Within the frame of

ProGEO

European Association for the Conservation of the Geological Heritage

The 12th Regional Conference on Geoconservation and ProGEO Working Group 1 Annual Meeting

GEOLOGICAL HERITAGE IN THE SOUTH-EASTERN EUROPE

Ljubljana, Slovenia, 5-9 September 2007

Organised by:

Slovenian Geological Society

Zavod Republike Slovenije za varstvo narave

Institute of the Republic of Slovenia for Nature Conservation

AGENCIJA ZA OKOLJE

Environmental Agency of the Republic of Slovenia

GeoZS

Geological Survey of Slovenia

Dedicated to:

planetearth Earth Sciences for Society

Earth Sciences for Society - an International Year of Planet Earth

FIELD GUIDE

Edited by: Branka Hlad and Uroš Herlec

Proof reading: Paul Morris

Photos on cover page (from upper left to lower right):
- Branka Hlad: Belogradchik geomorphology (Bulgaria)
- Miha Jeršek: Malachite and azurite mineralization (Slovenia)
- Marko Simić: Kapadokia columnar weathering of pyroclastic rocks (Turkey)
- Marko Simić: Planinska jama cave (Slovenia)
- Matevž Novak: Permian foraminifera *Sphaeroschwagerina carniolica*
- Miha Jeršek: Native mercury (Slovenia)
- Marko Simić: Planinska jama cave (Slovenia)
- Jure Žalohar: Miocene insect fossil (Slovenia)
- Branka Hlad: Pammukale travertine pools (Turkey)

CIP - Katložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

719:55(4-12)(063)

REGIONAL Conference on Geoconservation (12 ; 2007 ; Ljubljana)
Geological heritage in the South-European Europe. Field guide /
The 12th Regional Conference on Geoconservation and ProGEO Working
Group 1 Annual Meeting, Ljubljana, Slovenia, 5-9 September 2007 ;
[edited by Branka Hlad and Uroš Herlec]. - Ljubljana : Agencija RS
za okolje = Environmental Agency of the Republic of Slovenia, 2007

ISBN 978-961-6024-36-5
1. Gl. stv. nasl. 2. Hlad, Branka 3. ProGEO Working Group 1. Annual
Meeting (2007 ; Ljubljana)
234714112

The 12th Regional Conference on Geoconservation and
ProGEO Working Group 1 Annual Meeting

GEOLOGICAL HERITAGE IN THE SOUTH-EASTERN EUROPE

Ljubljana, Slovenia
Wednesday 5th – Sunday 9th September 2007

FIELD GUIDE

The conference was organised by

Slovensko geološko društvo - Slovenian Geological Society
Agencija RS za okolje - Environmental Agency of the Republic of Slovenia
Zavod RS za varstvo narave - Institute of the Republic of Slovenia for Nature Conservation and
Geološki zavod Slovenije - Geological Survey of Slovenia

Acknowledgements

The conference would not be possible without the generous sponsorship and support of the following organisations:

Adria Airways d.d.
DDC svetovanje inženiring, Družba za svetovanje in inženiring, d.o.o.
British Council
RTH Rudnik Trbovlje Hrastnik, d.o.o.
IRGO Inštitut za rudarstvo, geotehnologijo in okolje
Inženiring za vode d.o.o.
TERMIT d.d.
RSCM-Gradbeni materiali d.o.o.
Rudnik živega srebra Idrija v zapiranju, d.o.o.
Občina Idrija
Javni zavod Park Škocjanske jame, Slovenija
Treking šport d.o.o.
Premogovnik Velenje d.d.
Zavod za gradbeništvo Slovenije
Kremen d.d. Novo mesto
Telekom Slovenije d.d.
MFC.2, družba za arhiviranje dokumentov, podatkov in informacij, d.o.o., Ljubljana
Slovenska turistična organizacija
GEONOVA d.o.o.
Mestna občina Ljubljana
Turizem Bled

Further information about the conference is available on http://arsis.net/circular/

CONTENTS

FIELDTRIP ITINERARY

Day 1: Friday, 7th September 2007
Departure from the conference venue at 16.00h, a 2 km walk will take us to the Castle Hill for a stop. After the visit of Ljubljana Castle, participants have a free evening.

Day 2: Saturday 8th September 2007
Departure from Ljubljana at 7.30. Journey will take us to Cerknica Jezero Lake. After a stop at Lake Cerknica jezero, we will make a short visit to the Planinsko polje and continue to Divača to visit the caves Škocjanske jame. In the afternoon we will visit tourist mercury mine in Idria. The dinner is at 20.00h in Idria, after that we return to Ljubljana and overnight.

Day 3: Sunday 9th September 2007
Departure from Ljubljana at 7.30. A travel towards north will take us through gorge Dovžanova soteska. We than turn into northeast direction travelling to tourist lead and zinc mine Mežica and outcrops Čofatijev vrh in Topla valley. The dinner is in Črna na Koroškem at 19.00.

Trip leaders:
Ljubljana trip: Barbara Zupanc and Maruša Markovčič (Municipality of Ljubljana), Dr. Tea Kolar Jurkovšek (Geological Survey of Slovenia), Dr. Bogomir Celarc, Marko Simić (Environmental Agency of Slovenia), Dr. Andrej Mihevc (Karst Research Institute)
Karst trips: Dr. Andrej Mihevc (Institute for Karst Research), Marko Simić (Environmental Agency of Slovenia)
Idria mine: Bojan Režun (Idria mine), Dr. Uroš Herlec (University of Ljubljana)
Dovžanova soteska: Dr. Matevž Novak (Geological Survey)
Mežica mine: Dr. Uroš Herlec (Ljubljana University), Dr. Marko Vrabec (Ljubljana University), Mag. Suzana Fajmut Štrucl (Mežica mine)

Please note that this field guide includes some sites that we will not have time to visit on this trip. However they have been included to give those who may have the opportunity in the future to explore in grater depth the geological heritage of Slovenia.

SHORT OUTLINE OF GEOLOGY OF SLOVENIA

By Simon Pirc

Slovenia is situated on the contact of tectonic units of the Eastern Alps, Dinarides, Adriatic Foothills and the Pannonian Basin.

The Eastern Alps consist of metamorphic Paleozoic that is overlain by Mesozoic rocks in two belts, the northern one that belongs to the Northern Limestone Alps, and the southern, called the Drava belt, comprising the North Karavanke Mountains. Tertiary rocks are deposited in Mežica and Mislinja valleys and in N of the Pohorje Mts. The metamorphic basement was overthrust northward during Younger Paleozoic and Older Tertiary. The North Karavanke, however, were thrust northward on Paleozoic and Tertiary beds after Miocene.

The Eastern Alps are separated from the Dinarides by the Periadriatic Lineament. The Dinarides consist of the Southern Alps, the Outer and the Inner Dinarides subunits. They are characterized by large nappes of Mesozoic carbonates overthrust one above the other. South of the Periadriatic Lineament extend the Southern Limestone Alps. They comprise the South Karavanke, Julian, Kamnik-Savinja Alps and their eastward extensions into the Pannonian Basin, where they are covered with extensive deposition of Tertiary beds, some of the Alpine foothills and the Sava Folds tectonic unit. The almost unmetamorphosed Paleozoic is overlain by Mesozoic and Tertiary beds. The Mesozoic rocks were deposited in shallow water of the Julian carbonate platform, and in the deeper water Slovenian Basin. Tertiary beds fill the Ljubljana and Celje Basins and occur in smaller patches in the mountains. The nappes formed mostly between Eocene and Middle Oligocene. Owing to the thrust from N to S the structural elements strike W-E.
The Paleozoic rocks in Southern Alps are the basement for a larger nappe that consists of Mesozoic deposits of the Slovenian Basin. On it was overthrust the Julian nappe consisting prevailingly of rocks of the Julian carbonate platform.

The Southern Alps borders to the southerly lying Outer and Inner Dinarides along the Southern-Alpine Overthrust Front. The Outer Dinarides consist of deposits of the Mesozoic Dinaric Carbonate Platform, and the Inner Dinarides of contemporary deposits in a deeper Mesozoic Sea. The extent of the platform varied through Mesozoic which resulted in a Transition Zone between the Outer and Inner Dinarides. According to some geologists the Slovenian Basin and the Transition Zone are attributed to Inner Dinarides. The Dinarides are characterized by nappe structure thrusted to SW in the Upper Eocene and at transition Eocene/Oligocene. The Outer Dinarides themselves are thrust over the Adriatic Foothills which are a weakly deformed foreland of the Dinaric thrusts.

The forming of structure of Slovenia is connected with the development of the Tethys Ocean and its contraction during Mesozoic and Cenozoic as a result of approaching of the African and European Lithospheric Plates. In this, an important role was played by intermediate microplates, among others the Adriatic Plate. In the Outer Dinarides extensive deposition of flysch continued from Upper Cretaceous to Eocene times.

In addition to the nappe structure are important several dislocations with horizontal and vertical shifts. The most important is the W-E striking Periadriatic Tectonic Zone. The Periadriatic igneous rocks in the wider zone of the Periadriatic Lineament were emplaced at various times, and are associated with genesis of the lineament. Its easterly continuation might be the Balaton Lineament in Hungary. A second broad fault zone passes WSW-ENE in a broad belt east-central Slovenia towards central Hungary (Central Hungarian Tectonic Zone). The third, the Idrija tectonic zone comprises faults of NW-SE strike in the Outer Dinarides. All three tectonic fault zones form a triangle in which the structure of the Sava Folds was formed.

Typical for Slovenia is extensive development of karst. About 40% of country surface consists of karstified carbonate rocks of predominantly Mesozoic age. The karst phenomenon was first studied on the Slovenian territory, and even the term karst is derived from the name of the Kras region in western Slovenia.

In Slovenia occur deposits of mercury, lead and zinc, antimony, uranium, copper, iron and manganese ores. In the Idrija mercury deposit cinnabar and elementary mercury were emplaced during Middle Triassic igneous-tectonic activity. Mineralized were Upper Paleozoic and Lower and Middle Triassic sedimentary rocks. The now closed Idrija mine was second only to Spanish Almaden with respect to mercury produced - about 140.000 tons in 500 years of operation. Mercury was mined also at Podljubelj in the S Karavanke Mts.

The most important lead and zinc deposits in Slovenia are at Mežica in North Karavanke. Mineralized are Middle Triassic carbonate rocks with about 5% total Pb and Zn. Of economic importance were galena and sphalerite. Galena is without admixtures, and sphalerite contains some cadmium and germanium.
Molybdenum concentrate was produced from wulfenite. Lead ore was mined also in the Sava Folds, especially at Litija. Numerous ore veins cut the Younger Paleozoic beds in which also sedimentary exhalative ore was observed. Mineral association is very rich; next to numerous sulfides ore contains also sulfosalts. From ore veins in Carboniferous beds at Trojane the antimony ore with antimonite as main ore mineral was produced. The Middle Permian sandstone at Žirovski vrh contains pitchblende and coffinite as ore minerals, disseminated in cement of sandstones. The ore grade was on an average 850 g/t U_3O_8. In the upper part of Middle Permian sandstone the Škofje deposit contains chalcopyrite, bornite and chalcosite that were deposited in pores of sandstone. Between Jesenice and Tržic and at Vitanje in Southern Karavanke occurs in Carboniferous beds iron ore that contains mostly siderite. The mineral was deposited most probably during sedimentation. Limonitic kidney iron ore occurs in the Southern Alps and Dinarides. Manganese ore occurs in places in Jurassic beds.

In Slovenia, iron has been mined since prehistoric times, mercury since 1490, lead and zinc the last 350 years. In more recent times, also copper, antimony, manganese and uranium were mined. At present, however, no ore is extracted in Slovenia.

In Slovenia deposits of about 30 non-metallic commodities were discovered: quartz sand, chert, vein quartz, quartz conglomerate, quartz sandstone, quartz gravel, lake chalk, puzzolanic tuff, zeolitic tuff; bentonite, ceramic and brick clay, kaolin (illite), barite, feldspars, mica, natural mineral pigments, raw material for mineral wool, gypsum, anhydrite, soapstone, graphite, fluorite, limestone, dolomite, marl, sand and gravel (carbonatic), granodiorite, calcite (marmorized limestone), abrasive aggregates of keratophyre, diabase, porphyry and porphyrite. Presently, only quartz sand, chert, calcite, lake chalk, ceramic clay and tuff are produced. The extraction of construction materials, however, is booming, and it covers the needs of the fast developing country.

Slovenian coals contain from 65% C (Velenje lignite) over 75% C (Secovlje bituminous coal) to 94% C (Orle anthracite). At present are mined only lignite at Velenje with 4 millions tons and brown coal at Trbovlje-Hrastnik with about 600.000 millions tons of yearly production, as for 2003. Insignificant oil and natural gas are still produced in the Lendava oil-field from Late Tertiary beds of the Pannonian basin.

FIELDTRIP 1: GEOLOGY AND GEOSITES OF LJUBLJANA AREA

STOP 1 (a): Castle Hill in Ljubljana

LJUBLJANA MOOR THROUGH GEOLOGIC HISTORY

According to the Guidebook, Ljubljansko Barje through Geological Periods, written by Jernej Pavšič (1989)

Ljubljana Moor is a wide tectonic depression which was formed about two million years ago. The surface is mainly flat, with the exception of a few protruding isolated hills. It is crossed by numerous streams few of which remain natural.

Ljubljana Moor was formed by subsidence of an extended part of the Ljubljana Basin and at a later stage the Ljubljana Field north from Ljubljana and the Ljubljana Moor south from it. The Ljubljana Basin broadly comprises the entire subsided area, which is almost 40 km long and relativelly flat area from Ljubljana to Jesenice. In the narrower sense these names: Ljubljana Field and Ljubljana Moor are used for a territory close to the capital city of Slovenia. The broader basin was formed as a result of the strikeslip tectonics since some 30 million years ago, while the Ljubljana Field and the Ljubljana Moor are younger, dating from only about two million years ago. The Moor is dissected by numerous normal faults. Along the principal faults individual tectonic blocks were depressed. However not all the blocks did subside at the same time and at the same rate. The pattern of faults is relatively dense and largely not mapped since they are not easy to locate below the deep cover of sediments. They can only be reliably established by drilling, or by geophysics. The Moor is deepest in its southeast part (117 m). Some parts of the Moor basement rise above the younger sedimentary beds. These are the isolated hills. Their geological composition is similar to the borderland. Should one remove the sedimentary cover which currently fills at present the Moor basin, an agitated relief would be revealed? The rate of subsidence was relatively high at approximately 1 m in 500 years.

The drainage system of the Moor is quite dense. The streams come both from nearby typical karstic resurgences, such as the sources of Ljubljanica, Bistra and Ižica as well as from distant areas, reaching the Moor as surface streams such as Iška, Borovniščica, Želimeljščica, Škofeljščica and other smaller creeks. The Ljubljanica River carries its sedimentary load mainly in the form of dissolved limestone and therefore deposits little sediment. However the surface streams carry large quantities of gravel and sand, especially in spring and in autumn, and can deposit them in quick time over large areas. In this way the Ljubljana Moor has been filled with gravel by surface streams over thousands of years but during periodic lacustrine periods it was filled with silt and clay. The central base of the Moor subsided quickly due to this new sedimentary load whilst the rims were stable and perhaps even raised somewhat.

Knowledge of the depositional succession in the Ljubljana Moor enables the reconstruction of ancient environments. It can be seen that conditions changed fast. Sometimes the Moor was a vast gravel plain with interspersed water surfaces and at other times it was either a more or less a shallow lake with rich fauna and flora or an uncrossable turf swamp. During the deposition of the sedimentary beds of the Moor there were at least three occasions when the conditions were favourable for the formation of peat. The youngest and deepest peat seen near the surface was formed during the last lacustrine stage. This was the time of fascine dwellers. Where the thickness of the peat allows it has been excavated and used by the local population for heating as well as by various industries in and around Ljubljana. Today the peat seam is partially preserved near Bevke and south of the Grmez and Babna Gorica hills. Below the peat layer a whitish clay can be observed in ditch banks. This is the "snail clay" (polžarica) found throughout the Moor and a good indication of the ancient lake and its rich fauna.

The oldest sedimentary beds, just above a rocky basement were deposited about 400,000 years ago, and are attributed to the Mindel glaciation period. Overlaying beds at a depth of 90 meters belong to the interglacial periods between Mindel and Riss periods. Sediments from more than 70 meters deep boreholes were proved to be approximately 100,000 years old. From 44 meters upwards are overlaid by fine grained sands and silts deposited during youngest – the Wurm glacial period around 50,000 years ago. Upper 10 meters of youngest sediments are less than 4,000 years old and are result of the sedimentation during the Holocene.

The age of the oldest beds of the Moor has been determined by pollen analysis of flora during the Ice Age (Pleistocene). Ljubljana Moor was never glaciated and consequently always had a vegetation cover in which species would have changed depending on the temperature. During glaciations when a cold climate prevailed, the dominant species were mostly conifers, fir and spruce whilst in the warmer interglacial periods deciduous trees were abundant.

Most of Pleistocene mammifer finds and associated tools of Ice Age man come from cave localities and random gravel pits. In the Moor these remains are extremely scarce. The oldest bone remains were found on the Pleistocene terrace and include a jaw-bone of the Lower Pleistocene (Mindel) elk *Libralces aff. gallicus.* A second find which also indicates the glacial character of the surrounding loam was the antlers of the tundra reindeer *(Rangifer* sp.). Other historical finds include remains from numerous animals still living still today; exceptions being just aurochs *(Bos),* beaver *(Castor fiber),* lynx *(Felis lynx)* and elk *(Alces alces)*. With arrival of man on the Moor, undisturbed natural evolution of the Moor was terminated. The swampy area was farmed and settled. From Roman times until today many generations have attempted to drain the Moor without complete success. One of the most effective projects was the construction of the Gruber channel in 1780 and the removal of ancient mill dams along the Ljubljanica River.

Remains of the original moor can be found at the foot of the Kostanjevica hill where swampy meadow is overgrown with vegetation in which peat moss *(Sphagnum)* prevails.

The Ljubljanica River flows far before surfacing at the edge the Moor commencing at the slopes of Javorniki, Snežnik and Risnjak. On its journey it has created unique natural features like karst poljes and numerous caves with the latter offering shelter to many special animal species such as the famous proteus.

Figure 3: Landscape of Ljubljana Barje Moor with Ljubljanica River. Aerial photo: Marko Simić

GEOLOGICAL STRUCTURE OF THE LJUBLJANSKO BARJE (LJUBLJANA MOOR) BASIN

Bogomir Celarc, Geological Survey of Slovenia

The tectonically predisposed Ljubljansko Barje Basin (180 square kilometres) is situated south of Ljubljana and contains 170m of Quaternary sediments (Mencej, 1988). The depression is roughly rectangular in NE – SW direction. The structure of the pre-Quaternary surface shows that the basin subsided in line with normal faults orientated NE-SW and connected with NNW-SSE aligned dextral strike slip faults which are parallel to the regionally important Žužemberk Fault or merge with Idria Fault (Vrabec, 2001) all pointing to the divergent origin of the basin. The flat surface of the central part of the Ljubljansko Barje Basin indicates ongoing subsidence. In the southern, western and central parts the basement consists of shallow water Upper Triassic dolomite (Main Dolomite) and Jurassic limestone whilst in the northern and eastern parts, of Triassic and Permo-Carboniferous shale and sandstone belonging to the External Dinarides (Buser et al., 1967). Permo-Carboniferous rocks are thrust over the Triassic and Jurassic lithological units in the north – central part of the basin. Thrust contact is locally displaced along NW-SE trending strike-slip faults. With numerous boreholes and geophysical research it has been proved that the western part of the basin has subsided less than eastern with the result that the basement surface consists of local depressions connected with intermediary ridges. This kind of pattern explains the differential subsidence between NW – SE directed local strike slip faults.

The formation of the Ljubljansko Barje depression started in the Middle Pleistocene (Šifrer, 1984). In the lower and middle part the basin is filled with gravel and sandy sediments of alluvial fans which are important collectors of underground water. In the upper part, lacustrine and swamp clay sediments of the Holocene age (Šifrer, 1984) prevail. At the edges of the basin, alluvial gravel fans of local streams intermingle with lacustrine and swamp sediments. Because of the relatively good protection from surface pollution, ground water in gravel aquifers represents an important source of drinking water. The southern edge of the Ljubljansko Barje Basin consists of numerous Karst springs and the important Ljubljanica River which, after some surface and subsurface flow in the karstic area of SW Slovenia, finally reappears in the Vrhnika area.

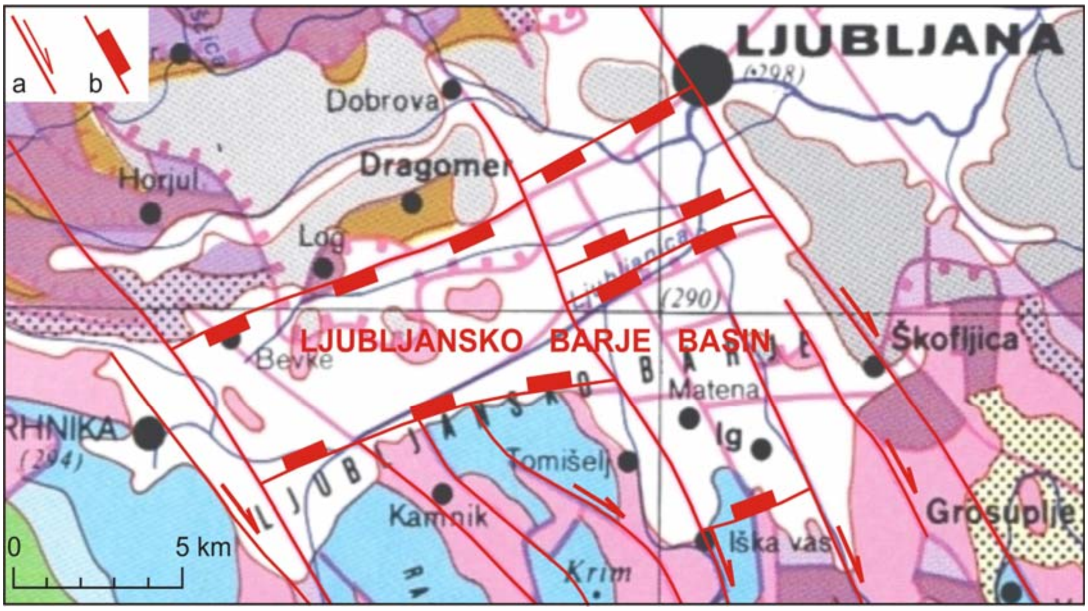


Figure 1. Structural map of the Ljubljansko Barje Basin. Modified from the Geological map of Slovenia after Buser & Draksler (1990); structural elements partly after Vrabec (2001). Quaternary sediments are represented in white; other colours indicate lithological units of the Late Palaeozoic and Mesozoic age. a) Strike slip fault. b) Normal fault.

