amphipod genus *Niphargus* as well as populations of *Asellus aquaticus* were isolated in the cave at different times. One of the most common species on the riverbed is the amphipod *Niphargus spoeckeri*, while the smaller *N. auilex dobati* is present within deeper interstitial layers in Planinska Cave. The cave shrimp *Troglocaris anophthalmus*, and the highly troglomorphic isopod *Asellus aquaticus cavernicolus* are present in pools (Sket, 2004).

First mentioned by Valvasor in 1689, the cave salamander *Proteus anguinus anguinus* Laurenti, 1768 remains an important model organism for understanding the biogeograhic history of cave animals and in adaptation to cave life (Bulog *et al.,* 2000). It is endemic to the underground waters of the Dinaric karst and is the only cave-dwelling chordate species found in Europe. It is eel-shaped amphibian, with 20 to 30 cm in long, the largest cave-dwelling animal in the world. It is an obligate neotenic animal, which means that preserves some larval or immature characters (e.g. external gills) in adulthood. *Proteus* is characterized by some general troglomorphic features, such as specialized sensory organs, elongated body parts, reduced eyes, skin depigmentation, slow metabolism, increased lifespan, etc. (Bulog, 2004). Owing to its fragmented and limited distribution, continuing decline in the number of mature individuals and susceptibility to water pollution, the olm is thus listed on the IUCN Red List as vulnerable species.

Figure 12: The iconic cave animal *Proteus anguinus anguinus* Laurenti, 1768 is distributed along the whole Dinaric karst. Photo by G. Aljančič.
Figura 12: *El icónico animal de cuevas* Proteus anguinus anguinus *Laurenti, 1768 se distribuye a lo largo de todo el sistema de karst dinárico. Foto de G. Aljančič.*

Figure 13: *Leptodirus hochenwartii* Schmidt, 1832 from the Postojnska jama cave. This is the first formally described cave animal. Photo by S. Polak.
Figura 13: Leptodirus hochenwartii *Schmidt, 1832 de la cueva Postojnska jama. Este es el primer animal de cuevas formalmente descrito. Foto de S. Polak.*

PPCS is a type locality of some other cave-dwelling animals, such as pseudoscorpions (*Neobisium speleaum*), spiders (*Stalita taenaria*), beetles (*Laemostenus schreibersi*, *L. cavicola*), springtails (*Onychiurs stillicidii*), ispods (*Titanethes albus*), likewise of some trogloxene crickets (*Troglophilus cavicola*), moths (*Triphosa dubitata* and *Scoliopteryx libathrix*), troglophile millipedes (*Brachydesmus subterraneus*), and snails (*Zospeum*) (Sket, 2004).

Among the 36 troglobionts found in the PPCS is also *Leptodirus hochenwartii* Schmidt, 1832 which represents the first described cavernicolous species in the world. In 1831 local cave guide Luka Čeč found the first troglobiotic beetle and one year later entomologist Ferdinand Schmidt recognized the beetle as a new species and also classified it as a new genus (Polak, 2005). The beetle is named according to its narrow neck and head and in honour of Hohenwart, the donor of the beetle. It is an 8–11 mm long, depigmented and eyeless troglobitic beetle. Domed elytra, which covers the abdomen, gives it most distinctive spherical body shape. Individuals usually inhabit large and deep caves with temperatures 5–12 °C. Its ecology and etology is poorly known. Specimens were noticed to feed on carcasses of cave crickets, bats and other organic material in cave. Usually they gather on damp flowstone walls with slow trickling water, where they presumably feed on organic matter from percolating water (Vrezec *et al.,* 2007).

Above the cave passages of PPCS is the rich epikarst community. Epikarst communities are best sampled by collection and filtration of drip water over extended periods of time. These are animals that have been swept out of their primary habitat. The drips exhibited considerable environmental heterogeneity. A total of 23 copepod species (4 Cyclopoida and 19 Harpacticoida) were found in the drips, including eight undescribed species. Six of these 23 species are endemic to PPCS. A total of five species were in a single genus—*Bryocamptus*. In addition to copepod fauna, species from 15 terrestrial and aquatic animal groups were found (Culver and Pipan, 2013).

