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FIELD-TRIP GUIDEBOOK

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Cover: Panoramic view from Kubus, Velebit Mt., Jurassic carbonate beds.

Your hosts:

Day 0


Danijela and Petar

Day 1

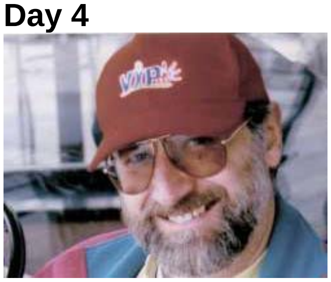


Dražen and Marijan

Days 2 and 3


Ervin

Day 4


Tihomir

All days ☺



Karmen, Jasenka and Renato

We wish you a very, very pleasant trip!

CONTENTS

The authors are entirely resposible for the contents of their contributions

1. FIELD TRIP ITINERARY

Republic of Croatia (*Republika Hrvatska*) is a country at the crossroads of the Mediterranean and Central Europe. It shares land borders with Slovenia and Hungary on the north, Serbia on the east, Bosnia and Herzegovina on the south and east, and Montenegro on the south, as well as a sea border with Italy to the west. Croatia has 56,542 square kilometers (plus its sea area - 31,900 km^2) 1,777 km of coastline with 1185 islands. There is 4,5 million of inhabitants.

Excursion route

We will start our tour in the first Croatian Geopark - Papuk Mt. in Eastern Croatia. The following days of our excursion are dedicated to the Karst Dinarides. We will see the most beautiful landscapes and interesting geological features in Plitvice National Park, Krka National Park, Paklenica National Park, Rab Geopark and Velebit Nature Park.

2. GEOLOGY OF CROATIA

Karmen Fio

A few different clasifications of this area have been made and discussed between geologists. By the old diversification (Herak, 1986), two Mesozoic carbonate platforms were proposed, Adriatic and Dinaric, separated by the deeper labile interplatform belt, Epiadriatic, and with Supradinaric in the Northern part. Proposed stratigraphic range for this two carbonate platforms was from late Triassic to Eocene. The newer concept suggests the existence of one carbonate platform with range from Late Lower Jurassic to Late Cretaceous, called Adriatic Carbonate Platform (AdCP, Vlahović et al., 2002). Underlying deposits of the Platform include Permian to Lower Triassic clastic and carbonate deposits of the northern Gondwana epeiric sea, thick Middle Triassic limestones and Upper Triassic to Middle Lower Jurassic carbonates of the Periadriatic carbonate platform. Overlying sediments comprise Paleogene Foraminiferal limestones and flysch deposits (Vlahović et al., 2002).

Even though Croatia and its surroundings is not a very wide area, geology of this part of Europe is quite diverse.

In Ordovician it was a part of the mobile Mediterranean geosinclinal area.

Still in Silurian, this area was part of the sea. Metamorphithic area with granithic rocks from the Papuk Mt. (Slavonia) is of the Paleozoic era (partly Silurian).