References:
Buser, S., Grad, K. & Pleničar, M., 1967: Osnovna geološka karta SFRJ, list Postojna, 1:100.000. Zvezni geološki zavod. Beograd.
Buser, S. & Draksler, V. 1990: Slovenija, Geološka karta 1: 500.000. Geodetski zavod Slovenije.
Mencej, Z., 1988: Prodni zasipi pod jezerskimi sedimenti Ljubljanskega barja. Geologija, 31-32, 517-553.
Šifrer, M., 1984: Nova dognanja o geomorfološkem razvoju Ljubljanskega Barja. – Geografski zbornik, 23, 8-48.
Vrabec, M., 2001: Strukturna analiza cone Savskega preloma med Trstenikom in Stahovico. – PhD thesis, 94 pp., Ljubljana.

STOP 1 (b): Castle Hill in Ljubljana

LATE CARBONIFEROUS MEGAFLORA

Tea Kolar-Jurkovšek & Bogdan Jurkovšek, Geological Survey of Slovenia

The Late Paleozoic beds of the Sava Folds are composed of quartz conglomerate, sandstone, siltstone and shaly claystone. Reports of their macroflora contents were known already in the nineteenth century. Among others, Morlot (1850) mentioned the species *Neuropteris tenuifolia* Schlotheim from Carboniferous shale of the Ljubljana Castle Hill. Plant fossils were later recorded in a wider Sava Folds region, especially in the surroundings of Litija (Lipold, 1857, 1858; Tornquist, 1929). Towards the end of the twentieth century followed a period of systematic studies of Paleozoic flora in more than forty localities between Ljubljana and Polšnik (Kolar-Jurkovšek & Jurkovšek, 1985, 1986, 1990). The Paleozoic sequence of the Sava Folds Paleozoic beds can be subdivided into three first-order superposition units that might represent three formations, or members of the same formation (Mlakar, 1987, 1994; Mlakar et al., 1993). Based on paleontological data the age of the b2 superposition unit can be precisely dated with megaflora in a number of localities between Mamolj and Janče (Kolar-Jurkovšek & Jurkovšek, 2002a, 2002b, 2004).

During the most recent study Late Carboniferous megaflora was collected at the Ljubljana Castle Hill which represents the westernmost locality in the Sava Folds (Kolar-Jurkovšek & Jurkovšek, 2007). The list of determined taxa includes:

Calamites (Mesocalamites) cf. *ramifer* Stur
Calamites (Mesocalamites) roemeri Goeppert
Calamites (Mesocalamites) cf. *roemeri* Goeppert
Calamites (Mesocalamites) cf. cistiiformis Stur
Calamites (Stylocalamites) undulatus Sternberg
Calamites sp.
Lepidodendron sp.
? Asolanus sp.
Sigillaria sp. (Syringodendron – Rhytidolepis group)
Stigmaria ficoides (Sternberg) Brongniart
Cyperites bicarinatus Lindley & Hutton
Eusphenopteris sp.
Neuropteris tenuifolia Schlotheim
Neuropteris cf. heterophylla Brongniart
Neuropteris sp.
Linopteris sp.
Trigonocarpus sp.
Noeggerathia sp.
Cordaites palmaeformis (Goeppert)
Cordaites principalis (Germar)
Cordaites sp.

The Westphalian age of the recovered fossil plant assemblage of the Ljubljana Castle Hill is based on the presence of mesocalamitic forms and certain neuropterid species, especially *Neuropteris tenuifolia* which occurs only in Westphalian. The flora is demostrated by prevailing articulates *(Calamites)* and pteridosperms *(Neuropteris, Linopteris)* accompanied by rarer lycopsids *(Lepidodendron, Sigillaria, Cyperites)* and cordaitaleans *(Cordaites).*

The collected plant assemblages of the Sava Folds correspond to the general features of the Euramerian flora that extended during Upper Carboniferous over the regions of present North America across Europe to Asia. Collected elements indicate the hydrophyle to hygrophyle flora that populated wet habitats of the swampy environments. The plants flourished in a warm and humid climate without appreciable seasonal temperature oscillations, which would correspond to the present subtropical or tropical conditions.

Figure 1: Reconstruction of the Late Carboniferous landscape (by Barbara Jurkovšek).

References:
Kolar-Jurkovšek, T. & Jurkovšek B.
1985: Nova nahajališča paleozojske flore v Posavskih gubah med Ljubljano in Litijo. - Razprave IV. razr. SAZU, 26, 199-218, Ljubljana.
1986: Karbonska (westfalijska) makroflora iz Zavrstnika. - Rud.-metal. zbor., 33/1-2, 3-34, Ljubljana.
1990: Karbonska makroflora med Jančami in Polšnikom v Posavskih gubah. - Rud.-metal. zbor., 37/3, 367-389.
2002a: Karbonski gozd. Karbonske plasti z rastlinskimi fosili pri Ljubljani. - Geološki zavod Slovenije, 191 str., Ljubljana.
2002b: Rastlinski fosili v karbonskih plasteh na trasi avtoceste pri Bizoviku. - Geologija, 45/2, 433-438, Ljubljana.
2004: Carboniferous flora of central Slovenia. - V: 32nd International Geological Congress, Florence, Italy, August 20-28, Florence.
2007: Zgornjekarbonska flora Grajskega hriba v Ljubljani / Late Carboniferous flora of Castle Hill in Ljubljana (Slovenia). - Geologija, 50/1, 9-17, Ljubljana.
Lipold, M.V. 1857: Bericht über die geologischen Aufnahmen in Oberkrain im Jahre 1856. - Jb. geol. R.-A., 8, 205-234, Wien.
Lipold, M.V. 1858: Bericht über die geologischen Aufnahmen in Unter-Krain im Jahre 1857. - Jb. geol. R.-A., 257-276, Wien.
Mlakar, I. 1987: Prispevek k poznavanju geološke zgradbe Posavskih gub in njihovega južnega obrobja. - Geologija, 28/29 (1985/86), 157-182, Ljubljana.

Mlakar, I. 1994: O problematiki Litijskega rudnega polja. - Geologija, 36 (1993), 249-338, Ljubljana.
Mlakar, I., Skaberne, D. & Drovenik, M. 1993: O geološki zgradbi in orudenju v karbonskih kameninah severno od Litije. - Geologija, 35 (1992), 229-286, Ljubljana.
Morlot, A.v. 1850: Über die geologischen Verhältnisse von Oberkrain. - Jb. Geol. R.-A., 389-411, Wien.
Tornquist, A. 1929: Die Blei-Zinklagestätte der Savefalten vom Typus Litija (Littai). - Berg und Hüttenmann. Jb., 77/1, 1-28, Wien.

NATIONALLY IMPORTANT GEOSITES IN THE LJUBLJANA MOOR SURROUNDINGS

Karstic lake Jezero. On the southern edge of the *Ljubljansko Barje* (Ljubljana Moor) near the village *Podpeč* up 10 m high dolomite ridge is separating the *Ljubljansko Barje* from a small closed oval shaped valley beneath *Krim* karst massif. Like the main part of *Ljubljansko Barje* a separated depression is filled with the sediments. They dam up the limestones of the karst hinterland so at the contact along the southern border of the depression there are several karst sprigs. From the springs the stream meanders to the karst lake *Jezero* in the northern part of the depression. The oval lake measuring between 120 and 135 m in diameter has no surface outlet. In the cross section it is funnel-shaped with a sinkhole at the bottom. The cave divers penetrated the vertical pit at the bottom to a depth of 46 m. After long and heavy rain when underground passages can not swallow all the water emerging at the karst springs the alluvial plane gets flooded. The lake Jezero has underground water connection with karst springs of Hruški potok, located at the border of the main Ljubljansko Barje depression some 300 m in a straight line from the lake. Hruški potok is a tributary of the Ljubljanica, what makes karst Jezero a part of Ljubljanica river karst system. In the past there were plans to cut a water passage trough the dolomite ridge and to drain the lake and alluvial plane. Fortunately that didn't happen and today the closed depression, karst springs and the karst lake are protected as a natural monument.

Karstic lake Jezero. Photo: Marko Simić

Karst uvala Ponikve. In the hinterland of Ljubljansko barje (Ljubljana moor), south of the village Preserje, there is a periodically flooded karst uvala Ponikve. It is relatively small (16 ha) but otherwise it has all the characteristics of the overflow karst polje. Beneath the south edge of the closed depression there are several karst springs where groundwater originating from karst massif of Krim and from sinkholes of Rakitna polje comes to light. Permanent and the most abundant spring is located in the southeastern edge of polje just below the Ponikvar farm. From there a creek crosses polje in picturesque meanders. There is also a tributary with the springs along the western part of polje. On the northern edge of karst polje, there are swallow holes in the alluvium covering limestone bedrock. After rain, when the amount of water exceeds the capacity of first sinkholes, the surface river extends towards the northern part of the alluvial plane. If the water inflow exceeds the sinking capabilities of the swallow holes, which happens several times a year, the whole alluvial plane is flooded. Sinking water flows underground for about 1200 m and reappears in karst springs of the tributary of the Ljubljanica on the edge of Ljubljansko Barje, what makes karst uvala Ponikve a part of Ljubljanica river karst system.

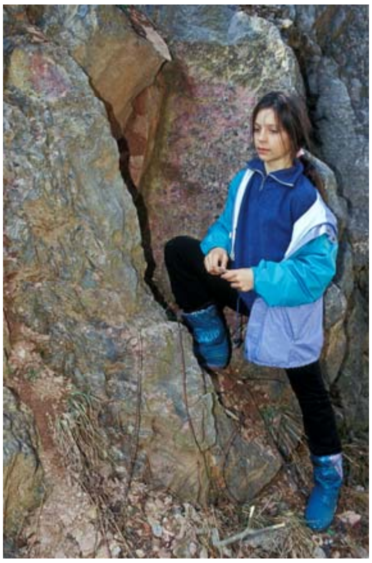
Karst uvala Ponikve. Photo: Marko Simić

Drenov Grič Quarry. In Slovenia many varieties of sedimentary rocks from the Triassic are preserved. They were deposited in seas of varying depths, some even in fresh water environments. In general limestones and dolomites prevail while other sedimentary rocks occur only subordinately. In the abandoned quarries of Drenov grič black limestone occurs interbedded with marly sheets of Upper Triassic as well as a profusion of various well preserved fossil shells.

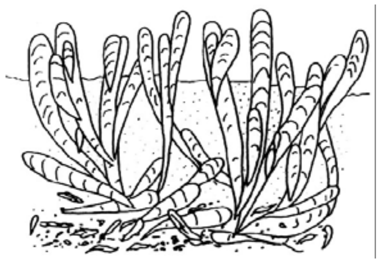
The quarry is protected as a natural monument.

Drenov Grič Quarry. Photo: Marko Simić

Podpeč Quarry. Lower Jurassic beds are widespread along the southern edge of the Ljubljansko Barje Moor. They are best exposed and studied in the Podpeč Quarry where in the upper part of the Liassic beds interesting bivalve fossils occur. The quarry was opened already in the Roman times, and the best quality ornamental stone was the reason, that Romans diverted the Ljubljanica River by an artificial channel closer to the village Podpeč. This enabled the transport of stone by boats to Emona. Roman settlement was located in the central area of modern Ljubljana. Within the Podpeč Quarry several limestone beds are composed of large mollusc shells *Pachymegalodus chamaeformis*, foraminifera *Orbitopsella praecursor,* brachiopods of genera *Terebratulla* and *Rhynchonella*. Podpeč ornamental stone became famous for embedded of white lithiotid shells into dark grey to almost black biomicritic limestone. Among Lithiotidae bivalves the most common genera in this quarry is *Lithioperna*. White bivalve remains of lithiotid shells give to this dark limestone a special appearance. Fashioned and polished can be admired in many buildings in Ljubljana today.



Outcrop with lithiotid bivalves in the Podpeč Quarry which is protected as a natural monument. Photo: Marko Simić



Growth position of the bivalve of genera *Lithiotis* (S. Buser, I. Debeljak)

Paleogeografic distribution of the genera *Lithiotis* bivalves and their probable migration routs.

According to: Broglio Loriga & Neri, 1976 in Nauss & Smith, 1988 (Buser, S., & Debeljak, I. 1996)

FIELDTRIP 2: GEOSITES OF KARSTIC LJUBLJANA RIVER

THE BASIC INFORMATION ON LJUBLJANICA RIVER SYSTEM

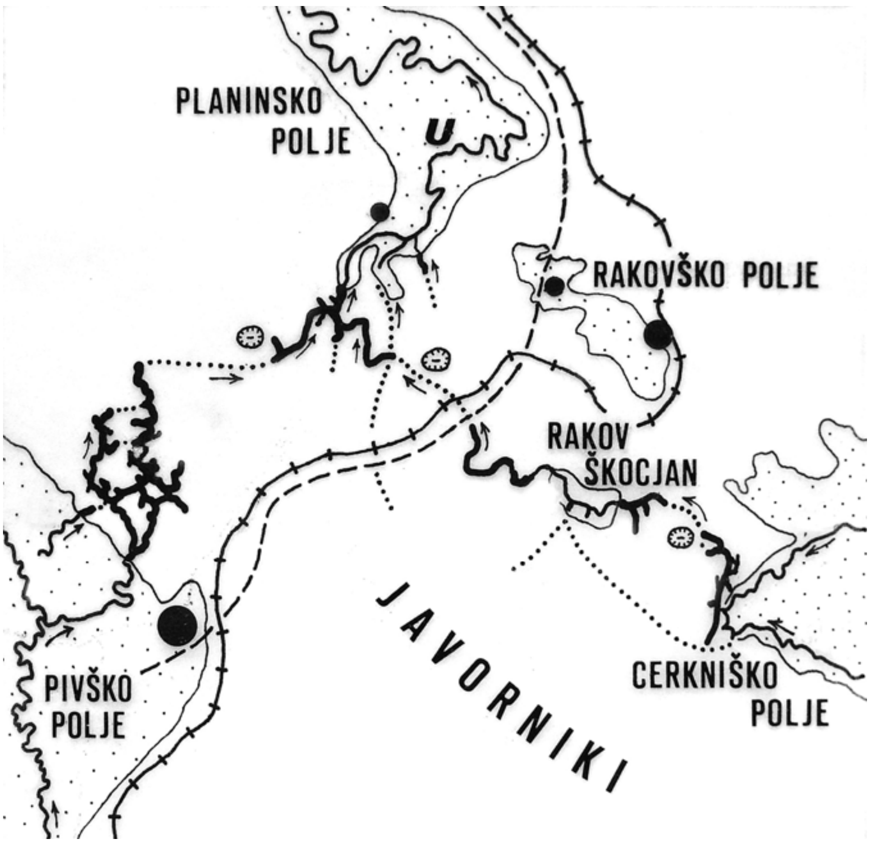
Marko Simić, Environmental Agency of the Republic of Slovenia

Brief description of Ljubljanica River

Beneath Mount *Snežnik* (1796 m) in southern Slovenia, a very special river with seven names has its springs. How can a river have seven different names? In the geological past the river flowed uninterrupted, but after a period of intesive karstfication the waterflow desintegrated into surface and underground karst passages, with each surface section having its own name; hence the (at least) seven names.

The river is generally known as *Ljubljanica* which is the name of the last surface section, flowing through *Ljubljana* and reaching the confluence with Sava some 5 kilometers east of the Slovenian capital. The *Ljubljanica* River basin has an area of 2066 km^2 which is roughly one tenth of the total area of Slovenia.

In plan the river system has the form of the letter Y. In the upper part of the river system there are two branches, Cerknica and Pivka, which meet in the cave *Planinska jama*. They are separated by the vast *Javorniki* and *Snežnik*, uninhabited and densely wooded (mostly Abieti-Fagetum dinaricum) karst mountains.



Map of the Notranjska cave triangle, Source: Smerdu, R., 1984: Od izvirov do izliva Ljubljanice. Proteus 46/6: 216-221.

The eastern **Cerknica branch** follows the famous Idria fault with its string of karst poljes. The river has a surface flow on karst poljes with an underground flow between them. The start of the Cerknica branch is the karst spring *Trbuhovica*, emerging south of *Prezid* in Croatia. After a short surface flow water reaches a ponor and reappears in the resurgence *Vrhniški Obrh* on *Loško polje* which is in Slovenia already. After passing Loško polje the river is called *Obrh* and disappears in sinkholes and ponor cave *Golobina* situated on northwestern border of Loško polje. After about 2 km the underground river reaches the eastern border of

Cerkniško polje at the karst springs of *Obrh*. The river now named *Stržen*, crosses a polje which has an area of 35 km^2 and reaches numerous sinkholes and caves on the western border of *Cerkniško polje*. There are two main ponor caves, *Velika* and *Mala Karlovica* with a combined length of 9,5 km.

At high water a periodical lake with an area of up to 26 km^2 is formed on *Cerkniško polje*. The polje is very important from an ornithological point of wiew.

Photo: Marko Simić

Cerkniško polje in summer drought. Photo Marko Simić

Photo Peter Skoberne

After some distance the stream reappears in the karst valley *Rakov Škocjan*, where a small stream *Rak* springs from the *Zelške jame* (total length over 4,7 km) and disappears in *Tkalca jama* (2,9 km of passages). On both sides of the 2,5 km long valley there are signs of collapsing cave ceilings. On the eastern part there are numerous collapsed dolinas in last section of *Zelške jame*. Two of them are divided by a *Mali naravni most* (Small natural bridge), the narrow leftover strip of the cave ceiling some 40 m above the stream below.

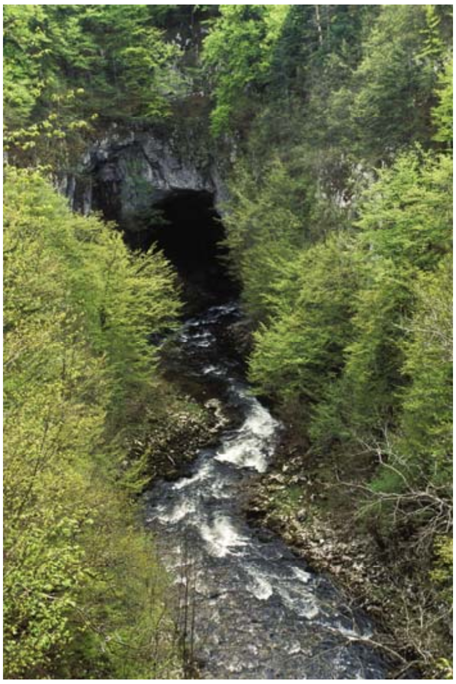
On the western part of the valley there is *Veliki naravni most* (Great natural bridge) followed by a nearly 40 m deep gorge.

The rock face with a large entrance to *Tkalca jama* closes the gorge on the east side.

Rakov Škocjan is unique because in a very small area it contains in a concentrated and beautifully illustrated manner, almost all of the classic karst features; sinking and ponor water caves, karst valleys, collapsed dolinas, karst springs, sink holes, natural bridges …a true natural museum.

Veliki naravni most (Great natural bridge). Photo: Marko Simić

From *Tkalca jama* in *Rakov Škocjan* the Cerknica branch flows through unexplored water filled passages towards cave *Planinska jama*.



Entrance into Tkalca jama cave. Photo Marko Simić

Planinska jama cave. Photo Marko Simić and Rafko Urankar

The Pivka branch has springs east of *Snežnik*, few kilometers north of *Knežak*.

The *Pivka* River meanders northwards and after confluence with *Nanoščica* reaches the northern border of the *Pivka* polje.

Nanoščica River. Aerial photo Marko Simić

There the *Pivka* River formed the world famous beautiful *Postojnska jama* cave system which, with some 20,5 km of explored passages, is the longest cave system in Slovenia and consists of five separate caves (*Postojnska jama*, *Pivka jama*, *Črna jama*, *Otoška jama*, *Magdalena jama*), interconnected by water passages. The final sump of *Postojnska jama* system drains water in the direction of *Planinska jama* cave.

Postojnska jama is a world famous show cave. In almost two hundred years of tourist activity, the cave installed electric lighting (in 1884), a cave railway (hand driven in 1872 and locomotive driven in 1914) and has been visited by over 30 millions of tourists. At present it has more then a half a million visitors per year and is now the most visited natural monument in Slovenia.

Planinska jama cave has two main water passages, each with one of the *Ljubljanica* River branches. *Rak* passage gets its water from *Tkalca jama* in *Rakov Škocjan* and in *Pivka* pasage a water emerges from the final sump of Postojnska jama system. There is a picturesque underground conjunction in the cave and after short underground flow, the river *Unica* leaves the cave through a spectacular cave entrance below a rock face before reaching *Planisko polje*. The total length of explored cave passages is over 6,5 km.

The area between the western edge of *Cerkniško polje*, the northern boundary of *Pivka* polje and the southwestern border of the *Planinsko polje* is the Notranjska cave triangle. It measures approximately 6 x 10 x 8 km on the surface with almost 45 km of explored cave passages. The *Postojnska jama* and *Planinska jama* cave system (20,5 km + 6,5 km, connected by 2 km of flooded unexplored passages) have particullary rich cave fauna. With 84 species of cave animals (35 in the dry parts of the system and 49 in aquatic part) it is the richest cave system in the world. The Notranjska cave triangle is a cradle of speleology and biospeleology.

The first described troglobionte species, the cave beetle *Leptodirus hochenwartii* and the first cave spider *Stalita taenaria* were found in Postojnska jama cave system.

The European cave salamander *Proteus anguinus* was first seen in its natural habitat in Črna jama in 1797. The Postojnska – Planinska cave system is the original location for 37 species of cave animals.