More elementary forms of life, microorganisms, from the underground were also intriguing. It is interesting that as early as from 1878 there exists a report on identification of two dinoflagelates from Postojnska jama), *Peridinium stygium* and *Gymnodimium* sp. (Culver et al., 2012). In 1977 some bacterial isolates from Planina Cave were successfully cultivated in the laboratory (Mulec, 2008). Fungus *Mucor troglophilus* was discovered on a living cave cricket *Troglophilus neglectus* and amoeba *Allovahlkampfia spelaea* in a community on stromatolitic stalagmite from Škocjan Caves (Walochnik and Mulec, 2009). Microbiology is slowly becoming an integral part of karst studies because we recently realized that many cave and karst features are/were linked with biogenic activities. Microbiological parameters are crucial in assessing water quality (Culver and Sket 2000, Culver *et al.,* 2012) and give many useful directions for future sustainable use of underground natural and cultural heritage.

An important part of the Postojna Cave is the speleobiological laboratory which dates back to 1931 and is now managed for tourist displays as the Vivarium Proteus, which displays various aspects of the cave environment. In the Tular cave the biologist Marko Aljančič established populations of *Proteus* in 1960 in a series of large artificial pools (Aljančič, 2008).

Additional biological, ecological, morphological, physiological and molecular analyses of selected subterranean species are performed, at the Karst Research Institute, mainly at the University of Ljubljana (Biotechnical Faculty) and at the University of Maribor (Faculty of Natural Sciences and Mathematics). Most attention has been devoted to the "human fish" *P. anguinus*, so called due to its skin colour, with an emphasis to pollution, destruction and threats to the karst underground (Polak, 2007). It took three years to even maintain adult fish in Tular but in 1991 both, Marko and his son Gregor Aljančič were successful in captive breeding.

Man and karst

The lack of soil cover and underground flow of water are the main characteristics of the karst. In the past, when most of the people made a living from farming, these two factors were also the main limiting factors for settlement.

They made water pools for cattle and reservoirs which were filled by rainwater for supplying people. Nowadays, most residents of karst areas are attached to public water pipelines. It was more difficult to solve the problem of the soil. Peasants cleared the surface of stones and piled them up or made dry walls. Thus, they acquired small fields mostly in the bottoms of dolines or where the soils were somewhat thicker (Kranjc, 1997).

For example, on the 4.8 km^2 of land owned by the village of Volčji grad on the Kras plateau that was cleaned of rocks that were piled to build dry walls, they gained 38.6 ha of fields and meadows respectively. Rocks were built into 19.4 km of dry walls that consist of 9812 m^3 of stones per square kilometre. The rest of the land that was too rocky to be meliorated is only pasture. (Mihevc, 2005).

Other more stony surfaces of the plateau were used for pastures, which replaced the natural forests.

In the areas closer to the sea, such as on the Kras plateau, the landscape was transformed into a bare rocky country, a real stone desert. In continental karst areas and mountains forests were never cut. At present the karst areas are the most forested part of Slovenia. The reasons for this are the change in the economy in the past century and deliberate effort towards reforestation.

Due to the lack of soil and water, karst landscapes in the past remained sparsely populated. That is why the karst is not facing agricultural or industrial pollution, which is today a great benefit and advantage. In recent decades, fewer and fewer people live only on agriculture, therefore the soil is no longer an important limiting factor and the water shortages are solved by regional water supply. So the karst terrains face the building of industry, traffic facilities and housing because of low land prices.

This new development brings risks. The rapid growth of population and inappropriate economic activity will, in a very short period of time, permanently erase a number of qualities which have been preserved in the landscape. Particularly endangered are water resources.

The main problems that appeared in recent decades are inappropriate locations for waste disposal, poor quality and bad locations for sewage purification stations and uncontrolled housing developed on the karst. The construction of modern motorways in Slovenia, where the basic guidelines for planning traffic routes include comprehensive assessment of the karst has been handled a little better. The selected traffic route should avoid specific exceptional karst features and the conservation of karst aquifers should be one of the priority planning goals.

The fact is that these motorways should have pipes and gutters along the roads and wastewater collectors. Untreated water should never reach the permeable karst surface. The existing wastewater collectors are often too small and abundant precipitation can easily wash the sediments from them. It is clear that the cooperation of karstologists in the construction of motorways in the kras regions have brought positive results. It is important that karstologists participate in the planning and construction of motorways and that they then monitor the impact of the motorways on the environment, that is, throughout the entire process of encroachment on the vulnerable karst landscape.

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