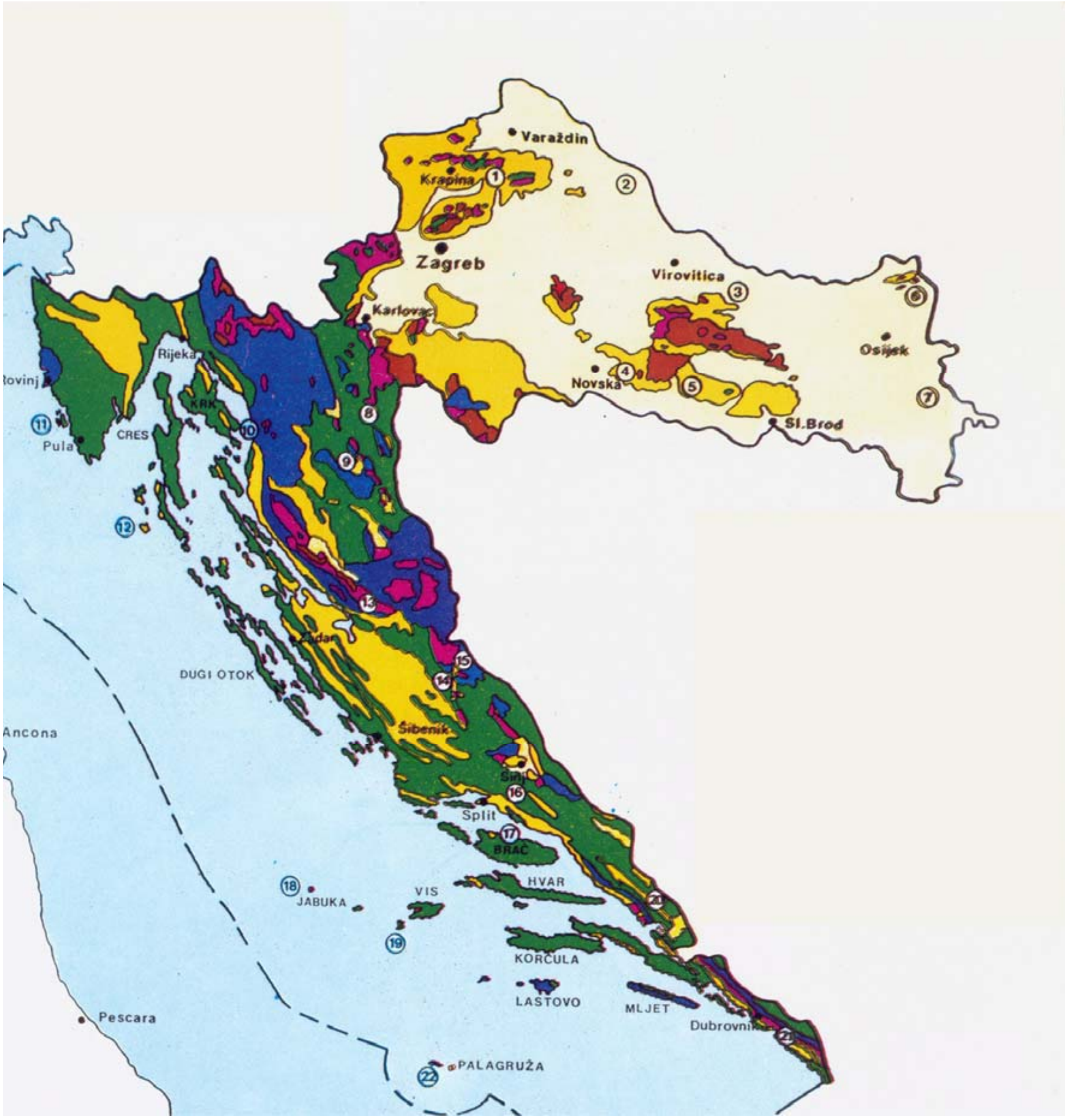
In Devonian we are still part of the deep sea, which is confirmed by the conodont findings in limestones.

The Middle part of the Carboniferous is found in Lika area, and the Upper Carboniferous in the area western from Zagreb, Medvednica Mt., Samobor Mt., Banija, Papuk Mt., Gorski kotar, Lika and Velebit Mt. and is mostly represented by clastites and limestones.

The first significant carbonate deposition in the area of the Karst Dinarides is of the Permian age – thick sequence of limestones and dolomites in lateral and vertical alternation with clastic deposits and evaporites, deposited in central Dalmatia, Bosnia and Lika in the form of an epeiric carbonate platform at the northern Gondwana margin. Continued sedimentation from the Uppermost Permian to the Lower Triassic can be followed in few areas of the Velebit Mt., while in some other areas (Lika) there is a hiatus in sedimentation.