Leptodirus hochenwartii. Photo Peter Skoberne

Proteus anguinus. Photo Peter Skoberne

Planinsko polje is regarded as the holotype of a polje and is a world famous example of a perfect and well preserved karst polje. Unlike the famous *Cerkniško polje* it is a completely enclosed depression with area of 11 km^2 and it has exclusively karstic influx (from caves and karst springs) and outflow (through sinkholes and ponors). After disappearing in the limestone border of *Planinsko polje* underground water passages can be reached in the important caves of *Logarček*, *Najdena jama* and *Gradišnica*.
Near *Vrhnika*, 20 kilometers southwest from *Ljubljana*, there used to be a sign with the inscription "The carst begins here". At the beginning (or the end of the karst, from the *Ljubljanica* River point of view) sediments filling the tectonic depression *Ljubljansko Barje* dam up the limestones so at contact there are numerous karst springs where the *Ljubljanica* appears at the surface for the last time. It is worth mentioning that being almost

exclusively a karst river, *Ljubljanica*, as it passes through *Ljubljana*, carries very little sediment. It is however carrying a few kilograms of dissolved limestone every second (with mean water quantity sQs around 55 m^3/s), a process that is slowly lowering the karst in catchment area.

Flooded Planinsko polje. Photo Marko Simić

History of the nature conservation of the area and major conservation challenges

For a very long time, the local population living on the edges of *Cerkniško* and *Planinsko* poljes has been trying hard to lessen flooding, if not to completely eradicate it. For that purpose the stream beds were regulated, sinking holes cleaned and narrows in the ponor caves widened. As a result flooding was only slightly diminished and agricultural use of poljes remained quite limited. During the last few decades hydroelectric interests in the *Ljubljanica* River prevailed with a plan to convert the *Cerkniško* and *Planinsko polje* into permanent accumulation lakes, guiding the water through tunnels to new hydroelectric plant located at *Verd*, near *Vrhnika*. Although the first initiative for protection of a big part of the system was published in 1967, the plans for hydroelectric use prompted the first serious nature conservation evaluation of the affected area. As a result the first outline proposal for establishing Notranjski Regional Park was prepared by the nature conservation authority in 1987. The basic idea was to ensure protection of the *Cerkniško* and *Planinsko polje* and the area above the Notranjsko cave triangle. The proposal entered a parliament procedure but was not adapted.

Despite the failure in the first attempt a new proposal was made ten years later. This time a big area of *Javorniki* and *Snežnik* between the branches of *Ljubljanica* was added to protect the habitat of big carnivorous animal species (brown bear, wolf and lynx). Finally a major part of *Pivka* polje was added to protect marshy areas along *Pivka* and *Nanoščica* rivers. At the official proposed Regional Park had an area of more then 800 km^2 within 6 communities in at least two historic regions. That was much more than a relatively weak nature conservation service could possibly manage in the process of establishing. It came not as surprise when after a few years of futile attempts to persuade communities that the park would be a benefit for each of them, the minister stopped a project in 2002. The consequences of the collapse of the most important nature protection project in Slovenia at the time are far reaching, as all the projects for the regional parks in Slovenia were stopped at the same time.

As a consequence only parts of the *Ljubljanica* River system are protected at the present. A part in the *Cerknica* community is protected under the official title *Notranjski Regijski Park*, established by community as an answer to a collapsed ambitious state project. Furthermore a karst valley *Rakov Škocjan* in *Cerknica* municipality is protected as natural monument since 1949 (only core zone without buffer zone which is essential for effective protection). Beside that a half of *Planinsko polje* (the part in municipality of *Postojna*) is protected and some of the major water caves *(Postojnska jama, Planinska jama)* are protected as natural monuments too.

Apart from caves and the highest parts of Snežnik there are no pristine nature areas in the *Ljubljanica* River system. Instead there is a cultural landscape, which was formed in hundreds of years of interaction between man and nature. The main human activity was extensive agriculture on periodically flooded poljes and their surroundings and prudent management of forests on demanding karst areas. So the major conservation and management challenge is how to maintain this landscape at a time when as a part of changing social economic times the human activity which formed and sustained a valuable cultural landscape is quickly disappearing. For instance: the local inhabitants are abandoning haymaking on meadows because a cattle breeding on small farms is becoming increasingly uneconomical. The undesired result is disappearance of the old cultural landscape with increasing reafforestation. The aggravating circumstance is the fact that neither Nature Conservation Act nor the Cultural Heritage Protection Act is a suitable tool for protection of cultural landscapes and quality landscapes in general. The Nature Conservation Act does not allow aesthetic criteria to be used. The problem then is how to protect “beautiful” landscapes with inadequate legislation.

Today a big part of the *Ljubljanica* karst river system is protected within the Natura 2000 network. Unfortunately the Natura 2000 legislation provides adequate protection only for habitats and birds. The valuable cultural landscape is left mainly without protection.

The *Ljubljanica* karst river system is vulnerable to changes in *Ljubljanica* water quality and quantity. This is especially true for caves and underground habitats in general. Unfortunately the *Ljubljanica* is burdened with effluents from numerous settlements within the catchment area and with pollution from agriculture use. In addition there are numerous transport corridors crossing the area; for example near *Postojna* there are major motorways and main highways as well an international main railway line; in fact a new, high speed railway is planned. There is a constant threat of heavy pollution in the case of a road or railway accident.

Few years ago new threat came to the region – the windmill electricity turbines. The *Snežnik* Mountain between both branches of the *Ljubljanica* River is one of few locations in Slovenia marginally suitable for wind use. Despite the habitats and bird species present that should be protected within the Natura 2000 network, there is a gap in Natura 2000 site on the *Snežnik* which enables the construction of 29 windmill turbines at the location which is utterly unacceptable from nature protection point of view.

Recently a new cause celebre has emerged! The proposal to build a European karst museum. The idea to have such a new iconic musem in Slovenia is to be welcomed. After all this country is the home of karst and the birthplace of academic studies in speleology and biospelology as well as scientific terminologies eg karst, doline, polje. The problem is that it is in the wrong place! The original architectural concept has been conceived in two didactical circles. Firstly the inner circle is an indoor interpretation predominantly by way of multimedia technology; the outer circle to be located in the immediate vicinity of the museum, will present the key karstic formations on the ground outside so enabling an experience of natural karst features at first hand. This unique connection between the virtual and the real requires a quite specific excellent location that is as untouched by man as possible. Under the strong political pressure there was proposed a building with tourist facilities for 100.000 visitors per year; not in vicinity of the *Postojnska jama* which would have been the logical decision, but in the core area of karst valley *Rakov Škocjan* only 300 m from the stream, 115 m from the alluvial plane and 500 m from Great natural bridge. That location is pristine and thus unacceptable from a nature conservation perspective. The museum building and attendant infrastructure need to be separated from the natural landscape features and located in a suitable distance from core area with the visitors allowed pedestrian access or use of a public transportation system.

Major conservation and management challenges in future

1. There are no suitable tools within the legislation for effective protection of cultural landscape. With the demise of the traditional extensive farming quick eutrofication of periodic lakes on poljes and reafforestation of remaining areas is to be expected.
2. Park involves large area, several local communities, several historic regions, demands carefully structured communication with local communities.
3. Local communities have had some unfortunate experiences with the state administration and previous conservation projects resulting in a climate of distrust.
4. Protection of big areas demands close cooperation between different government sectors. A strong political will is needed to enforce it. Nature conservation projects are tolerated by the political structures at best so there is no real political power behind generally too ambitious park projects. A big capacity building is needed for the nongovernmental organizations to enable them to effectively demand creating of the regional parks.
5. Specific knowledge is needed for local population to engage in sustainable tourism activities. There is big lack of people with that knowledge in the area.

Major interpretation challenges

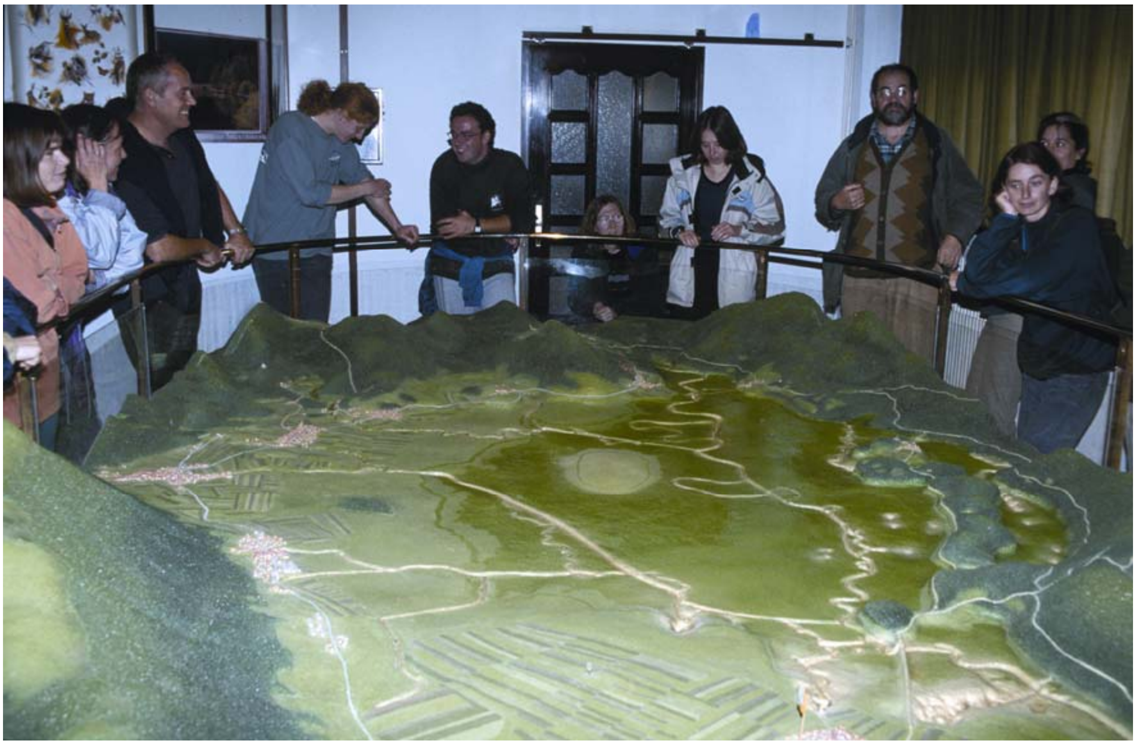
Ljubljanica karst river system is a vast and complex area, not easy to understand and especially not easy to communicate. Two examples of good practice are well worth mentioning.

Cerkniško polje is a very complicated karst polje because it has karst and non karst influx and the situation is furthermore complicated by the fact that except at the highest water there are more separated hydrological systems on the polje. One can talk for hours to explain it to the public and he must be very good interpreter to be successful. Vekoslav Kebe, an innkeeper from the village *Dolenje jezero* on *Cerkniško polje* got fed up with explaining the functioning of the polje so he constructed **a working model of the Cerkniško polje** with water flowing in and out as in nature. In 15 minutes visitor can observe what is going on the polje from total drought to full flooding and back to dry state. The ingenious model is a big interpretation success and assures innkeeper a good income.

Another example of a good practice is **Speleobiological laboratory - Proteus Vivarium** in Postojna cave. The Italians, who managed the Postojna caves between two world wars, constructed an underground speleobiological laboratory as a part of Speleological Institute in Postojna. The laboratory, which was used for scientific purposes, was completed in year 1931. It was located not far from the entrance to the caves in a passage not visited by the tourists during their visit to *Postojnska jama*.

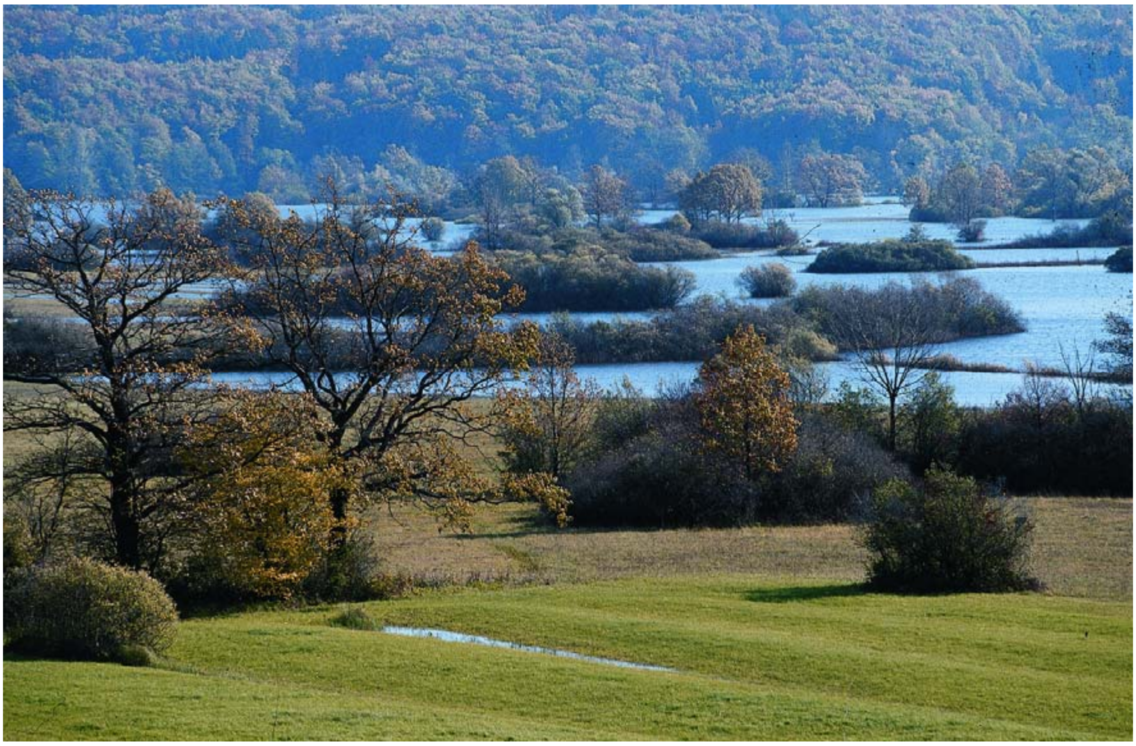
In the last decades of 20th century the laboratory was not used any more and the infrastructure slowly fell into decay. The management of *Postojnska jama* in cooperation with *Notranjski muzej* (Notranjska museum) from Postojna decided to convert the former speleobiological laboratory into a vivarium for showing the most prominent cave animals in natural environment. Strict rules regarding keeping live animals, especially the troglobionte species, which are enforced in Slovenia, were obeyed. For the visitors of the vivarium not to interfere with the normal tourist visit to a cave a new entrance to the vivarium was cleared. That was possible because there was a natural entrance to the caves in geological past which filled with the sediments. The information centre with multimedia presentation was built at the entrance. The new Speleobiological laboratory - Proteus Vivarium offers a first class interpretation of the cave environment, cave habitat and cave animals to the visitors, mostly schoolchildren.

STOP 2 (a): Living model of Cerkniško jezero



Interpretation model Muzejski hram in Dolenje Jezero. Photo Marko Simić

STOP 2 (b): Planinsko polje - a typical karst polje



Planinsko polje. Photo Marko Simić

FIELDTRIP 3: GEOLOGY OF CLASSICAL KARST (KRAS)

GEOLOGY OF KRAS IN THE LIGHT OF PALEOGEOGRAPHY AND MAIN EVENTS

Bogdan Jurkovšek, Geological Survey of Slovenia

The territory of western Slovenia belongs, from north to south, to the Southern Alps and the Inner and Outer Dinarides. The present subdivision is closely related to their paleogeographic origin. The Southern Alps correspond to the paleogeographic unit of the Julian carbonate platform. The Inner Dinarides were formed in the Slovenian basin, while the Outer Dinarides belong to the Adriatic-Dinaric carbonate platform (Buser 1989, Jurkovšek *et al.* 1996). During Mesozoic the south-western Slovenia was a part of Adriatic-Dinaric carbonate platform (= Adriatic carbonate platform), which was one of the largest Mesozoic carbonate platforms of the Perimediterranean region.

Kras in the wider geotectonic sense belongs to the Outer Dinarides, but in a strict tectonic sense, it can be defined as the Trieste - Komen plateau (synclinorium) or the Komen thrust sheet. The greater part of central Kras belongs to Cretaceous formations alternating vertically and horizontally, depending upon tectonically induced changes of relative sea level and global influences on the sedimentary environment. Among the latter, there were most distinctly the global changes of sea level and oceanic anoxic events that were variously reflected in different parts of the Adriatic-Dinaric carbonate platform (Gušić & Jelaska, 1990, Jurkovšek *et al*., 1996, Vlahović *et al*. 2005).

However, in southwest Slovenia, the carbonate platform is mainly formed of shallow-water carbonates and it was paleogeographically homogeneous in Early Cretaceous and in lowermost Late Cretaceous during sedimentation Brje and Povir Formations. This is supported by certain stratigraphic levels that are developed even in a wider area of the Adriatic-Dinaric carbonate platform. In the Lower Cretaceous these are Palorbitolina level, Mesorbitolina level and the emersion breccia between them (Jurkovšek *et al*. 1996). The following important geological event on the platform took place at the Cenomanian - Turonian boundary. Eustatic sea level rise during the Late Cenomanian - Early Turonian (Gušić & Jelaska 1990, 1993, Haq *et al*. 1987, Jelaska *et al*. 1995, Jenkyns, 1991, Vlahović *et al*. 2005) caused temporary drowning of the entire platform. The drowning event lasted for a shorter period in the south-eastern part, which is explained by tectonic upthrow. The limestones that were deposited during that time on the Trieste-Komen plateau have been assembled into the Repen Formation (Jurkovšek *et al*. 1996) that next to the bioclastic rudist limestones includes also the calcisphaera-bearing micrites.

In the Late Turonian the sudden drop of the eustatic sea level (Haq *et al*. 1987) interrupted the deposition of the Repen Formation. This change in the sea level had its expression in a rapid lithologic transition into shallow marine limestones, often with desiccation pores, and locally to oncoidal limestones. Some shorter emersion phases are observed too. A stable shallow water sedimentation followed that in the Trieste-Komen plateau resulted in a thick beds of the Sežana and Lipica Formations. In the Upper Santonian, and even more marked in the Campanian, a slow paleogeographic differentiation of the region became observable. In one part of the Trieste-Komen plateau a Late Santonian-Campanian eustatic sea level rise was reflected in the sediments (Cavin *et al*. 2000, Summesberger *et al*. 1999, Jurkovšek & Kolar-Jurkovšek 2007) while in the other parts an emersion took place at the same time (Pleničar & Jurkovšek 1997).

The age of the emersion boundary between Lipica Formation and Upper Cretaceous / Paleogene limestones of the Kras Group gradually increases from the northeast to the southwest. The unconformity is expressed by paleocarstic surface, locally marked by minor bauxite deposits (Debeljak *et al*. 2002, Košir 2004, Košir & Otoničar 1997).

Late Cretaceous and Paleogene paralic and shallow-water sediments of the Kras Group (Košir, 2003) constitute the final megasequence of the Adriatic-Dinaric carbonate platform. It consists of the Liburnian Formation, Trstelj Formation and Alveolinid-numulitid Limestone (Devalle & Buser 1990, Drobne 1977, Drobne 1981, Drobne *et al*. 1988, Jurkovšek *et al*. 1996, 1997, Ogorelec *et al*. 2001, Otoničar 2007, Pavlovec 1963, Stache 1889, Tentor *et al*. 1994).

The last important geological event is represented by disintegration of the carbonate platform by prograding hemipelagic marls and deep water flysch.

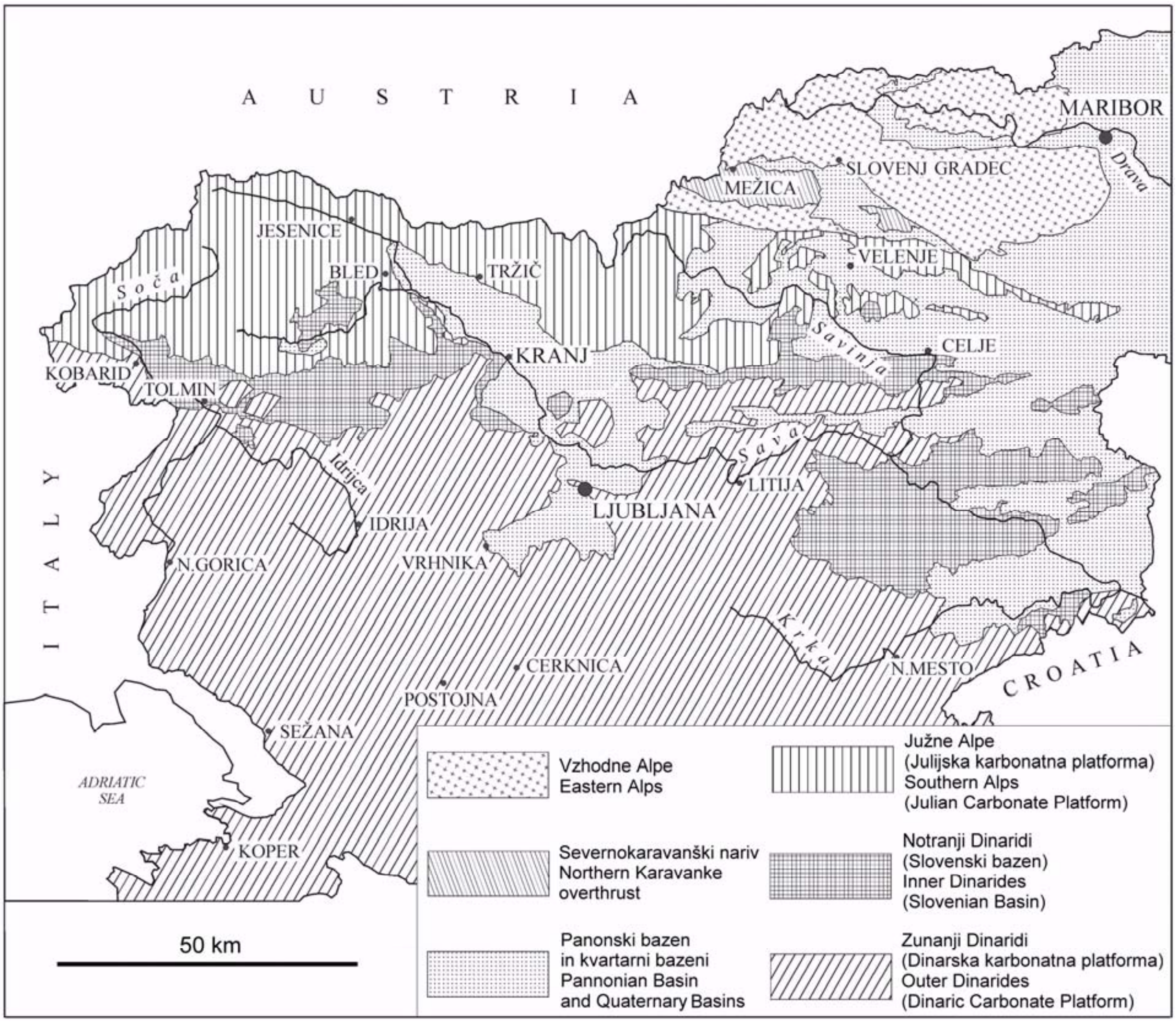


Figure 1: Actual position of geotectonic units in western and central Slovenia with extension of the ancient Julian and Dinaric (= Adriatic-Dinaric) carbonate Platforms and the intermediate Slovenian Basin (after Buser *et al*. 2007)

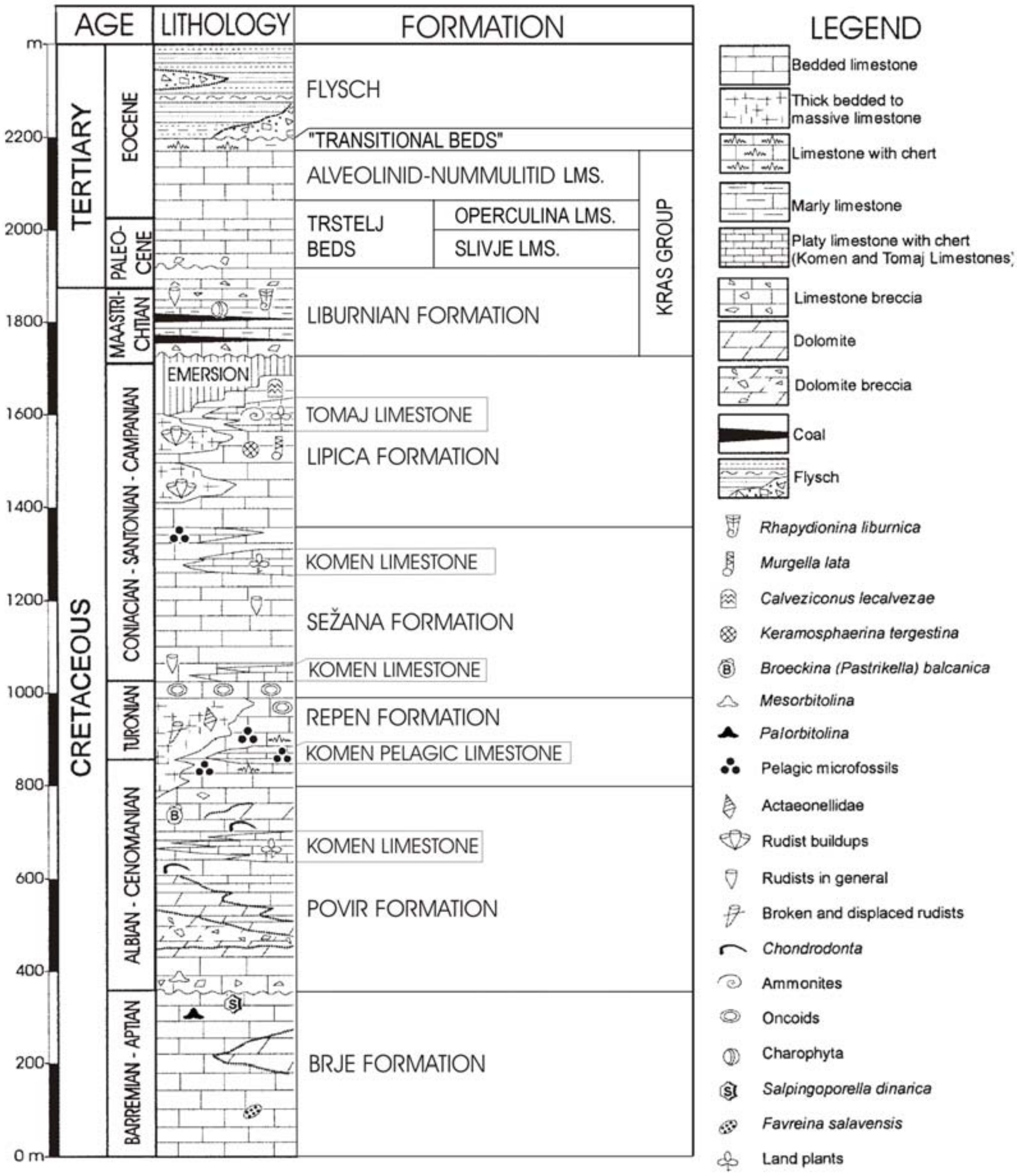


Figure 2: Stratigraphic column of the Cretaceous beds of the Trieste-Komen plateau

References

Buser, S. 1989: Development of the Dinaric and the Julian Carbonate Platforms and of the intermediate Slovenian Basin (NW Yugoslavia). Mem. Soc. Geol. Ital. 40 (1987), 313 – 320, Roma.

Buser, S. 2007: Triasni konodonti Slovenskega bazena. Geologija 50/1, Ljubljana.

Cavin, L., Jurkovšek, B. & Kolar-Jurkovšek, T. 2000: Stratigraphic succession of the Upper Cretaceous fish assemblages of Kras (Slovenia). Geologija 43/2, 165 -195, Ljubljana.

Debeljak, I., Košir, A., Buffetaut, E. & Otoničar, B. 2002: The Late Cretaceous dinosaurs and crocodiles of Kozina (SW Slovenia): a preliminary study. Mem. Soc. Geol. Ital. 57, 193 – 201, Roma.

Devalle, D & Buser, S. 1990: Macrofacies analysis of limestones from the Upper Cretaceous to the Lower Eocene of SW Slovenia (Yugoslavia). Geologija 31, 351 -394, Ljubljna.

Drobne, K. 1977: Alveolines paléogenes de la Slovénie et de la Slovenia et de l'Istria. Mémoires suisses de Paléeontologie 77, 132 s., 21 pls., Basel.

Drobne, K. 1981: Značilne foraminifere in njih združbe v podlagi danijskih plasti. Simpozij o problemih danija v Jugoslaviji: Zbornik referatov 2, 85 – 97, Ljubljana.

Drobne, K., Ogorelec, B., Pleničar, M., Zucchi–Stolfa, M. L. & Turnšek, D., 1988: Maastrichtian, Danian and Thanetian Beds in Dolenja vas (NW Dinarides, Yugoslavia) – Mikrofacies, Foraminifers, Rudists and Corals. Razprave SAZU, 4.razr. 29, 147-224, Ljubljana.

Gušić, I. & Jelaska, V. 1990: Stratigrafija gornjokrednih naslaga otoka Brača u okviru geodinamske evolucije Jadranske karbonatne platforme (Upper Cretaceous Stratigraphy of the Island of Brač). Djela Jugosl. akademije znan. i um., Razr. prir. znan. 69: 1-160, Zagreb.

Gušić, I. & Jelaska, V., 1993: Upper Cenomanian-Lower Turonian sea-level rise and its consequences on the Adriatic-Dinaric carbonate platform. Geol. Rundsch. 82/4: 676 - 686, Stuttgart.

Haq, B.U., Hardenbol, J. & Vail, P.R., 1987: Chronology of Fluctuating Sea Levels since the Triassic. Science 235: 1156 - 1167, Washington D. C.

Jelaska, V., Gušić, I., Jurkovšek, B., Ogorelec, B., Ćosović, V., Šribar, L. & Toman, M., 1995: The Upper Cretaceous geodynamic evolution of the Adriatic-Dinaric carbonate platform(s). Géol. Méditerran. 21/3-4: 89-91, Marseille.

Jenkyns, H.C., 1991: Impact of Cretaceous Sea Level Rise and Anoxic Events in Mesozoic Carbonate Platform of Yugoslavia. Am. Assoc. Petrol. Geol. Bull. 75/6: 1007 - 1017, Tulsa

Jurkovšek, B., Toman, M., Ogorelec, B., Šribar, L., Drobne, K., Poljak, M. & Šribar, L. 1996: Formacijska geološka karta južnega dela Tržaško-komenske planote 1:50.000. Kredne in paleogenske karbonatne kamnine (Geological map of the southern part of the Trieste-Komen plateau 1:50,000. Cretaceous and Paleogene carbonate rocks). Inštitut za geologijo, geotehniko in geofiziko, 1-143, Ljubljana.

Jurkovšek, B., Kolar-Jurkovšek, T. & Ogorelec, B. 1997: Rezultati geološke spremljave gradbenih del na odseku avtoceste med Divačo in Kozino. Annales 11, 161 – 186, Koper.

Jurkovšek, B. & Kolar-Jurkovšek, B. 2007: Fossil assemblages from the Upper Cretaceous Komen and Tomaj Limestones of Kras (Slovenia). N. Jb. Geol. Palaeont. 243, Stuttgart (in press).

Košir, A. 2004: Microcodium revisited: Root calcification products of terrestrial plants on carbonate–rich substrates. Journal of sedimentary research 74, 6, 845 – 857

Ogorelec, B., Drobne, K., Jurkovšek, B., Dolenec, T. & Toman, M. 2001: Paleocene beds of the Liburnia Formation in Čebulovica (Slovenia, NW Adriatic – Dinaric Platform). Geologija 44/1, 15 - 65, Ljubljana.

Otoničar, B. 2007: Upper Cretaceous to Paleogene forbulge unconformity associated with foreland basin evolution (Kras, Matarsko Podolje and Istria; SW Slovenia and NW Croatia). Acta Carsologica 36/1, 101 – 120, Postojna.

Pavlovec, R. 1963: Stratigrafski razvoj starejšega paleogena v južnozahodni Sloveniji. Razprave SAZU 7, 419 - 556, Ljubljana.

Pleničar, M. & Jurkovšek, B. 1997: Rudists from the Lipica Formation in the Lipica quarry. Annales 11, 115 - 140, Koper.

Summesberger, H., Jurkovšek, B. & Kolar-Jurkovšek, T. 1999: Rollmarks of soft parts and a possible crop content of Late Cretaceous ammonites from the Slovenian Karst. - In: Oloriz, F. & Rodriguez-Tovar, F.J. (Eds.): Advancing Research on Living and Fossil Cephalopods, Kluwer Academic / Plenum Publishers, 335-344, New York.

Stache, G. 1889: Die Liburnische Stufe und deren Grenz-Horizonte. Abhandlungen der K.K. geologischen Reichanstalt 13, 1 - 170, 8 Taf., Wien.

Tentor, M., Tunis, G. & Venturini, S. 1994: Schema stratigrafico e tettonico del Carso Isontino. Natura Nascosta, 9, 1 - 32, Monfalcone.

Vlahović, I., Tišljar, J., Velić, I. & Matičec, D. 2005: Evolution of the Adriatic Carbonate Platform : Paleogeography, main events and depositional dynamics. Palaeogeography, Palaeoclimatology, Palaeoecology 220, 333 – 360.

RAŠA FAULT
Ladislav Placer, Geological Survey of Slovenia

The Raša fault passes NW-SE from the Southern Alps presumably to the Velebit mountains (see the map). It is one of the faults in the External Dinarides along which the North-Adriatic block is being laterally shifted and thrust under the Southern Alps. Consequently, it is an important object of the recent tectonic model of the Earth crust in this region. In the road-cut in front of us you see a cross-section of its fault zone core, and on the panel board the photograph of the road-cut taken from our standing point, and below, the sketch with its simplified description.

Outcrop along motorway and information board with the text above. Photo Martina Stupar

STOP 3: Škocjan Caves

THE BASIC INFORMATION ON UNESCO WORLD HERITAGE SITE ŠKOCJANSKE JAME
Marko Simić, Environmental Agency of the Republic of Slovenia

Name: Škocjanske jame (Škocjan Caves)
Known as: Reka Höhlen und Dolinen von St. Kanzian (before 1918), Grotten un Höhlen von Sankt Kanzian (before 1918), Grotte di San Canziano (between 1918 in 1945)

Mode of protection: Škocjan Caves Regional Park *(Regijski park Škocjanske jame).* In accordance with the Law of the Škocjan Caves Regional Park, the government of the Republic of Slovenia founded the Škocjan Caves Park Management Authority *(Javni zavod Park Škocjanske jame)*. The head quarters of the public agency and the information centre of the park are located in the beautifully renovated *Gamboč* House in village *Škocjan*.

Geographical location: In the community of *Divača*, in the Republic of Slovenia, 13 km east of *Trst (Trieste, Triest)*, 45° 40' N, 14° 00' E.

Date and history of establishment: *Škocjanske jame* have been under legal protection since 1980 and the caves were put on the World Heritage List on 26th November 1986 (Criteria iii).

Protected Area:
1. Škocjan Caves Regional Park Core area: 413 ha. The regional park includes: the downstream *Reka* canyon from the bridge at *Famlje,* the lower part of the *Sušica* River, the area of *Velika Dolina* and *Mala Dolina*, the entire area above the known cave sections. The region also includes some large collapse dolines,

such as *Sokolak, Globočak, Sapendol and Lisičina*, which are geological traces of the former *Reka* ponors in the surrounding area of *Škocjanske jame.*

2. Škocjan Caves Regional Park Buffer zone: The 450 km^2 area includes the complete catchment area of the *Reka* River. Activities which could change the existing water regime of the *Reka* with regard to the quality or quantity and so threaten the protected area of the regional park, are prohibited within the buffer zone.

Altitudes:
1796 m (Mount *Snežnik*, the highest point of the buffer zone);
474.5 m (the highest point of the core protected area);
270 m (the river *Reka* at the entrance to *Škocjanske jame* in *Velika Dolina*);
214 m (the sump lake *Mrtvo jezero*).

Land tenure: The caves, real assets and equipment in the caves as well as those outside intended for tourist use, are in state ownership under the management of the Škocjan Caves Park Management Authority. The houses and most of the meadows and scrubland are private property.

Brief description of Škocjanske jame Caves

Škocjanske jame is a typical and extremely beautifully developed example of contact karst. From the east, the river *Reka* flows towards *Škocjanske jame*. The *Reka* has a catchment area with 450 km^2 surface which predominantly consists of flysch which forms a normally developed relief. South of the village of *Gornje Vreme*, the *Reka*, flowing from the flysch, reaches the limestoneand just before the entrance to the caves and has created a canyon about 2,5 km long, the bottom of which is covered with flysch pebbles. In the geological past, the *Reka* ponors were situated in the vicinity; traces of the former stream are seen in the large collapse dolines in the surrounding area of *Škocjanske jame*: *Sokolak, Globočak, Sapendol*, and *Lisičina*.

At the end of the canyon, the *Reka* enters the first section of *Škocjanske jame*, previously called *Male jame*, through a 40 m high entrance. The section *Male jame* consists of *Mahorčičeva jama* and *Mariničeva jama*. The *Reka*, flowing through *Mahorčičeva jama*, reaches *Mariničeva jama* without any conspicuous transition and then daylight in the collapse doline *Mala Dolina*. Right above the underground section *Male jame*, in the village of *Škocjan*, there is a circular, wall-enclosed entrance to the 76 m deep shaft *Okroglica*, leading down to *Mahorčičeva jama*.

In previous geological times the cave ceiling between *Mariničeva jama* and the final ponor of the *Reka* into *Škocjanske jame*, collapsed forming two collapse dolines, *Velika Dolina* and *Mala Dolina*, which are divided by a natural bridge below which the *Reka* threads its way over rapids and two waterfalls. The volume of the collapsed dolines is 3,290,000 m^3. In *Velika Dolina* there are two interesting and important caves: the 600 m long *Tominčeva jama* (archaeological site), and the *Ozka špilja* (palaeontological site), situated higher up the rock face.

Velika Dolina and *Mala Dolina* have similar vegetation and, due to the microclimatic conditions present in the collapsed galleries and the shallow chasms of the river valley, a mixture of habitats are represented corresponding to the floras of Central Europe, the Mediterranean, Submediterranean, Ilyrian and Alpine all of which are present side by side in the *Velika Dolina*. This unique combination allows Mediterranean species (such as *Adiantum capillus veneris*) to grow next to Alpine species (such as *Primula auricula*). The endemic *Campanula justiniana* is present here at its type locality.

The surface flow of the *Reka* terminates at a ponor below a 164 m high rock face. In the cave near the ponor there are about 100 rimstone pools up to 0.4 m deep. Beyond the ponor, the river enters a 1620 m long underground canyon. On its route it negotiates 56 m of height difference in 25 waterfalls, the highest of which is the sixth (3 m). In its initial section, the canyon is wide, but it narrows into the *Hankejev kanal*, a nearly metre-wide and 80 metre high section. Before the start of the *Hankejev kanal*, under the ceiling of the underground canyon, there is an entrance to the 650 m long section *Tiha jama.*

Beyond the *Hankejev kanal*, the canyon widens and just before the end, the ceiling gains height for the last time in the chamber *Martelova dvorana*. The survey by the Karst Research Institute of the Slovenian Academy of Sciences and Arts indicated that *Martelova dvorana* is 308 m long and 123 m wide. The mean height of the chamber is over 100 m, the highest point is as much as 146 m above the underground river. The volume of *Martelova dvorana* is 2,200,000 m^3, the surface of the largest cross section is 1,2 ha. Right beyond *Martelova dvorana*, the ceiling descends to river level. After 160 m of water passage, the cave finishes in the sump lake *Mrtvo jezero*.

However just before the end of the cave, in the lake *Marchesettijevo jezero*, divers negotiated the 20 m deep and 60 m long sump *Ledeni dihnik* in 1991. Towards the north, the new cave section ends with another sump draining the *Reka* waters along still unexplored channels towards the inlet sump of the cave *Kačna jama* near *Divača*. The underground flow of the *Reka* may also be observed in the cave *Labodnica* (Italian: Grotta di Trebiciano), having its entrance near *Trebče* (Italian: Trebiciano) in Italy, right on the Slovene-Italian border. Before World War One, water-tracing attempts indicated that the underground flow of the *Reka* is directed into the karst springs of the river *Timava* (Italian: Timavo) near *Devin* (Italian: Duino), situated in the vicinity of the Adriatic Sea, Italy.

The entire system of *Škocjanske jame* is over 5,800 m long and 250 m deep.

Fauna: The underground galleries hold five species of wintering bat in reasonable numbers. The area is a wintering site for *Tichodroma muraria* and habitat for *Microtus nivalis*. Endemic *Proteus anguinus* was not found in *Škocjanske jame*, but lives in the same hydrographical system (in nearby *Mejame* and *Kačna jama*).

Local human population: The three villages (*Škocjan pri Divači, Matavun* and *Betanja*) within the core area have resident population of 67.

Visitors and visitor facilities: The cave and both the collapse dolines, *Velika Dolina* and *Mala Dolina*, have been used for tourism since 1819. Before World War One, the managers provided a system of paved paths with a total length of more then 12,000 m (more than twice the length of the total cave passages.). A vertiginous tourist trail was also made along the whole underground canyon as far as the sump lake.

The present tourist path starts in the collapse doline *Globočak,* with some sections illuminated. The entrance along a 120 m long artificial tunnel leads into a nicely decorated section with flowstone and dripstone. *Tiha jama*, which is a lateral inactive cave section. Using this tunnel, which was finished in 1933, the Italians, who managed the cave between both world wars, solved the problem of visitor congestion, since after the construction of the tunnel, visitors entering the cave and those leaving could follow separate paths. The tourist path through *Tiha jama* leads down to the underground canyon, which is crossed by a bridge 47 m above the underground river. The way along the tourist path continues upstream alongside the river on the right side of the canyon as far as the collapse doline *Velika Dolina*. The major part of the canyon, including the biggest chamber *Martelova dvorana*, is not accessible for visitors.

The next tourist problem in the cave is the big drop in height (about 150 m) between the cave exit near the *Reka* ponor in *Velika Dolina* and the edge of the collapse doline. This was solved after intense discussions by the construction of an escalator in 1986 on the south slope of *Velika Dolina*.

In the cave a year long guiding service is provided, even though there is a seasonal variation in numbers.

Cave visits: In year 2005 there were 19,933 visitors from Slovenia and 71,221 from abroad.

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total	23,807	31,965	33,919	42,116	41,590	41,343	47,200	48,600	44,704	51,766	56,838	67,105	75,395	89,700	91,154

Exploration and scientific research: Exploration of *Škocjanske jame* started already in 1815, when an innkeeper from Trst *(Trieste)*, Joseph Eggenhöffner, swam through the sections *Mahorčičeva jama* and *Mariničeva jama*, reaching the collapse doline *Mala Dolina*. There followed a courageous attempt by Jakob Svetina (1807-1872), who in 1840 dared to enter the initial sections of *Škocjanske jame* in a boat and reached the second waterfall. In 1851 the world famous Viennese geographer Dr. Adolf Schmidl succeeded in reaching the fourth waterfall.

In 1883 another period of exploration began when Anton Hanke, Joseph Marinitsch and Friedrich Müller, members of the Coastal Section of the German-Austrian Alpinist Club, tackled the cave. The real leader was a metallurgical engineer and mining councillor, Anton Hanke (1840-1891). The downstream exploration was finished on 6th September 1893, when the sump lake *Mrtvo jezero* was reached.

After this successful achievement there followed another period in which explorations were tackled in "alpine" style. Paths were cut partly into the bedrock and partly followed wooden boards secured by iron holders, thus enabling access to different side passages and other places of interest high above the river. In the course of time, the entire cave was criss-crossed with these precarious paths which today are a true technical monument to the local workers (now largely forgotten "heroes") who had to earn a living from this strenuous and dangerous work.