With the beginning of the Triassic there was an enhanced terrestric influence, with mica sandstones and siltstones. Lower Triassic is represented mostly by the clastites, and we can differentate grey Seissian beds and redish Campilian beds, often containing ammonites and other fossils. Middle Triassic is mostly represented by the limestones, with less clastites which are usually in combination with the igneous rocks, showing the stabilization of the sea area. The whole area becomes consolidatet and is the base for the formation of the stable carbonate platform which lasts throughout the whole Mezozoic in the Outer Dinarides. Between Middle and Upper Triassic there was a significant regional emersion which led to the carstification of the Middle Triassic limestones. Today, in these areas we have big morphological forms filled with bauxite, Fe-minerals and transgressive clastites of the Upper Triassic. In the Carnian, Rabellian beds represent dark marls and limestones with fossils of terrestrial plants. On top of the clastic beds, in Norian and Rhaetian there was a continuous deposition of shallow marine carbonate deposits – "Hauptdolomite" and "Dachstein limestone".

In Jurassic period continuous carbonate sedimentation takes place with massive and well-bedded limestones. In Early Jurassic, carbonate sedimentation continues from the Late Triassic, and for the late part representative are „spotted" limestones with marls. Middle Jurassic limestones are not very rich in fossil communities and in some parts there is a break in sedimentation. In the Upper Jurassic there are some reef carbonates, lagoonal and pelagic limestones. Limestones with hornfels are found in the Svilaja Mt.



Geological map of Croatia

Transition from the Jurassic to the Cretaceous is continuous or transgressive. Cretaceous is mostly represented by limestones and dolomites, with some clastic sediments in the northern Croatian parts. In the Upper Cretaceous, bioclastic rudist limestones dominate. Senonian sediments have the widest spreading because of the transgression, and there are three facial units showing the more expressed morphological differentiation in environments: (1) rudist limestones, (2) lagoonal beds – flysch, (3) sediments of the open sea – thin-bedded limestones with hornfels.

At the end of the Cretaceous, the Laramian orogenetic phase starts with the tipical emersion characteristics, and with the formation of the tectonical structures which have opened the deeper parts. Emersion took place in Istria.

In Paleogene, there are some stronger tectonic movements. In Eocene, a transgression over a very differentiated paleorelief resulted in significant facies changes over small distances. The sedimentation of flysch begins, and it is strong also in the Pirinean orogenetic phase (Eocene/Oligocene) when the structural figuration of this area starts. A major part of the material was produced by large benthic foraminifera (miliolids, alveolinids, nummulitids and discocyclinids) and is known as the Foraminiferal limestone. Because of the strong sinsedimentary tectonics, it is common to find „Globigerina marls“ and flysch deposits on top, since the carbonate production was not capable to follow strong and fast tectonic movements. In the Lower Paleogene we mostly find limestones, sometimes with the coals in the base, and these are then Liburnian beds. In the Upper Paleogene we mostly find flysch, Promina beds (fine- and coarse-grained clastites, marls, limestones) and Jelar-beds (coarse-grained carbonate clastites).

The final collision in the area of the former carbonate platform took place mainly in Oligocene and Miocene, causing the uplift of the Dinaridic mountain chain. After the regression in the Oligocene, Neogene is characterized by the flooding of the continental areas. In the area between Alps, Dinarides and Carpaths, and to the Aralo-Caspian in the East, the Paratethys is formed, which occasionally loses the connection with the Mediterranean. At the end of Miocene, in Messinian, the whole Mediterranean part gets dried out, and the erosional base gets lower than before, enabling the carstification. After that, the final sedimentation of clastites takes place in separated Neogene basins, and the carstifications goes on even today in the uncovered parts.

Summary of the main events in the evolution of the Karst Dinarides (Vlahović et al., 2002):

1) Deposition of the mixed carbonate-clastic sediments on an epeiric (epicontinental) carbonate platform along the northern Gondwana margin during the Paleozoic and Early Triassic.
2) An initiation phase characterised by the formation of steep faults in the basement and separation of the Adria Microplate (Middle Trriassic);
3) A platform phase (from Late Triassic to Late Lower Jurassic) with temporary synsedimentary deformation which were reinforced towards the end of Cretaceous;
4) A disintegration phase characterised by the establishment of flysch basin(s) from the Late Cretaceous, and especially in the Paleogene (Middle to late Eocene);
5) Tectonic contraction of the platform area resulting in the uplift of the Dinarides (Oligocene-Miocene).