The question of which direction is taken by the water from the sump lake Mrtvo jezero was solved in 1912 when Guido Timeus published the results of the first dye-tracing attempts, which proved the long assumed connection between *Škocjanske jame*, the cave *Labodnica* and the sources of the river Timavo on the coast of the Adriatic Sea. In 1927, the then Italian Royal Institute of Sea Biology based from *Rovinj* carried out an extraordinary tracing attempt which also proved the connection of the *Reka* with the sources of the Timava (Timavo). Marked eels were put into the *Reka* and reappeared in the karst springs of the Timava (Timavo) in the vicinity of the Adriatic Sea.

The last important discovery in the "classical" period of exploration was made on 22nd July 1904, when the locals discovered a large black opening high above the underground stream of the *Reka* at the entrance to *Hankejev kanal*. The continuation led to *Tiha jama,* a 650 m long, beautifully decorated section which nowadays can be seen by tourists in the first section of their underground route.

Despite continuous explorations in *Škocjanske jame* and the discovery of *Tiha jama* there were no new important discoveries in the cave for decades. In 1991, cave divers found an entrance to a 20 m deep sump of *Marchesettijevo jezero*, just before *Mrtvo jezero*. The sump led them into new cave passages. The continuation towards the cave *Kačna jama* then soon terminated in another sump.

In the cave *Kačna jama,* situated in the vicinity of *Škocjanske jame*, there appears the underground stream of the *Reka* at the lowest level of the cave. Cavers have tried to penetrate as far as possible along the underground *Reka* for several decades now. Since penetration along the water section on both the inflow and outflow sides was halted by two demanding sumps, divers tackled a less demanding sump at a higher level. In March 1997, they discovered beyond the sump a passage over 2 km long. This led them to the underground *Reka* only about 1000 m from the outlet sump of *Škocjanske jame*. In next few years both the large cave systems are expected to be connected.

The importance of the caves is reflected in an extremely comprehensive bibliography. The first writing was done by Ferrante Imperato as long ago as 1599. After that followed publications written by Athanasius Kircher in 1678 and eleven years later J. W. Valvasor. Subsequently there have been many more. In cooperation with the Karst Research Institute of the Slovenian Academy of Sciences and Arts and the Slovenian National Commission for UNESCO, a booklet "Škocjanske jame, a contribution to Bibliography" was published in 1996. It contains as many as 399 articles written by 222 different authors.

The site has been fundamental to research on karst phenomena since the 19th century and has given rise to two specific geomorphological terms, "karst" and "doline". The archaeological finds are possibly among the most significant in Europe with accompanying documentation lodged in a number of museums in Trieste, Vienna, Postojna and Ljubljana.

Major management challenges

1. Caves formed by surface rivers in contact with limestone (such as *Škocjanske jame)* and are most vulnerable to changes in water quality and quantity. For decades before 1991 the main conservation problem for *Škocjanske jame* was the high level of pollution of the *Reka*, sinking into the cave systems. In addition to the population living within the catchment area of *Reka*, the main pollutants were two factories in *Ilirska Bistrica*. Numerous measures had been taken, but the water condition had hardly improved. For financial reasons the Factory of Organic Acids closed down in 1992 and the other factory introduced a cleaner technology, so at present the quality of water is considerably improved. Nevertheless the *Reka* is still burdened with effluents from the numerous settlements within the catchment area.

East of the caves a major road runs along the river with lots of tankers passing daily which presents a constant threat of possible heavy pollution if a road accident should occur. The Skocjan Caves Park Management Authority is trying to establish a properly equipped and financed intervention unit to deal with any such emergency.

2. Due to its large dimensions and its natural ventilation (ponor water, large masses of air), the cave is capable of coping with an increasing number of tourists; given proper management. However the surface infrastructure (parking places and other tourist facilities) will be a limiting factor and will need to be relocated away from the core area which will necessitate a public transport system.

3. As a part of the socio-econonomic changes affecting the whole of Slovenia (and indeed Europe); traditional agricultural practices in the Park have declined, with farmers abandoning haymaking meadows and cattle breeding on small farms. The result is natural reafforestation which presents the Skocjan Caves Park Management Authority with a major problem. The challenge will be to try to select appropriate meadows as future habitats and encourage (subsidise?) local inhabitants to farm in the traditional manner.

4. As already stated the connection between *Škocjanske jame* and *Kačna jama* is imminent. The resulting new system, with total length of more then 18.500 m, will be the second longest cave system in Slovenia. When cave divers finally finish exploring the water filled channels between both cave systems, a whole new set of conservation problems will arise since *Kačna jama* is situated beneath the town of *Divača*, a major railway and a major highway.

5. Quite a few major European transportation corridors cross Slovenia. Škocjanske jame is situated in the hinterland of two important north Adriatic ports, Koper and Trst *(Trieste),* where these corridors are dense. There is a major road and a highway passing in close proximity to the western core area boundary and there is a major railway not far from north boundary of core area.

Plans for new transport infrastructures in the vicinity of the core protected area are threatening to encircle the park. A new airport (using the former grass air-strip of a local aviation club, just north of *Škocjanske jame)* is planned as a regional, mainly tourist airport with attendent infrastructure. The runway is already paved and construction of the facilities in due to begin. Then there is a plan for construction of a new highway from Divača to Ilirska Bistrica, north of the core protected area. Eventually there will be a new high speed railway connecting Trst *(Trieste)* and Ljubljana (fifth European corridor Barcelona – Kiev) close to the borders of the park.

6. The Slovenian coast area has a big water supply problem. There is a plan to construct a dam on the river *Padež*, a tributary of the *Reka* River, which will supply the coast area with the drinking water. This will affect the water regime of the *Reka* (quantity of water and its dynamics). Already during the dry summer season the *Reka* doesn't supply the caves with enough water. The river bed in the surface canyon is covered with flysch deposits and during the drought periods, the river disappears into the limestone beneath it. In the past there were mills in the canyon and the owners regularly filled the sinkholes but now there is nobody to do that

demanding job. Skocjan Caves Regional Park management is facing a tough dilemma. Is this summer disappearance of the river a natural process and so to be left to nature? Is the small quantity of clean water from the local underground catchment area that flows through the cave in summer, enough to for sustain the water cave habitats in *Škocjanske jame*? Or should management demand that measures to ensure the impermeability of the river bed all the way to the entrance to the caves should be included in the construction plans for the dam on *Padež*?

Major interpretation challenges

For the visitor to understand contact karst and the formation of the Škocjan caves it is better to follow the river from the surface down into the caves. Unfortunately because of the big height differential the tourist route was designed in the opposite direction. The present tourist path starts in the collapse doline *Globočak* where a 120 m long artificial tunnel leads into the attractive flowstone and dripstone 650 m long *Tiha jama*, which is a lateral inactive cave section. There the tourist gets the wrong impression that they are visiting an ordinary show cave. The tourist path through *Tiha jama* then leads down to the underground canyon following in the opposite direction to the water flow. The tourists then leave the caves by the elevator in *Velika Dolina* so they never see the river outside of the cave system at all.

Such a general misconception of cave importance is readily apparent if we examine the special postage stamp issued by the Slovenian Post Office (Pošta Slovenije) on the occasion of the tenth anniversary of the inscription of the *Škocjanske jame* on the UNESCO World Heritage List. It wasn't a world famous underground canyon on the stamp as one would imagine. Instead the rimstone pools from the entrance section of the caves are portrayed. Yes they are beautiful but definitely not the reason that makes *Škocjanske jame* unique amongst the show caves of Slovenia and indeed the world.

There is a plan to reconstruct tourist pathways through Male jame, so that small groups will have access to the caves alongside the river.

The special postage stamp issued by the Slovenian Post Office (Pošta Slovenije) on the occasion of the tenth anniversary of the inscription of the *Škocjanske jame* on the UNESCO World Heritage List.

Photo Marko Simić

The photo of Velika and Mala dolina and village Škocjan taken from belvedere above Velika Dolina. Photo Marko Simić

FIELDTRIP 4: MERCURY MINE IDRIJA

STOP 4: Tourist Mine

MERCURY ORE DEPOSIT IDRIJA

Uroš Herlec, University of Ljubljana

Adaptation and translation of the article »Rudišče živega srebra v Idriji", written by Uroš Herlec, Bojan Režun and Aleksander Rečnik«.

The history of the Idrija mercury deposit started in 1490 when the discovery of native mercury drops on the surface of carboniferous shale was first reported. More than 500-year-long history of exploitation, the size and variety of mineralization, and technical and cultural heritage position Idrija mine among the World's cultural and natural heritage gems.

Idrija ore deposit is around 1,500 m long, 300-600 m wide and 450 m deep. On 15 horizons, around 700 kms of adits were mined out. The lowest horizon was 36 m below the present sea level. In the mine 158 ore bodies were found, 141 mineralized by cinnabar (14 ore bodies mainly by singenetic type of mineralization and 127 prevailingly or exclusively by an epigenetic type of the ore). In the remaining 17 ore bodies, native mercury prevails. Within the whole work time span of the mine there were 12.5 million tonnes of ore, with around 145,000 t of mercury mined out, i.e. 13 % of the historical world's production of the Hg metal. On the market 107,829 t were sold. This means that during the metallurgical process almost 40,000 t of Hg were »lost« in environment, which is still a source of pollution. Most polluted are sediments of the rivers Idrijca and Soča and its delta at the Adriatic Sea.

The ore deposit was formed around 30 km NW of the present position in Idrija, somewhere in the area of the present high plateau Jelovica. To the present position it was thrusted in the Miocene. From the overfolds and recumbent fold thrust was formed. Detailed structural analyses revealed that one third of the mineral deposit was split off and remained somewhere deep below the nappe. In the youngest tectonic phase along the still active Idrija fault, which is oriented in the Dinaric direction along the Idrijca River, a smaller, lower part of the Idrija deposit (Ljubevč) moved towards the southeast direction for around 2,5 kms. The geological composition and structure is very complex. Idrija and the surrounding area is built from four nappes. The mineral deposit is in the lower part of the fourth Žirovsko-Trnovski nappe, in the so-called Idrija tectonic slice. The ore is in the carboniferous slaty shales with lenses of quartz sandstones, within Middle Permian Gröden sandstones, Upper Permian dolomites, Scythian or Lower Triassic dolomites within slaty mudstones and in the lenses of oolitic limestones, Anisian dolomites and Ladinian clastic and pyroclastic sediments. Multiphase tectonic activity had severely transformed the original structure of the Idrija mineral deposit that was formed in the Middle Triassic (from Middle to Late Anisian to the end of Ladinian) Idrija tectonic graben. Palaeozoic, Triassic and Cretaceous sedimentary rocks were thrusted onto younger Cretaceous and Eocene beds, and older rocks were overthrusted.

The mercury mineralization has a genetic link with the origin of Idrija tectonic graben and the start of rifting of the Slovenian carbonate platform. The mercury ores were formed in two mineralizing phases. The first, Idrija tectonic phase, between Middle and Upper Anisian during degassing of the upper mantle from ultramafic rocks, along steep faults vapours of mercury were transported all the way up to the surface of the Earth crust. Along with the temperature drop the vapours gradually condensed and liquid mercury precipitated. Part of mercury was bonded to sulphur into cinnabar. Isotopic analyses of sulphur revealed that the sulphur partly came into the ore deposit with hydrothermal fluids from the magmatic source deep down, some sulphur is of sedimentary origin, as it has been proved that it was dissolved by hydrothermal fluids along the fractured fault zones from the beds and lenses of gypsum and anhydrite within Upper Permian dolomites. In the synsedimentary ores there is some sulphur from marine water sulphate and connate pore waters. Ore mineralizing fluids poured out on the surface as well.

Cinnabar of the first - Anisian phase of mineralization filled open voids and fractures in the fractured rocks and formed vein-impregnation, vein, breccias, and metasomatic replacement of ore textures. Cinnabar precipitated along the faults in the permeable fractured rocks and cemented it. The »richest« vein type massive fine-grained cinnabar ore from open space filled type mineralization is the »steel ore« with the characteristic metal lustre. Within the mineralised rock succession acid hydrothermal ore brines selectively dissolved calcite and they somatically replaced it by cinnabar. Dolomite has lower solubility and remained intact. Rich metasomatic cinnabar ore bodies were formed by the replacement of politic limestones below less permeable marls within the Lower Triassic beds. Liquid native mercury filled the primary and secondary tectonic fracture porosity mainly in the lower part of the mineral deposit, where there was a lack of sulphur for the cinnabar precipitation. According to the ore appearance miners named the typical red, less mineralised ore *the brick ore*, dark red-brown *the liver ore* and the most common and less mineralised ore with some cinnabar impregnation the *baschperch*. Especially interesting is *the karoli ore*, consisting of cinnabar cementation of the pyrite and marcasite crustyform concretions, sometimes enveloped by pyrite crystals. It was named after Karoly from the Habsburg sovereign family, the owner of the mine at that time. Analyses proved that pyrite-cinnabar *karoli ore* was formed along zones of most intensive inflow of reduced ore fluids. Carboniferous early diagenetic pyrite and marcasite concretions accumulated along partly eroded slope within the Idrija tectonic graben were cemented by cinnabar and second phase epigenetic pyrite.

The second – Ladinian phase of mineralization: due to larger geothermal flow synchronously with the volcanism in the area of Idrija, a large part of native mercury was transported into newly formed sediments into the rifted Idrija tectonic graben. Hydrothermal fluids more or less mineralised partly or non-consolidated sediments along the feeding faults. Ore brines were expelled into coastal swamps. Around subsurface hot springs with the presence of marine sulphate sedimentary exhalation (SEDEX) ores made of cinnabar chalcedony precipitate were formed in the reduced swamp environment. At the bottom of the swamp in the area of the largest fluid flow, sedimentary massive fine-grained, often laminated ore (SEDEX »steel« ore) was formed. It was found in lenses up to around 1 m thick, and several tens of metres wide and long. This was the largest concentration of mercury found in the world's mining history. The discovery gave the development of Idrija mine the most important impetus. Cinnabar precipitated in black swamp bituminous sediment formed dark red ore called *the liver ore* that has some uranium content. Uranium is only in the organic matter and is not bonded into any mineral composition. Phosphate fossil shells of brachiopods of the genus *Discina* can be found. They were incorrectly determined by the miners as corals at the time of the first finds, and the mineralised brachiopodes are still named *coral ore*. Synchronous explosive volcanic activity gave laminated air fall tuffaceous pyroclastic sediments that can be mineralised selectively by cinnabarite, regarding their grain size composition and porosity/permeability. Bedded and laminated ores and ores with graded bedding of air fall deposits were formed.

Until the present, Idrija is the only known mercury mineral deposit with coexisting synchronous origin of epigenetic, vein, vein impregnation and metasomatic replacement, and sedimentary exhalative SEDEX types of mineralization.

Idrija mine has morphologically very interesting cinnabar crystals. Largest and most developed can be found in porous late-diagenetic dolomite and its voids, where porosity and permeability of the rock was relatively low, but still sufficient to enable slow inflow of weak mercury and sulphur ore solution. Cinnabar crystals have silvery-red metallic to diamond lustre. Often they are translucent, very rarely transparent. Cinnabar formed in several phases. Crystal forms have not been analysed properly yet. Crystals are mostly only few millimetres long and seldom exceed the size of 1 cm. The biggest cinnabar twin from Idrija is 3 cm long. In mineralogical collections, cinnabar from Idrija is appreciated because it does not fracture due to internal tensions as Chinese cinnabar often does, and because of the impressive history of the mine. Simple crystals and interpenetrative twins are the most common habitus. Best cinnabar crystals came from the Grübler ore body. Detailed fluid inclusion studies revealed the temperature range of the fluid from 160 to 180 °C. Salinity of the NaCl ore fluids was from 2.6 to 12.8 weight %.

Native mercury is in the form of »silver« drops mainly in black carboniferous and lower Permian slaty claystone, named by miners *the silver shists.*

Most interesting are the minerals in the fractured fault zones in Triassic dolomites with vugs and voids covered by tiny dolomite crystals. In the mineralised parts of the fault zones in such small geodes there are crystals of cinnabar, pyrite, and very seldom sphalerite, galenite and metacinnabarite. Primary non ore minerals are a few mm long quartz crystals, fluorite, calcite, barite and microscopic crystals of celestine and kaolinite. Secondary minerals are gypsum, vivianite, paligorskite, melanterite, and epsomite.

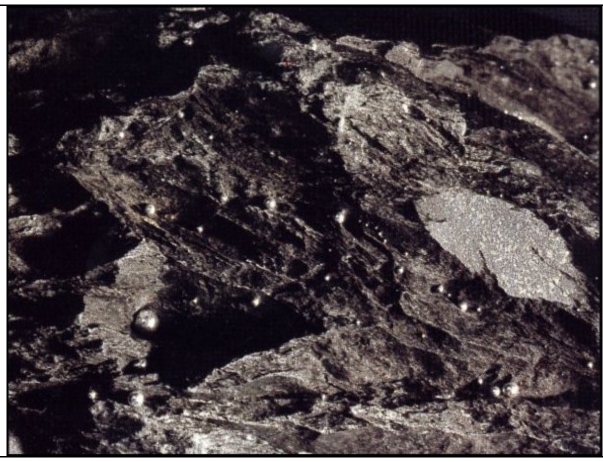
In the cinnabar rich veins there is often black pyrobitumen, and crustyform, earthy, nodular or massive solid mixture of polycyclic aromatic hydrocarbons – idrialite (the old name is *idrialine*), in yellow-green or pistacia colour. Idrialite is an organic mineral, found and described in Idrija. Very interesting is occurrence of metacinnabarite, which is the cubic modification of HgS. Crystals of metacinnabarite can be found with calcite crystals in the fractures of mineralised Lower Triassic oolitic limestone. Individual crystals are up to 1 mm in size and they form up to 5 mm intergrowths. Crystals are black and have metallic lustre. It was found in the orebody Grübler in the form of zoned colloidal textures together with cinnabarite, where they were alternating precipitation of both polymorphs.

In the voids of dolomite breccia there are long-prysmatic quartz crystals up to 10 mm long. Fluorite is very rare. Violet cubes up to 2 mm in size can be found on dolomite. Within the Grübler ore body barite crystals up to 8 mm are found together with calcite, quartz and cinnabar. Barite crystals are white and/or transparent with vitreous lustre. Often they are zoned. Lately, crystals of celestine have been found by using a microscope.

Among rare minerals of the oxidation zone of the ore deposit is vivianite. We found it in the upper parts of the kine in fractures of black sandstones spatially connected to the ore packed by phosphatic brachiopodes. Vivianite crystals, up to 2 mm in size, are transparent and have typical blue-green colour. Due to oxidation of the primary minerals, epsomite and melanterite are formed. Most often they are growing from the fractures on the walls of abandoned mine adits and shafts, connected to oxidation process of iron sulphides and dedolomitisation, where mine waters dissolve and transport magnesium and iron. They both are very soluble in water (iron without the presence of free oxygen only), Weak fuid flow and dry adits with strong evaporation are needed for their fast growth. Epsomite forms hairlike pearly-white crystals up to several decimetres in length. Longest were up to 2 metres long. Most common is it in the stalactite and stalagmite form, developed in abandoned and poorly ventilated adits. Melanterite forms translucent green, seldom yellow, brown and pink coloured crystals up to 10 mm high. It is rarely transparent with vitreous lustre. Similarly as epsomite, also melanterite forms stalactite and stalagmite forms.

The town of Idrija with its surroundings is a wonderful monument of natural, technical and cultural heritage, worth of a detailed excursion. The part of the mine, which will not be flooded and will remain accessible, is in the procedure of legislative protection as a geosite of state and world importance. The accessible and preserved geological curiosities will be ready for visits and investigations of next generations.

Numerous natural and cultural curiosities of the Mercury Mine Idria are the reason that this area becomes a World Heritage Site. Among many types of the ore deposits there is also syngenetic bedded ore. Photo Marko Simić



Native mercury is in the form of »silver« drops mainly in black carboniferous and lower Permian slaty claystone, named by miners the silver shists. Photo: Marko SImić

Fig. 1: Proposal of the idealised schematic cross-section of the Idria ore deposite in the period of sedimentation of Langobardian pyroclastites (Placer, Čar, 1977).

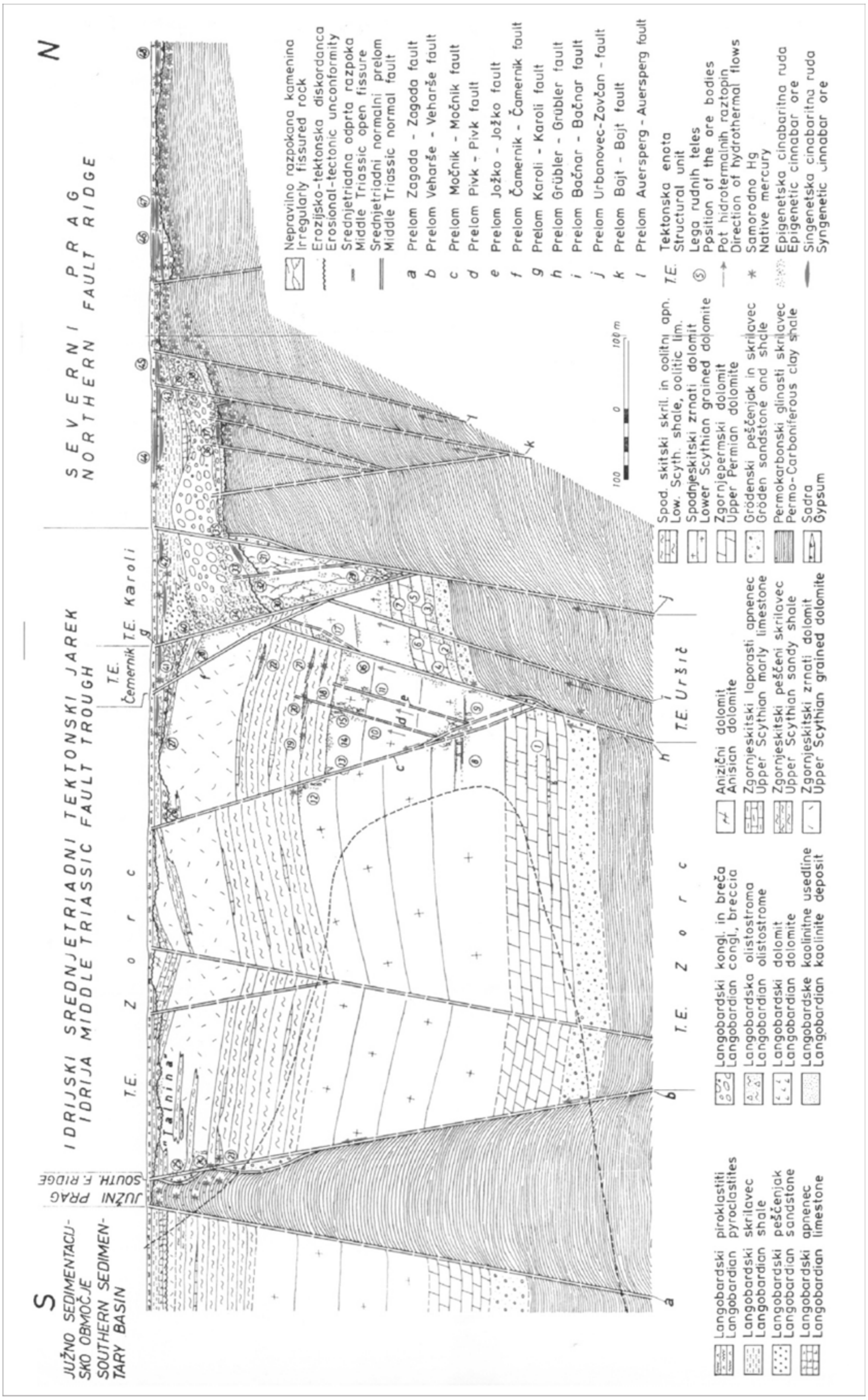
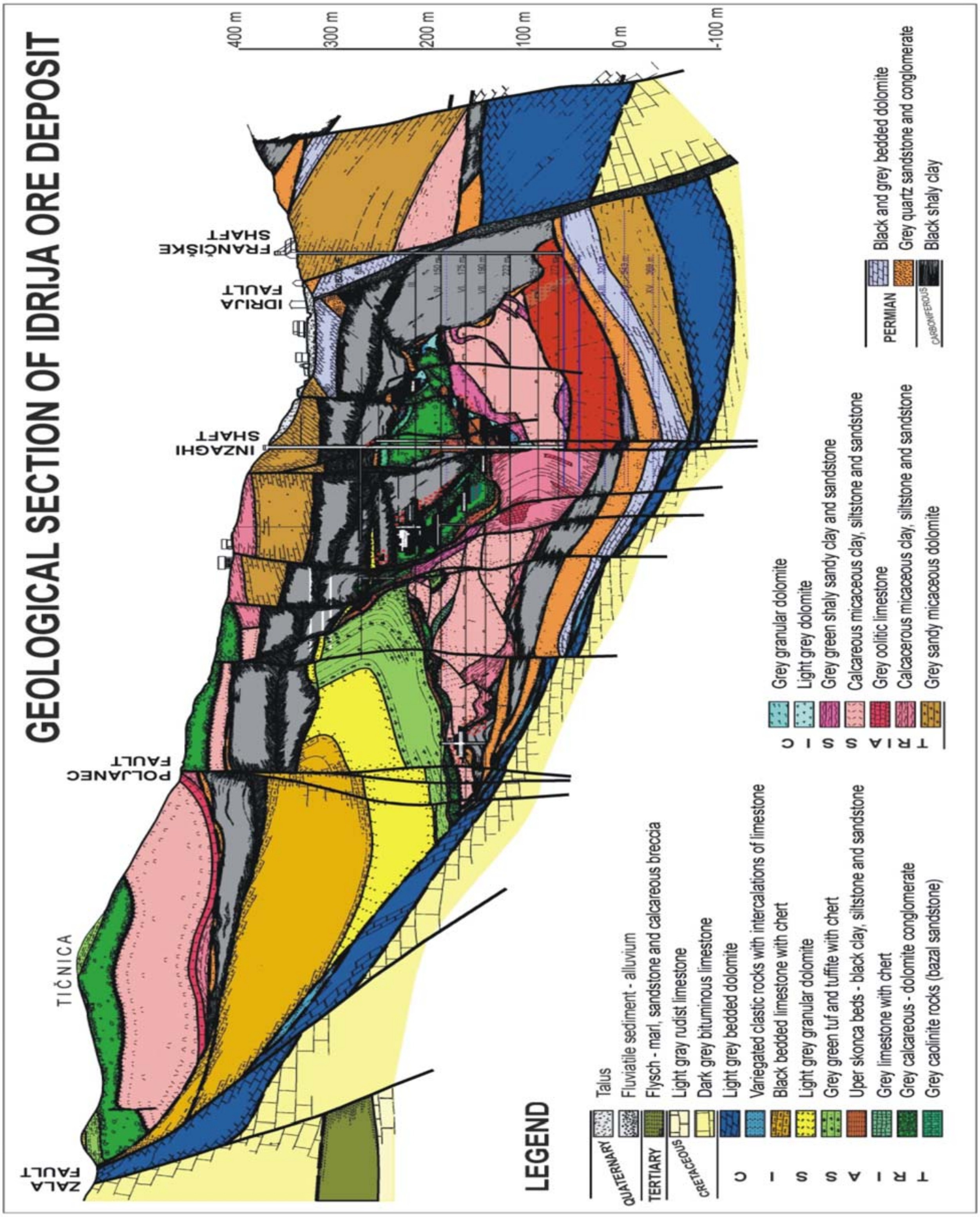


Fig. 2: General geological profile through the Idria ore deposit (Čar, 1985).



FIELDTRIP 5: DOVŽANOVA SOTESKA GORGE

DOVŽANOVA SOTESKA: CLASSICAL LOCALITY OF FOSSIL-RICH LATE PALEOZOIC ROCKS

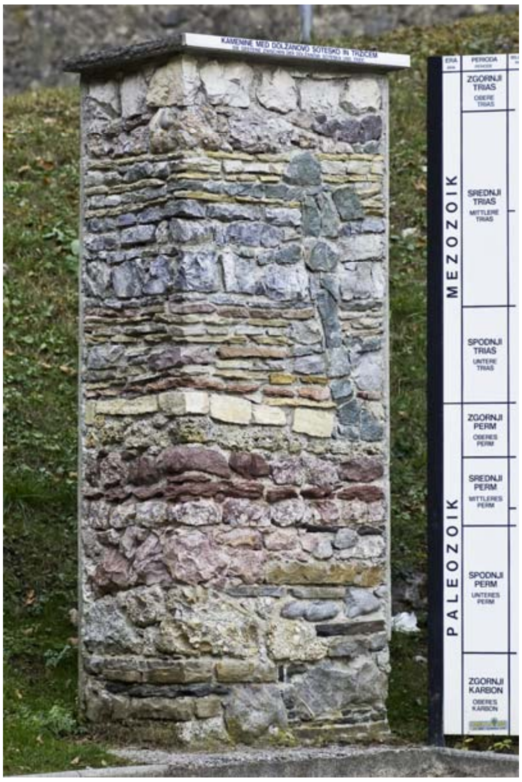
Matevž Novak, Geological Survey of Slovenia

Introduction

The Dovžanova soteska (Dovžan's gorge), NE of the town of Tržič, also known in literature as Teufelsschlucht (devil's gorge), is geologically one of the most interesting places in Slovenia. This scenic north-south trending valley of the Tržiška Bistrica River, sculptured by tectonic forces and differential weathering processes, cuts deep into southern slopes of the Karavanke Mountains and exposes a long section of fossil-rich Late Carboniferous and Permian beds. Especially due to a long history of paleontological studies of numerous and diverse fossils, the Dovžanova soteska has become famous worldwide (see Forke & Novak, this volume).

Generally, beds dip steeply toward southwest and are therefore gradually older from the lower entrance through the tunnel upwards to the village of Dolina.

Entrance to the george Dovžanova soteska. Photo Marko Simić



Geological column as an interpretation approach. Photo Marko Simić

Stop 1

The oldest part of the sequence is composed of quartz-rich conglomerates, trough and hummocky cross-bedded sandstones and bioturbated siltstones. Ichnofossil genera *Zoophycos*, *Thalassinoides*, *Chondrites*, *Skolithos*, and *Arenicolites* are elements of mixed *Cruziana-Skolithos* ichnofacies. Thick limestone complexes between siliciclastics represent algal mounds in which basal, core, flanking and capping beds can be distinguished. Basal beds are usually very rich in fusulinid foraminifera *Quasifusulina longissima ultima*, *Daixina alpina*, *D. communis*, *Dutkevitchia* aff. *multiseptata*, and *"Schellwienia"*, smaller foraminifera, ostracodes, gastropods, brachiopods, and bryozoans. Almost unbroken thalii of *Anthacoporella spectabilis* and *Archaeolithophyllum missouriense* in growth position build the delicate framework of the massive micritic mound core. In flanking beds, they are accompanied by fragments of phylloid algae and encrusted with *Tubiphytes* or small sessile foraminifera. The capping beds are composed predominantly of crinoid debris.

Based on fusulinids and lithological similarities the described beds are correlated with Auernig Formation of Gzhelian E. However, in the upper part of this sequence large inflated forms belonging to subgenus *Daixina (Bosbytauella)* occur together with *Dutkevitchia expansa*, *Rugosofusulina stabilis*, *Schwageriniformis* sp., and *Ruzhenzevites* aff. *parasolidus*. This assemblage indicates Gzhelian F and corresponds to fusulinid fauna of the Schulterkofel Formation in Carnic Alps. It is also present in oolitic limestone covering the thick massive to thick-bedded quartz conglomerate unit and thus speaking for its uppermost Carboniferous age (Novak, 2007).

The sedimentary succession shows cyclic clastic-carbonate deposition pattern, known as Auernig cyclothems in the similarly developed units in Carnic Alps (Austria/Italy). Lithofacies types indicate sedimentation on a gently steeping ramp with storm dominated depositional mechanisms in a coastal to shallow marine setting and strong influence of coarse-grained fluvial/deltaic deposits from the hinterland. Just below the storm wave base calcareous algae formed massive mounds. Rapid facies changes reflect both high frequency and high amplitudes of sea-level changes due to glacio–eustatic control associated with waxing and waning of the Gondwanan ice sheet.

Stop 2:

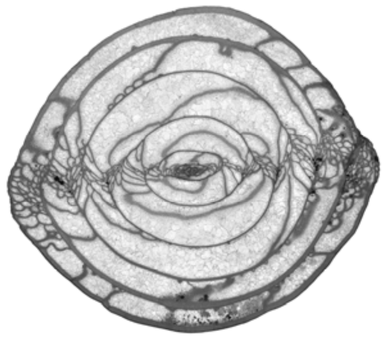
In Dovžanova soteska, the Carboniferous/Permian boundary is not exposed due to tectonic contact. Lowermost Permian succession of the Dovžanova soteska Formation shows clear transgressive-regressive trend starting with dark nodular fossiliferous limestones with marl intercalations and micaceous siltstones full of crinoid stems and lense-shapped sandstone interlayers. These beds are overlain by dark grey thin-bedded limestones gradually passing into light grey to pale red indistinctly bedded to massive Dovžanova soteska limestone Member. Lacking true reef-building metazoans and reefal cementation, this limestone consisting of bryozoan, spongial and algal debris encrusted with *Tubiphytes* and sessile foraminifera in micritic matrix forms, what we call a reef (or skeletal) mound. Limestone of the upper part of this unit that was erroneously correlated with much younger Trogkofel Limestone in Carnic Alps for decades is thick-bedded and characteristically dark red coloured. In times when they were cutting architectonic stone in the now abandoned quarry, many fossils were collected from this horizon. Ernst Schellwien was the first to study these fossils systematically. In two papers (Schellwien, 1898a, b) he first reported of the 75 different taxa of foraminifers, gastropods, bivalves, brachiopods, corals, and ammonites from this limestone. In the following monography (Schellwien, 1898c), he described fusulinids and in the next one (Schellwien, 1900) brachiopods. Among 81 listed taxa of productids, spiriferids, terebratulids, and rhynchonellids, 21 were new. Both monographies hold good to be basic standard works on systematic paleontology of these two fossil groups in Southern Alps. Schellwien's work was later resumed by Franz Heritsch with a revision of brachiopod determinations and description of corals and first trilobite find (*Phillipsia oehlerti*) (Heritsch, 1933, 1938). Later, Anton Ramovš established a new brachiopod subfamily Karavankininae with a new species *Karavankina schellwieni* from these beds (Ramovš, 1966). Recently found conodonts of genera *Streptognathodus*, *Hindeodus*, and *Diplognathodus* together with fusulinids *Dutkevitchia complicata*, *Pseudoschwagerina* aff. *uddeni*, *Sphaeroschwagerina citriformis*, and *Sph. carniolica* speak for early to middle Asselian age of these limestones, deposited on a reef-flank in forereef setting (Buser & Forke, 1996; Forke, 2002; Novak, 2007).

Stop 3:

The basal quartz conglomerate of the Born Formation cuts into brecciated uppermost beds of red limestone with a clear erosional disconformity. Due to transgression, the sedimentation moved to deeper water environment on the slope of the shelf. Often folded beds of dark hemipelagic limestones with shale intercalations contain numerous thalii of phylloid algae *Epimastopora alpina* and *E. likana*, many genera of smaller foraminifera and fusulinids, and in some places many large planispiral euomphalid gastropods. In 1937, Franz and Gustava Kahler described a new fusulinid species *"Pseudochwagerina"* (later emended into *Sphaeroschwagerina*) *carniolica* from these limestone beds. This large spherical foraminifer has become a local symbol for geological heritage of the Dovžanova soteska.

One of the rock pyramids is built of massive light grey micritic limestone with rugose coral *Carinthiaphyllum kahleri* forming isolated bioherms (Holzer & Ramovš, 1979). Siliciclastic to mixed carbonate-siliciclastic rocks that interrupt limestone succession three times have characters of turbiditic and debritic systems (Novak, 2007). Fusulinid assemblage of *Sphaeroschwagerina carniolica*, *Paraschwageria pseudomira*, *Pseudochusenella pseudopointeli*, *Rugosofusulina latispiralis*, and *R. likana* indicates middle to late Asselian age of these beds.

Sphaeroschwagerina carniolica - axial section. One cm in diameter. Photo Matevž Novak



Sphaeroschwagerina carniolica - equatorial section. One cm in diameter. Photo Matevž Novak

Stop 4:
With the deposition of Tarvis breccia, a new tectono-sedimentary cycle started in Southern Alps in the Middle Permian. This formation discordantly overlying older rocks and consists of thick layers of colourful coarse-grained polymict limestone breccia intercalated with equally thick layers of violet-red quartz siltstone. Upwards and laterally these beds pass gradually into clastic red beds of the Val Gardena Formation. They have been interpreted as the deposits of alluvial fans and/or delta fans with periodic lacustrine pans and sabkhas.

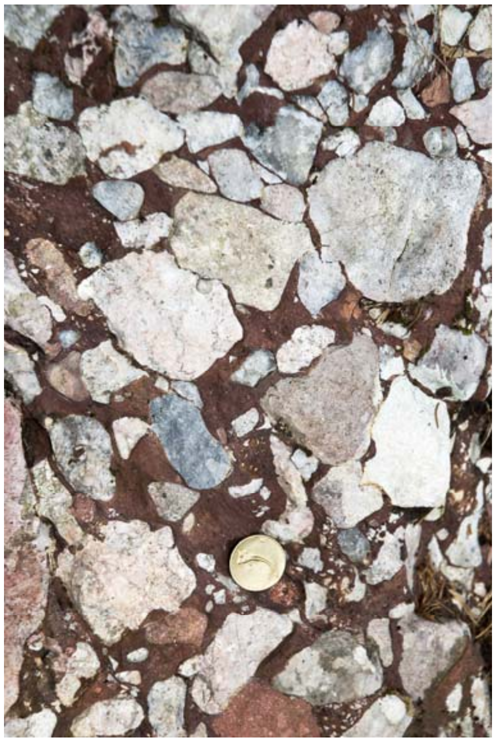


Photo Marko Simić

References

Buser, S. & Forke, H. C. 1996: Lower Permian conodonts from the Karavanke Mts. (Slovenia). – *Geologija* 37, 38 (1994/95), 153-171, 5 figs., 1 tab., 2 pls., Ljubljana.

Forke, H. C. 2002: Biostratigraphic Subdivision and Correlation of Uppermost Carboniferous/Lower Permian Sediments in the Southern Alps: Fusulinoidean and Conodont Faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). – *Facies* 47, 201-276, 17 figs., pls. 35-44, Erlangen.

Heritsch, F. 1933: Rugose Korallen aus dem Trogkofelkalk der Karawanken und der Karnischen Alpen. – *Prirod. razprave* 2, 42-55, Taf. 5-6, Ljubljana.

Heritsch, F. 1938: Die stratigraphische Stellung des Trogkofelkalkes. – *N. Jb. Min. etc.* Bd. 79, Abt. B, 63-186, Stuttgart.

Holzer, H. L. & Ramovš, A. 1979: Neue rugose Korallen aus dem Unterperm der Karawanken. – *Geologija* 22/1, 1-20, 3 sl., 2 tab. med tekstom, 5 tab., Ljubljana.

Kahler, F. & Kahler, G. 1937: Beiträge zur Kenntnis der Fusuliniden der Ostalpen: Die Pseudoschwagerinen der Grenzlandbänke und des oberen Pseudoschwagerinenkalkes. – *Palaeontographica* 87/Abt. A, 1-44, Stuttgart.

Novak, M. 2007: Biostratigrafija mlajšega paleozoika Dovžanove soteske. Ph. D. Thessis – *Fac. for nat. sci. and engineering, University of Ljubljana*, 159 pp., 45 Pls., Ljubljana.
Ramovš, A. 1966: Revision des "Productus elegans" (Brachiopoda) im ostalpinen Jungpaläozoikum. – *N. Jb. Geol. Paläont. Abh*. 125, 118-124, 1 Abb., Taf. 11., Stuttgart.
Schellwien, E. 1898a: Die Auffindung einer permokarbonischen Fauna in den Ostalpen. – *Verh. Geol. R.-A*. (1898), 358-363, Wien.
Schellwien, E. 1898b: Bericht über die Ergebnisse einer Reise in die karnischen Alpen und die Karawanken. – *Sitzungsberichte der k. preuss. Akademie der Wissenschaften, Phys.-math. Kl*., 693-700, Berlin.
Schellwien, E. 1898c: Die Fauna des karnischen Fusulinenkalkes, Teil II: Foraminifera. – *Palaeontographica* 44, 237-282, 7 Abb., Taf. 17-24, Stuttgart.
Schellwien, E. 1900: Die Fauna der Trogkofelschichten in den Karnischen Alpen und den Karawanken. – *Abh. Geol. R.-A*. Band 16, Heft 1, 1-122, 15 Abb., 15 Taf., Wien.

ON THE HISTORY OF FUSULINID AND BRACHIOPOD COLLECTIONS FROM DOVŽANOVA SOTESKA

Holger Forke, Museum für Naturkunde Berlin
Matevž Novak, Geological Survey of Slovenia

The Dovžanova soteska (Dovžan's gorge), NE of the town of Tržič, is one of the richest localities of Late Paleozoic fossils in the Southern Alps (see Novak, this volume). By being the locus typicus of many newly described species, it is not only interesting for amateur fossil-collectors, but also for experts in paleontology. However, the Dovžanova soteska is also an example of how problematic can be both, the "in situ" and the "ex-situ" preservations of natural heritage. Nowadays unfortunately, very little is left to be seen along the road at what used to be the richest places. To find a nice piece, one has to climb up the steep slopes of the gorge. One would face with similar difficulties, if he would be interested in the study of specimens, described in literature. They are scattered about museums, institutes, faculties, and private collections, unfortunately, some of them are lost or destroyed. The preservation of the type material, however, is one of the very important scientific aspects for the protection of the collections and the locality itself.

Ernst Schellwien was the first to study fossils of Dovžanova soteska systematically. He made his dissertation on brachiopods from the Carnic Alps at the Martin-Luther University in Halle-Wittemberg (Germany). In 1896, he became a Professor at the Albertina University Königsberg (today's Kaliningrad). Schellwien first solicited Conrad Schwager, one of the leading foraminifera specialists at that time, to investigate the fusulinid collection from the Carnic Alps and Karavanke Mts. Unfortunately, Conrad Schwager died and Schellwien decided to undertake the task himself (1898, p. 237). He additionally gathered material from all over the world to write a monography about fusulinid foraminifera. Furthermore, he loaned material from the famous Valerian v. Moeller's collection of Russian holotypes from the Moscow Basin. The first part about the fusulinids from the Carnic Alps and Karavanke Mts. (Dovžanova soteska and surroundings) was published in 1898. During the final stage of his manuscript on the fusulinids from Russia, the Arctic, and Central Asia, he was suddenly overtaken by death in 1906. The successor, Prof. Tornquist, has sent the material to Schellwien's colleague and friend Prof. Frech in Breslau (today's Wroclaw).

Prof. Frech instructed his assistant Hans v. Staff to continue the work of Schellwien. Staff dedicated his work from then on to the study of fusulinids. He posthumously published the second part of Schellwien's monography with the material from Russia and the Arctic (1908). However, already in 1908 he moved to the Museum of Natural History at the University of Berlin, where he qualified as an academic lecturer in 1909. Since 1911, he became involved in the famous Tendaguru Expeditions (1909-1912), where he worked as a geomorphologist. In 1914, he became an Extraordinary Professor at the University of Berlin and left for Namibia as government geologist. He was infected by typhus and died in South Africa in 1915.

After v. Staff had left Breslau, Prof. Frech instructed his assistant Dr. Günther Dyhrenfurth to finalize the work on Schellwien's material. The third part of the monography dealt with the fusulinid material from Central Asia (1909). Günther Dyhrenfurth and his wife (Hettie Dyhrenfurth), however, were more fascinated by the Himalaya mountain ranges and became a famous alpinist couple. They were among the first, who were filming and climbing above 7000m during several Himalayan Expeditions (1930, 1934). They received the “Prix olympique d’alpinisme” for their merits during the Olympic Games 1936 in Berlin.

The fusulinid collection of Prof. Schellwien has obviously been sent back to the University of Königsberg before 1910 (Staff, 1912, p. 163). Since then, the collection was buried in oblivion, and it was most likely destroyed at the end of the World War II, when the city of Königsberg was razed to the ground.

Schellwien also studied the exceptionally numerous and diverse brachiopod fauna from light-grey to dark-red Lower Permian limestone complex in the Dovžanova soteska. Some of the specimens he found himself, but the majority was collected by the workers in the quarry and sent to him by it's director. Brachiopods of this large collection, from which Schellwien described 81 taxa in 1900 are mainly stored in the Geological Survey (GBA) in Wien, some specimens obviously are reposited in Tübingen, Graz and Berlin. They are listed in the nicely arranged database, accessible at http://www.oeaw.ac.at/austrofossil/.

In the 1930ies, Austrian scientists from the University of Graz (Heritsch, Kahler, and Metz, 1934) started a new campaign to study the Late Paleozoic sequences in the Carnic Alps and Karavanke Mts.. Prof. Franz Kahler with his wife Gustava collected material from the Dovžanova soteska and described several new species (e.g. “*Schwagerina*” *carniolica*, “*Schwagerina*” *citriformis*) (Kahler, F. & Kahler G., 1937, 1941). After Kahler’s death in 1996, the material has been donated by his son in law (famous Prof. Eric Flügel) to the Senckenberg Museum in Frankfurt/Main (Germany).

Franz Heritsch, while undertaking a revision of Shellwien's brachiopod determinations, described also few specimens, lent to him by Prof. Ivan Rakovec from the collection of Department of Geology at the University of Ljubljana. Among them, he described *Spirifer rakoveci* as a new species (Heritsch, 1938).

Recently, the Kahler's fusulinid collection in Frankfurt has been recently expanded with new material from the Dovžanova soteska by Forke, who also described two new species *Rugosofusulina latispiralis* and *Rugosofusulina minuta* (Forke, 2002).

A large collection of thin-sections with fusulinids and many isolated specimens, recently described in Novak's Ph. D. Thesis (Novak, 2007) is held in Geological Survey of Slovenia.

References

Forke, H. C. 2002: Biostratigraphic Subdivision and Correlation of Uppermost Carboniferous/Lower Permian Sediments in the Southern Alps: Fusulinoidean and Conodont Faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). – *Facies* 47, 201-276, 17 figs., pls. 35-44, Erlangen.

Heritsch, F. 1938: Die stratigraphische Stellung des Trogkofelkalkes. – *N. Jb. Min. etc*. Bd. 79, Abt. B, 63-186, Stuttgart.

Heritsch, F., Kahler, F. & Metz, K. 1934: Die Schichtfolge von Oberkarbon und Unterperm. In: Heritsch, F., (ed.), Die Stratigraphie von Oberkarbon und Perm in den Karnischen Alpen. – *Mitt. geol. Ges.* 26, 163-180, Wien.

Kahler, F. & Kahler, G. 1937: Beiträge zur Kenntnis der Fusuliniden der Ostalpen: Die Pseudoschwagerinen der Grenzlandbänke und des oberen Pseudoschwagerinenkalkes. – *Palaeontographica* 87/Abt. A, 1-44, Stuttgart.

Kahler, F. & Kahler, G. 1941: Beiträge zur Kenntnis der Fusuliniden der Ostalpen: Die Gattung *Pseudoschwagerina* und ihre Vertreter im Unteren Schwagerinenkalk und im Trogkofelkalk. – *Palaeontographica* 92/Abt. A, 59-98, Stuttgart.

Novak, M. 2007: Biostratigrafija mlajšega paleozoika Dovžanove soteske (Ph. D. Thessis). – *Fac. nat. sci. and engineering, University of Ljubljana*, 159 pp., 45 Pls., Ljubljana.

Schellwien, E. 1898a: Bericht über die Ergebnisse einer Reise in die karnischen Alpen und die Karawanken. – *Sitzungsberichte der k. preuss. Akademie der Wissenschaften, Phys.-math. Kl*., 693-700, Berlin.

Schellwien, E. 1898c: Die Fauna des karnischen Fusulinenkalkes, Teil II: Foraminifera. – *Palaeontographica* 44, 237-282, 7 Abb., Taf. 17-24, Stuttgart.

Schellwien, E. 1900: Die Fauna der Trogkofelschichten in den Karnischen Alpen und den Karawanken. – *Abh. Geol. Reichsanst.* Band 16, Heft 1, 1-122, 15 Abb., 15 Taf., Wien.

Schellwien, E. 1908: Monographie der Fusulinen. Teil I: Die Fusulinen des russisch-arktischen Meeresgebietes (von H. v. Staff). – *Palaeontographica* 55, 145-194, 8 pls., Stuttgart.

Schellwien, E. 1909: Monographie der Fusulinen. Teil II: Die asiatischen Fusulinen (von G. Dyhrenfurth). A. Die Fusulinen von Darwas. – *Palaeontographica*, 56, 137-170, 4 pls., Stuttgart.

Staff, v. H. 1908: Über Schalenverschmelzungen und Dimorphismus bei Fusulinen. – *Sbr. Ges. Naturf. Freunde Berlin* 9, 217-237, Berlin.

FIELDTRIP 6: LEAD AND ZINC MINE MEŽICA

SHORT OVERVIEW OF THE MEŽICA SURROUNDINGS

Adapted and translated by Marko Vrabec and Uroš Herlec.
Based on an article written by Placer, L., Vrabec, M., Trajanova, M. Kratek pregled geologije okolice Mežice (Short overview of the Mežica surroundings).- In: Horvat, A. et al. (eds.). 1. slovenski geološki kongres, Črna na Koroškem, 9.-11. oktober 2002. *Vodnik po ekskurzijah*. Ljubljana: Geološki zavod Slovenije, 2002, 3-14.

The field trip is intended for an informative visit of the geological structure of Mežica mines of lead and zinc and their close surroundings. For a short introduction main stratigraphic, tectonic and ore genetic characteristics are presented. We used data from several already published articles, which are listed at the end of this presentation.

STRATIGRAPHY OF THE NORTHERN KARAVANKE MTS.

Northern Karavanke Mts. are part of the uppermost structural unit of the Eastern Alps and together with Zilian Alps belong to the Drauzug Unit, which in most part outcrops in the territory of Austria. Stratigraphic development of the rock succession is almost identical to those in the Northern Calcareous Alps and it is shown at the Stratigraphic column on the Fig. 1.1. In the area of Northern Karavanke Mts. West of the Labot (Lavanttal) fault metamorphic rocks of the Pohorje Formation crop out, with prevailing gneisses and laterally and vertically intercalated micashists, and minor lenticular bodies of marble, amphibolite and quartzite. Also rocks of the ultrahigh pressure eclogite facies outcrop in the core of the Pohorje massive, but are not present in the excursion area. Deepest part of the Pohorje Formation can be followed on the surface east of the Mežica region along the regionally important Labot fault in the area between Slovenj Gradec and Dravograd. Here, amphibolite lenses and sporadically marble lenses are present within the gneiss-micashist country rock. At a higher structural level, in the belt running from Ravne na Koroškem north-westward towards Libeliče, there are also regionally metamorphosed pegmatite dikes. In deep gorges the pegmatites also crop out south of Ravne and Prevalje. Pohorje Fm. was formed during regional metamorphism of pelitic sediments and marls sedimented on the past continental margin. Mineral paragenesis, as well as the succession and type of deformations indicate multiphase progressive metamorphosis and partial secondary retrograde alterations. Progressive regional metamorphosis is assigned to the Varistic and Early Alpine Orogeny achieved mineral stability of sillimanite respectively filed of the granite melt formation with maximal temperatures up to around 600ºC. Progressive metamorphosis is the result of the Cretaceous Eoalpine orogenetic phase retrograde metamorphic alteration took place in the Middle and Late Alpine cycle. The area then underwent extensional collapse in Upper Cretaceous, and finally rapid extensional exhumation in Miocene during the opening of the Pannonian basin. Retrograde metamorphism, reactivation and neoformation of mylontic fabric, Neogene magmatism, low-temperature rock alteration processes, and eventually brittle deformation affected the region.

On the Strojna Mts. and some smaller areas south of Prevalje, Pohorje Fm is overlain by biotite amphibolitic shists which contain epidote and tiny garnets (in the lower parts). Upwards, rock varieties with more chlorite prevail. In the lower part of the unit, there is locally a transition of amphibolite schist into amphibolite (actually metadiabase). These rocks are of greenschists facies and form the Strojna thrust sheet.

The next structurally higher unit is the Phyllite Fm. east of the Labot Fault phyllite gradually changes into greenschist but in the area of Strojna the contact between the two rock types is a low-angle fault. It is now believed that the Phyllite unit is actually the strongly mylonitized principal shear zone of the Pohorje-Kozjak extensional core complex, which was active in middle Miocene.

Rocks of this formation belong to chlorite sub-facies of the greenschists. They presumably formed from clastic rocks ranging from claystones to sandstones, containing some acidic tuffitic admixture. The formation also contains dykes of the quartz meta-keratophyre, lenses of marble with silicates, and some quartzite. Together with the already described greenschists with basic to more acid metavolcanites, they indicate synorogenic volcanic activity along the continental margin.

The metamorphic formations are not present in the eastern part of the Northern Karavanke Mts. The only exception is the Štalenska gora (Magdalensberg) Fm, which extends into the area from Austria. This formation crops out at the

Čofatijev vrh hill, around the town of Črna na Koroškem, and in Javorski potok and Velunja valleys. On the Čofatijev vrh hill the rocks were altered into hornfels due to contact metamorphism at the contact with the syenogranite intrusion.

The Štalenska gora Formation is divided into two levels. The lower, Ordovician to Silurian level consists of weakly metamorphosed claystone with well-preserved sedimentary structures. It is dissected by dikes of Miocene age. The upper, Silurian to Devonian level is represented by violet and green mafic tuffitic clayey shists, occasionally altered into meta-marls and meta-carbonates containing diabase dikes and sills of the spilitic character. This formation was initially interpreted as a weakly metamorphosed tectonic repetition of the greenschist formation, but it was later discovered that the rocks differ significantly in geochemical composition. The upper horizon is intersected by diabase dikes and sills. Geochemical analyses show that these are submarine alkali olivine basalts and can be separated from much different tholeitic basalts. They were interpreted either as old dikes of the oceanic island back arcs (BAB), or as non-simatic island arc formed in the intra-oceanic realm.

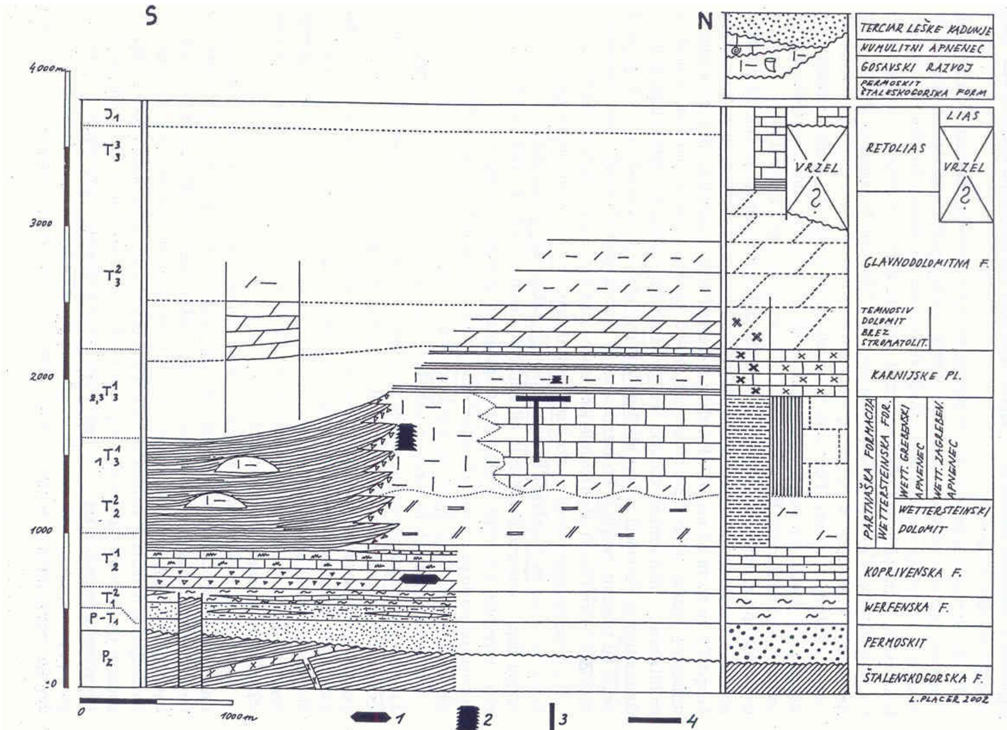
Unique are the metamorphic rocks of the Železna kapla (Eisenkappel) Magmatic Zone, wedged between the syenogranite and the tonalite. They are in a primary intrusive contact with syenogranite, and in tectonic (steep to subvertical fault) contact with tonalite. Probably they were formed by the contact metamorphosis of the Štalenska gora Fm., which is much more altered here than at the northern contact and transformed into very fine blastic biotite gneiss and micashist. The contact metamorphic facies corresponds to the transition from amphibolite to K-feldspar cordierite hornfels facies.

Alpine [Tethyan] cycle of sedimentation started with sedimentation of Permo-Scythian clastites discordantly on the metamorphic rocks of Štalenska gora Fm. Marls, sandstones and carbonates of the Lower Triassic Werfen Fm. and rocks of predominately Anisian age, named »Alpiner Muschelkalk« by Austrian researchers, follow. There are some differences between the stratigraphic development in the Topla valley and in the Javorski potok area. In both areas, dolomites are present in the lower part, and limestones in the upper part, however the dolomite of the Topla region contains a singenetic zinc-lead ore deposits, whereas in Javorje this horizon is characterised by widespread denticulate intercalations of dolomite intraformational breccias with limestone marly matrix. Weathered and selectively dissolved matrix reveals honeycomb and cellular texture. In the overlying limestone beds there are beds and nodules of chert. In the higher part of the limestone horizon there are also beds of green tuff.

Above the Koprivna Fm., there are two different developments of the Middle Triassic rocks. In the southern part of the Karavanke Mts., limestone with chert nodules is replaced by marl and mudstone in the higher parts of the succession. Of the Partnach Fm. with some slope reef formation up to I hundred metres in lengths and several tens of metres wide. In the central and northern part, thinly-bedded limestone changes to coarse-grained non-layered dolomite of the Wetterstein Fm. The Wetterstein Fm. in the central area of the Eastern Karavanke Mt consist of two facies, the Wetterstein reef massive limestone, and the Wetterstein thickly bedded back-reef limestone, occurring in the northern part. Wetterstein and Partnach Fms are covered by clastic rocks and carbonates of Carnian age, supposed to become thicker above the Partnach Fm. and thinly bedded above the reef and back reef facies of the Wetterstein Fm. Carnian beds comprise a succession of three clastic and three carbonate horizons.

The Carnian beds are uniformly covered by platy limestone, which in the area north of the Wetterstein reef gradually changes into the lower horizon of well-bedded stromatolitic Main Dolomite (Hauptdolomit) Fm., covered by weakly-bedded coarse grain dolomite. A special type of the lower horizon of the Main dolomite Fm. is developed in the area of the Partnach Fm. It is thicker than the synchronously deposited beds above the platform, it does not have stromatolites, and it is more or less dark gray in colour. It was formed in the constantly flooded environment, and it is probably connected with the compaction of the clastic rocks within the Partnach and Rabelj Fms. When compaction was finished, the level of sedimentation of the Main dolomite Fm. was levelled, and from then on the sedimentary succession is uniform in the whole area of the Northern Karavanke Mts.

Stratigraphic development above the Main dolomite Fm. is one of the least investigated stratigraphic problems of the Eastern Karavanke Mts. Due to the fact that it only outcrops away from the mineralised areas, it was never thoroughly investigated. According to the present knowledge there are two developments, the first in the area of Mežica, where it seems that the Main dolomite Fm. is replaced by black claystone, which could be correlated to the Koessen Fm, and then thickly bedded limestone of the Rhetian age. This limestone is gradually replaced by bedded Lower Jurassic limestone. Disconformity is partly erosional, and partly also presumably an angular unconformity, which indicates intensive tectonics on the border between Triassic and Jurassic.



Slika 1.1. Litostratigrafska lestvica Severnih Karavank. Legenda: 1 – singenetsko orudenje (konkordantno), 2 – impregnacijsko orudenje, 3 – žilno orudenje (diskordantno), 4 – medplastovno orudenje (konkordantno).

Fig. 1.1. Lithostratigraphic column of the Northern Karavanke Mts. Legend: 1 - syngenetic mineralization of the Topla mine within the Anisian Koprivna Fm.; Epigenetic ore deposits within the Ladinian Wetterstein Fm: 2 – open void filling and metasomatic replacement, 3 – epigenetic vein (discordant) type of mineralization, 4 – epigenetic stratabound (concordant) mineralization along the permeable paleokarst horizons.

On the **Fig. 1.1**, the stratigraphic column of the presented formation is idealised. Rock of the Cretaceous and younger age are present at the northern foot of the Eastern Karavanke Mts. Upper Cretaceous non-bedded limestones with rudist bivalves can be found at Vrhe near Slovenj Gradec, where there are lying discordantly on Štalenska gora Fm. Eocene limestone with nummulites is tectonically bonded within the thrust zone of the Northern Karavanke Thrust. Miocene clastic sediments fill up the Leše tertiary basin and build the hills between the Eastern Karavanke Mts. and the Labot fault. Miocene beds were deposited discordantly over the Northern Karavanke Mesozoic unit. Tertiary clastic rocks of a fluvial fan facies were found on top of the Northern Karavanke sedimentary succession, but their precise age was not determined yet.

MAGMATIC ACTIVITY

In the area of the Eastern Karavanke Mts., the Pohorje Fm contains pegmatitic dikes, subsequently regionally metamorphosed. They were formed with partial melting of the surrounding metapelites around 186 to 172 million years. Within the Phyllite Fm., there are intrusions of meta porphyry, whose age has not been determined radiometrically yet, Chemically they correspond to volcanic equivalents of granitic magma. The already mentioned horizon of Silurian to Devonian splitised diabase in the Štalenska gora Fm. follows. Tuff was found in the upper part of the Anisian Koprivna Fm., which was mapped in Topla, but not properly analysed yet. Tuffs within this formation were also reported from the western part of the Northern Karavanke Mts. The third known magmatic horizon is represented by Miocene dacite in the eastern part of the Eastern Karavanke, occurring as dikes within the Štalenska gora Fm. and within heavily tectonized Upper Triassic dolomite of the Northern Karavanke thrust.

Within the Železna kapla (Eisenkappel) magmatic zone, there are two magmatic units of different age and lithology. The northern syenogranitic body is of the Upper Permian to Triassic age, indicated by radiometric measurement (from around 244 to around 224 Ma). Prevailing are syenogramites and syenites with enclaves of mafic and intermediate composition, which prove the interaction of mafic and felsic magma supported by the rapakivi texture. They are interpreted to be of anorogenic to postorogenic tectonic character, presumably corresponding to the Western Mediterranean magmatic province. Southern body of the Železna kapla magmatic zone is of tonalitic composition. It belongs to the Oligocene intrusives, emplaced along the Periadriatic fault zone. Geochemistry of the rare and trace elements implies fractionated crystallisation of the primary mafic magma and considerable admixture of the continental crust. The Železna kapla tonalite belongs to the field of Adamello pluton and is of post-orogenetic type.

STRUCTURE OF THE NORTHERN KARAVANKE Mts.

Brittle faulting and thrusting, mainly related to motion along the Periadriatic fault zone, are the predominant mechanisms of deformation in the Northern Karavanke Mts.

Periadriatic fault system is one of the most prominent structures in the Alps. It can be followed along the entire orogen in the length of more than 700 km and divides the Southern Alps from the northerly lying Western, Central and Eastern Alps (**Fig 1.2**) It was formed in the youngest, post collisional stage of tectonic development of Alps, which started approximately 35 Ma ago. Before that, between 50 and 35 Ma, when subduction of the oceanic crust in the alpine realm was ended, the Adriatic and European continental plates collided. In Oligocene the heavy subducted oceanic slab break off and sunk into the mantle. Partial melting of the mantle along the slab tear is believed to have resulted in tonalite and granite intrusions, concentrated in a narrow linear belt along the Periadriatic fault. The steeply dipping fabric of the Periadriatic fault channelled the magma flow. Some researchers also suppose that the movements along the Periadriatic fault accelerated magma uplift. Alternatively, the location of the Periadriatic fault could be predetermined with the linear zone of heating above the slab tear-off.

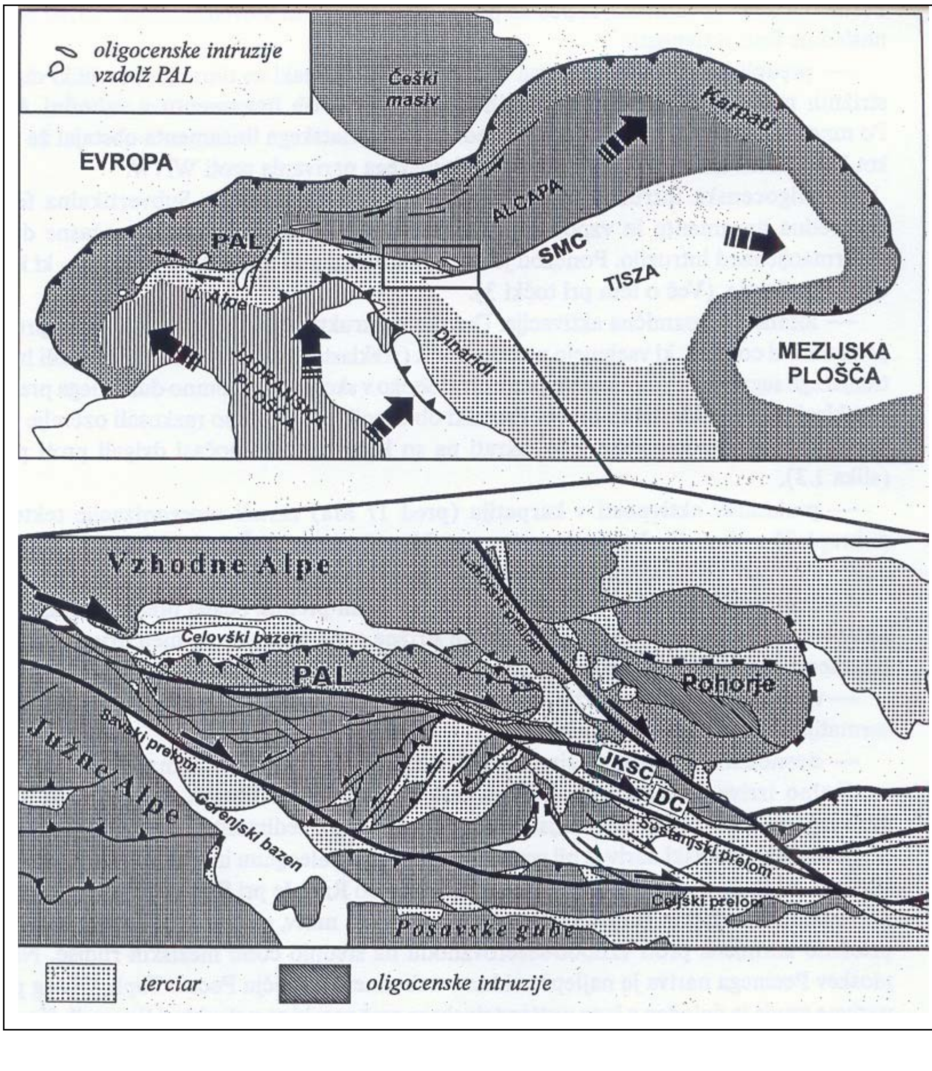


Fig. 1.2. Position and geometry of the Periadriatic fault system (PAL) within the Alpine orogen. The location of major Oligocene magmatic intrusions along the PAL is shown. Enlarged sector on the lower figure present the structure of the PAL and associated faults in Slovenia (modified after Fodor et al., 1998). Legend: DC – Donačka gora zone, JKSC – Southern Karavanke shear zone, PAL – Periadriatic fault, SMC – Middle Hungarian zone.

Further convergence of the lithospheric plates was absorbed by collisional processes. At the beginning of Miocene, the indenting Adriatic lithosphere longitudinally split the European lithosphere, producing as a consequence vertical extrusion of the deep parts of the Central Alps and backthrusting of the Southern Alps towards the south. But and important part of the N-S convergence between Adria and Europe was also absorbed by lateral extrusion of the mass outside of the collisional zone. During Oligocene and Miocene, the entire area of the Eastern Alps was extruded in the eastward direction for a distance of more than 100 km. A major part of this motion was laterally accommodated by dextral slip on the Periadriatic fault. In the territory of Slovenia, the Periadriatic fault cut and displaced the sedimentary basin of Paleogene age. The northern half of the basin, previously attached to its southern counterpart in Slovenia, is now outcropping in Central Hungary, indicating some 500 km of dextral separation. However, only about 100 km of this distance can be attributed to actual dextral motion on the fault, the rest being a result of extreme extension within the extruding unit during middle and upper Miocene.

Due to continuous tectonic activity since Oligocene and synchronous uplift toward the surface, which had exposed the originally deeper parts of the crust, the outcrops in the Periadriatic fault zone offer fantastic insight into the many ductile and brittle mechanisms of deformation which act within the fault zones. In the easternmost outcroping part of the Periadriatic fault, which is crossing the territory of Austria and Slovenia (**Fig. 1.2**), the following phases of activity were documented:

- Pre Oligocene sinistral strike-slip tectonics, which can be recognised in the form of ductile shear microstructures in the magmatic rocks near the fault in Tyrol, Austria. Tectonic and paleogeographic considerations imply that the precursor of the Periadriatic fault existed already in Cretaceous, acting as a sinistral strike-slip transfer fault, accomodating motion of the Austroalpine thrusts towards WNW.
- Oligocene intrusion of tonalitic magmas along the fault. Subvertical foliation parallel to the fault and fault-parallel stretching lineation indicate N-S flattening of the intrusion. Solid-state mylonitic fabric, indicating dextral shear along the fault, was observed at some outcrops. (More explanation at the Stop).
- Brittle dextral strike slip reactivation. Ductile structures are cut by brittle faults with fault zones containing pseudotachylite (vitreous rock, generated 10-15 km deep in the litosphere due to instanteneous frictional heating of rock during earthquakes, close to the brittle-ductile transition), cataclasites and cataclastic breccias. Secondary brittle faults form a contractional strike-slip duplex strucutre, characterized by elongated lenses of rock. Synchronously, the rocks were slowly uplifted towards the surface (**Fig. 1.3**).
- Interruption of tectonic activity in Carpathian (17 Ma ago) due to reorganisation of tectonic microplates in the area of Pannonian basin. On the east, between Šaleška kotlina depression and Vitanje, the Periadriatic fault zone was discordantly overlain by Carpathian sediments.
- Dextral strike slip reactivation. Dextral deformation was transferred eastward along the heavily deformed zone of Southern Karavanke and Donat shear zones
- Probably another termination of tectonic activity in the Upper Miocene, when whole area was covered by Sarmatian clastic sediments.
- Dextral strike slip transpressive reactivation in the Pliocene. Deformation was accompanied by vertical extrusion of the Karavanke Mts. (»Karavanke palm structure«, **Fig. 1.3**) and their thrusting towards north above Sarmatian and even Quaternary sediments. Thrusting of the Peca nappe is believed to belong to this episode.
- GPS measurments indicate that the Periadriatic fault system is recently still active, and that the extrusion of the Eastern Alps might still be going on (Vrabec et al., 2006)

North Karavanke Nappe probably formed in Palaeogene and was then reactivated in Pliocene and Quaternary times. We can follow it from Podgorje near Podrožca in Austria towards Raduša near Slovenj Gradec in Slovenia. For the structure of the Mežica mineral deposits the Peca nappe is more important The Peca Mt. was transpressively thrusted in the E-NE direction over the Central Zone of Mežica Mine **(Fig. 1.5.)**. The most beautiful part of the thrust plane of the Peca thrust can be seen in the west slope of Peca in the Topla valley. Extension of the Peca Thrust Block is defined by the position of the Wetterstein reef, which extends in the west-east direction in the structure of the Northern Karavanke Mts. In the Northern Karavanke Thrust Block exists only in the Eastern Karavanke Mts. and it is just west from the town of Črna, wedged out along the Železna Kapla Magmatic Zone, and we can find it again in the front of the Peca Thrust Block and it extends from its front on the eastern slopes of Peca Mt. to its western border.

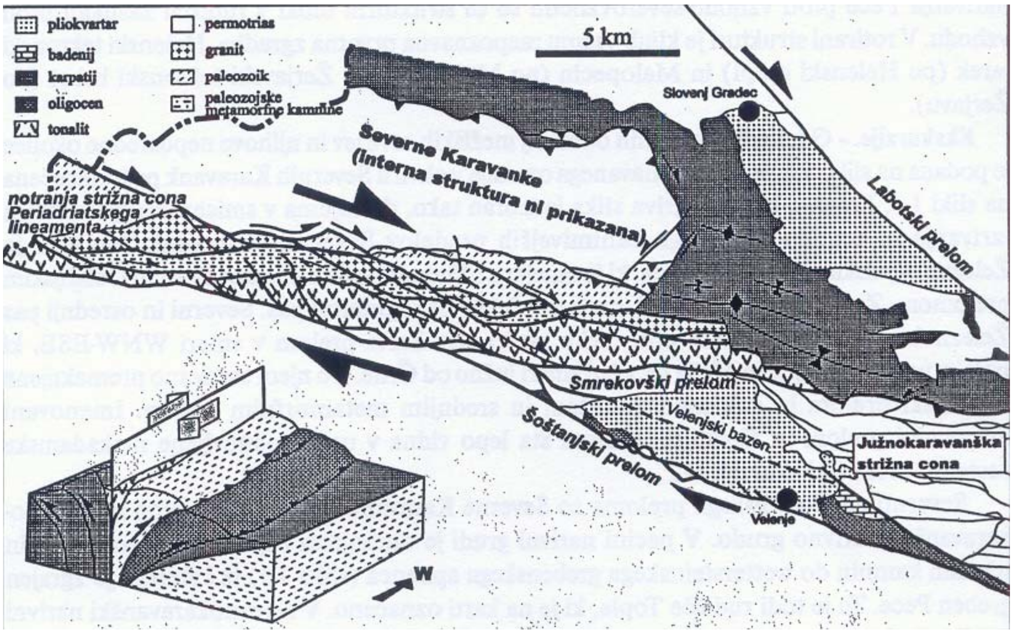


Fig. 1.3. Draft of the structure of the zone of Periadriatic fault zone in Slovenia (arranged from the data of Basic geological map of sheet Slovenj Gradec and Ravne na Koroškem (Mioč and Žnidarčič, 1976, 1981), reinterpretation after Fodor et al., 1998). Blocks of magmatic and metamorphic rocks within the Karavanke Magmatic Zone are bound and clearly displaced along dextral strike-slip faults of the Periadriatic fault zone, metamorphic rocks crop out in tectonic lenses (strike-slip duplexes). The master fault of the zone is the Smrekovec Fault, which runs along the southern boundary of the PAL. In the east, the master shear zone is overlain by Carpathian sediments, indicating cessation of the first phase activity of the PAL and blocking of further movements along this part of the zone. Dextral deformation from the western part has been transferred to the Southern Karavanke shear zone, Donat zone, and finally, in Plio-Quaternary, to the Šoštanj Fault. Three-dimensional sketch in the left lower part of the Figure shows schematic structure of the main zone of the PAL and the territory of the Karavanke Mts., which was formed by the combination of the dextral strike slip since the Oligocene and transpressive thrusting in Pliocene and Quaternary (adapted from Nemes et al, 1997).

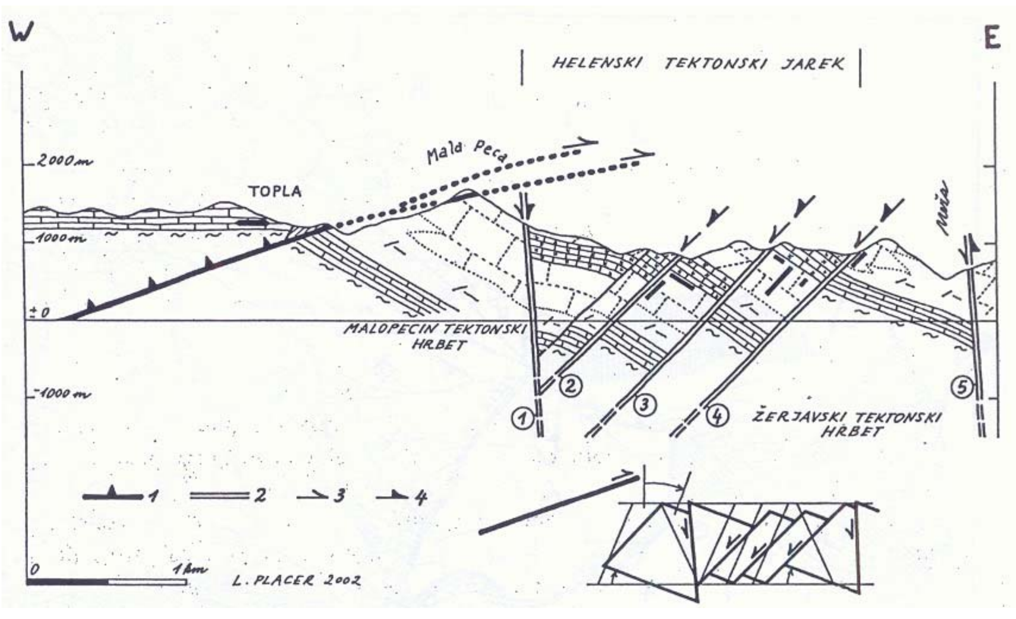


Fig. 1.5 Corss-section A – B through Mežica ore deposit in E – W direction.

MEŽICA LEAD AND ZINC DEPOSITS ORIGIN AND CHARACTERISTICS

Uroš Herlec, Dept. of Geology, Faculty for Natural Sciences and Engineering, University of Ljubljana

The mining history of the Northern Karavanke Mts has more than 340 years long records. Until the year 1874, only galena ore was mined out, and production of the sphalerite concentrate started afterwards. In the whole history, 19 millions tonnes of ore from more than 1000 km of adits and shafts was produced. More than 1 million tonnes of lead and 500.000 tonnes of zinc metal placed the Mežica Mine among important European producer. During the 2nd World War due to the German demand for molybdenum more than 3000 t of wulfenite ($PbMO_4$) concentrate was produced. Unfortunately, most wulfenite deposits were exploited at that time. Spectacular mineral wulfenite samples, few of them were exhibited in numerous public and private collections worldwide, were crushed, and used for the canon's steel production. Due to low market prices, Mežica mine was closed in 2004. As a part of the RSCM – Building material Ltd, which still operate part of the ex mine separation and produce the building material from the ore gangue, there is a Tourist Mine and Museum, which keep part of the mine still open for public, students and research. Three Mine Districts: Moring, Helena and Topla are still accessible due to the geosites and technical cultural heritage that can be observed there.

Mining activities took place on the area of almost 10 km^2. The area with all ore occurrences and prospects has 64 km^2. Around 350 mineral ore bodies were mined. The adit made at the highest altitude was just below the Peca Mt., at 2060 m above sea level, and the deepest adit in the Graben ore district at the level 268 m above the sea level.

Most lead and zinc mineral deposits (99%) are within the Northern Karavanke Trust Block. Only small but rich zinc and lead mineral deposit Topla, with three orebodies, with only about 1% of the whole Mežica Mine production is a part of the Peca Thrust block. Positions of orebodies within the stratigraphic column are shown in the Fig. 1.1. in addition, their tectonic position on the Fig. 1.5. The Topla mineral deposit in the Anisian dolomite of the Koprivna Fm is syngenetic. Epigenetic mineral deposits of the central zone of Mežica mine are bounded to Ladinian Wetterstein Fm., mainly to the back reef lagoonal limestone. Orebodies within the Graben ore district are part of the mineralised outer rim of reef limestones of the Wetterstein Fm. Around one third of mineral ore bodies within the back reef lagoonal carbonate platform limestone are strata bound (subparallel) or "concordant" mineral deposits. It was found that mineralization was controlled by higher permeability of cyclic emersional breccias, that were formed during emersions and shallow karstification of the carbonate sediments on the platform during the low stand of the sea level (i.e. "A" horizon of the Lopher cyclotheme). These paleokarst horizons were found in all mineralised blocks of the mined area at the same levels below the first Carnian covering impermeable shale. Several orebodies of this type have sedimentary textures, which look stratiform, but recently it was found, that they are mimetic replacement of internal karst sediments only. About two thirds of orebodies are "discordant" to the carbonates bedding and genetically linked to the mineralization within the system of fractures, which steeply subvertically intersect limestones and dolomites beds approximately in the meridian direction. Numbers of mineral orebodies are of the combined type. Some irregularly shaped orebodies are also strongly permeability controlled. Apart the Topla Anisian up to 7 m thick syngenetic ore deposit, almost all epigenetic ore deposits are confined to upper 600 metres of the Wetterstein Fm. The whole succession of Anisian, Ladinian, and Upper Triassic platform carbonates is 2000 – 2400 metres thick.

Stable sulphur, oxygen, and carbon isotope, trace, and rare-earth elements studies disproved any magmatic or volcanic fluid source for both genetic types of deposits.

Recently we assigned the first mineralising event for Topla to the Middle to Late Anisian rifting phase. Salt brine flow was expelled onto the carbonate platform, where nitrogen rich cyanobacteria mats organic matter, and reduced environment on the brine pool floor, enabled the early diagenetic precipitation of sphalerite, galena and iron sulphides. Lead isotope studies clearly proved different source of mineralising fluids for Topla and Mežica orebodies.

Detailed microscopic studies of carbonate cement stratigraphy and cathodolumniscence microscopy of prevailing epigenetic mineral deposits revealed, that the same saddle dolomite cements which shortly pre-date the precipitation of ore minerals can be found in the whole Northern Karavanke Mts rock succession up to Lower Jurassic sediments. Successive generations of ore and gangue minerals can be found up to Lower Jurassic sediments. Geochemical signature of successive sphalerite generation is the same within the whole Northern Karavanke Mts region. This proved the fact that the main mineralising event in the most productive part of the Mežica mineral deposit was of an epigenetic type of mineralization. It was assigned to late Lower Jurassic to Middle Jurassic extensional (Alpine Tethys or Penninicum Ocean opening) tectonic event, which gave rise to low temperature lead and zinc brines.

Main ore minerals are galena and sphalerite, followed by pyrite and marcasite, which are generally not very common, which proves the oxidised character of the ore fluids, which are believed to be reduced on site of the mineralization. Colloform sphalerite, galena and carbonates often form spectacular cockade ore textures within selectively dissolved carbonate rocks. Galena cubo-otaedric crystals up to three centimetres are rare. Sphalerite is tectonically fragmented and multiply twinned, and not interesting for collectors. Small crystals of fluorite and barite up to few mm are seldom.

From the mineralogical point of view are more interesting secondary minerals, which are result of oxidation of the primary mineral assemblage due to tectonic uplift of the mineralised succession and inflow of the oxygen rich meteoric water from the surface. Secondary mineralization is easily recognisable by the iron oxide presence. Quite often there are anglesite, cerussite, hydrozincite, and gypsum.

Anglesite was formed with oxidation of the galena. Crystals up to 5 cm are rare. Anglesite was followed by cerussite in presence of carbonate in the water. It has typical prismatic or pyramidal habitus, and common twining. Crystals can be up to 5 cm in height. Most common secondary zinc mineral is fine-grained hydrozincite forming tiny snow-white colloform overgrowths of the limestone or dolomite. As the product of sphalerite dissolution smithsonite is common.

Calcite of the area is known by its various morphology. Several types of crystals were detail studied. Scalenohedrons up to several tens of centimetres are not rare. They were often overgrown by successive generation of prismatic calcite crystals or with their rhombohedron habitus. The last are steep rhombhedron to steep scalenohedron crystals.

Wulfenite is the most known mineral of the Mežica mine. Molybdenum source was most probably sphalerite, which was dissolved by the meteoric water while and zinc sulphate was washed away. Molybdenum reacted with lead on less soluble galena and formed wulfenite

Lower levels of the mine have thinner tabular crystals. On the upper levels thicker tabular crystals were followed by pyramidal habitus. Most crystals are twinned. Wulfenite can be yellow, orange, brown, green yellow, colourless or black. The largest found were up to 7 centimetres high. On highest mine levels is overgrown by the last calcite generation, which still grow.

Mineral paragenesis of the Mežica mine is unique due to heterogeneous appearance and crystal morphology. Mežica mineral deposits have one of the highest positions among most important technical - cultural and natural geological heritage of Slovenia. We must preserve most educative and instructive outcrops and accessible part of the mine for public and future research, Topla zinc and lead type of mineralization belongs to unique genetic environment, and we believe, that is of the world's geoheritage importance.

At the 490 m level of the Union district some crystals of wulfenite have pyramidal habitis with crystal faces n{011} and $\bar{c}$ {01$\bar{1}$}. The size of the crystal is 7 x 6 mm. Collection and photo: Mirjan Žorž

Topla zinc and lead type of mineralization belongs to unique genetic environment, and it is believed, that it is of the world's geoheritage importance. Photo Marko Simić

References:

JERŠEK, M., ZEBEC, V., MIRTIČ, B., BERMANEC, V., DOBNIKAR, M., DOLENEC, T., KRIVOGRAD, F. Morfogeneza kristalov kalcita iz mežiških rudišč: Miha Jeršek . In. HORVAT, A. et. al. (ed.). 1. slovenski geološki kongres, Črna na Koroškem, 9.-11. oktober 2002. *Knjiga povzetkov*. Ljubljana: Geološki zavod Slovenije, 2002b, str. 34.

KUHLEMANN, J, VENNEMANN, T, HERLEC, U, ZEEH, S, BECHSTÄDT, T. Variations of sulfur isotopes, trace elements compositions, and cathodoluminescence of Mississippi valey-type Pb-Zn ores from the drau range, Eastern Alps (Slovenia-Austria): implications for ore deposition on a regional versus microscale. *Econ. geol.*, 2001, vol. 96, no. 8, str. 1931-1941.

SPANGENBERG, J. E., HERLEC, U.: Hydrocarbon Biomarkers in the Topla-Mežica Zinc-Lead Deposits, Northern Karavanke/Drau Range, Slovenia: Paleoenvironment at the Site of Ore Formation.- *Economic Geology*; 2006; Vol. 101; No. 5; 997-1021;

ŽORŽ, M., REČNIK, A., MIRTIČ, B., in KRIVOGRAD, F. Morphology of wulfenite crystals from Mežica Mines. *Materials and Geoenvironment, 1*998, vol. 45. št. 3-4, str. 315 - 344.

Supported by:

Adria Airways d.d. The Airline of Slovenia	DDC svetovanje inženiring Družba za svetovanje in inženiring, d.o.o. DDC Consulting & Engineering Ltd	With support of British Council
Rudnik Trbovlje-Hrastnik d.o.o. Trbovlje-Hrastnik Coal Mine Ltd	Inštitut za rudarstvo, geotehnologijo in okolje Institute for Mining, Geotechnology and Environment	Inženiring za vode d.o.o. Water Engineering Ltd
RSCM-Gradbeni materiali d.o.o. RSCM-Building Materials Ltd	Rudnik živega srebra Idrija v zapiranju, d.o.o. Mercury Mine Idria in closing Ltd	Rudarsko podjetje kremenovih peskov in oplemenitenje nekovin d.d. Design, production and sale of quartz sands and auxiliary compaunds for foundries
Javni zavod Park Škocjanske jame, Slovenija	Občina Idrija Municipality of Idrija	Treking šport d.o.o.
Premogovnik Velenje d.d. Velenje Coal Mine comp.	Slovenska turistična organizacija Slovenian Tourist Board	Zavod za gradbeništvo Slovenije Slovenian National Building and Civil Engineering Institute
Kremen d.d. Novo mesto	Telekom Slovenije d.d.	Družba za arhiviranje dokumentov, podatkov in informacij, d.o.o., Ljubljana
Geonova d.o.o.	Mestna občina Ljubljana Municipality of Ljubljana	Turizem Bled Bled Tourist Board