There are also variations concerning the name of the Mesozoic platform of the present Karst Dinarides, suggesting Adriatic Carbonate Platform, Dinaric Carbonate Platform or Adriatic–Dinaric Carbonate Platform. One of the conclusions is that on the fondation of the Adria Microplate during the Mesozoic, a single, morphologically variable Adriatic Carbonate Platform (AdCP) was formed, and its disintegration in the Cenozoic resulted in the formation of the Dinaridic mountain chain (Vlahović et al., 2002, 2005).

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3. DAY 0

CITY OF ZAGREB

Petar Boromisa

City of Zagreb is an old Central European city and the largest city in the Republic of Croatia. It is located on the intersection of several important routes between the Adriatic coast and Central Europe. As the capital of Croatia, it has special status regulated in the Constitution.

City of Zagreb is cultural, scientific, economic, political and administrative center of the Republic of Croatia with seat of Parliament, President and Government of the Republic of Croatia.

Geographic position: longitude 15° 59' E, latitude 45° 49' N / (Grič reference point),

Altitude Grič 158 m; Zrinjevac 122 m; Sljeme 1035 m.

Area: 641.4 km^2

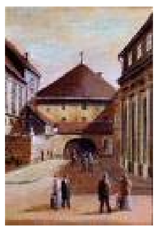
Climate: maximum temperature +33,7°C, minimum temperature -12,5°C, average air pressure 997,9 hPa, total hour of sunshine 1 961.5, rainfall (annual) 988,1 mm.

Population: 779 145 (data from 2001.), 1.300.000 (including satellite settlements)




A Brief History of Zagreb:

Zagreb has grown out of two medieval settlements developed on neighbouring hills. The first written data of the city say that a diocese was founded on Kaptol 1094, while in 1242, neighbouring Gradec was proclaimed a free and royal city. Both the settlements were surrounded by high walls and towers, remains of which are still preserved.

Gradec (Zagrabia) and Kaptol (Capitl)


During the Turkish onslaughts on Europe, between the 14th and 18th century, Zagreb was an important border fortress. The Baroque reconstruction of the city in the 17th and 18th centuries changed the appearance of the city. The old wooden houses were demolished, opulent palaces, monasteries and churches were built. Many trade fairs, the revenues from landed estates and the offerings of the many craft workshops greatly contributed to the wealth of the city. Affluent aristocratic families, royal officials, church dignitaries and rich traders from the whole of Europe moved into the city. Schools and hospitals were opened, and the manners of European capitals were adopted. The city outgrew its medieval borders and spread to the lowlands. The first parks and country houses were built. Zagreb confirmed its position as the administrative, cultural and economic centre of Croatia.

When Kaptol, Gradec and the surrounding settlements were administratively combined into the integrated city of Zagreb in 1850, the development accelerated even more. The disastrous earthquake of 1880 sparked off the reconstruction and modernization of many shabby neighbourhoods and buildings. Prestigious public buildings were erected, parks and fountains were made, and transportation and other infrastructures were organized.

In the 19th century the population increased tenfold. The twentieth century brought the Secession style to Zagreb. The city lived in the plenty of a civil society, with firm links with all the central European centres. With an increase in wealth and industry from the 1960's on, the city spread out over the wide plains alongside the Sava River, where a new, contemporary business city has developed, ready for the challenges of the third millennium.

http://www.zagreb.hr/
http://www.zagreb-touristinfo.hr/?id=21&l=e&nav=&solo=
http://www.voyager.hr/zvw/

4. DAY 1 – Papuk Geopark

Dražen Balen[1]
with assistance of Marijan Kovačić[1], Goran Radonić[2], Goran Pavić[2] and Vladimir Tomić[1]

[1]Faculty of Science, University of Zagreb
[2]Nature Park Papuk

Route to the Papuk Mt. (Day 1)

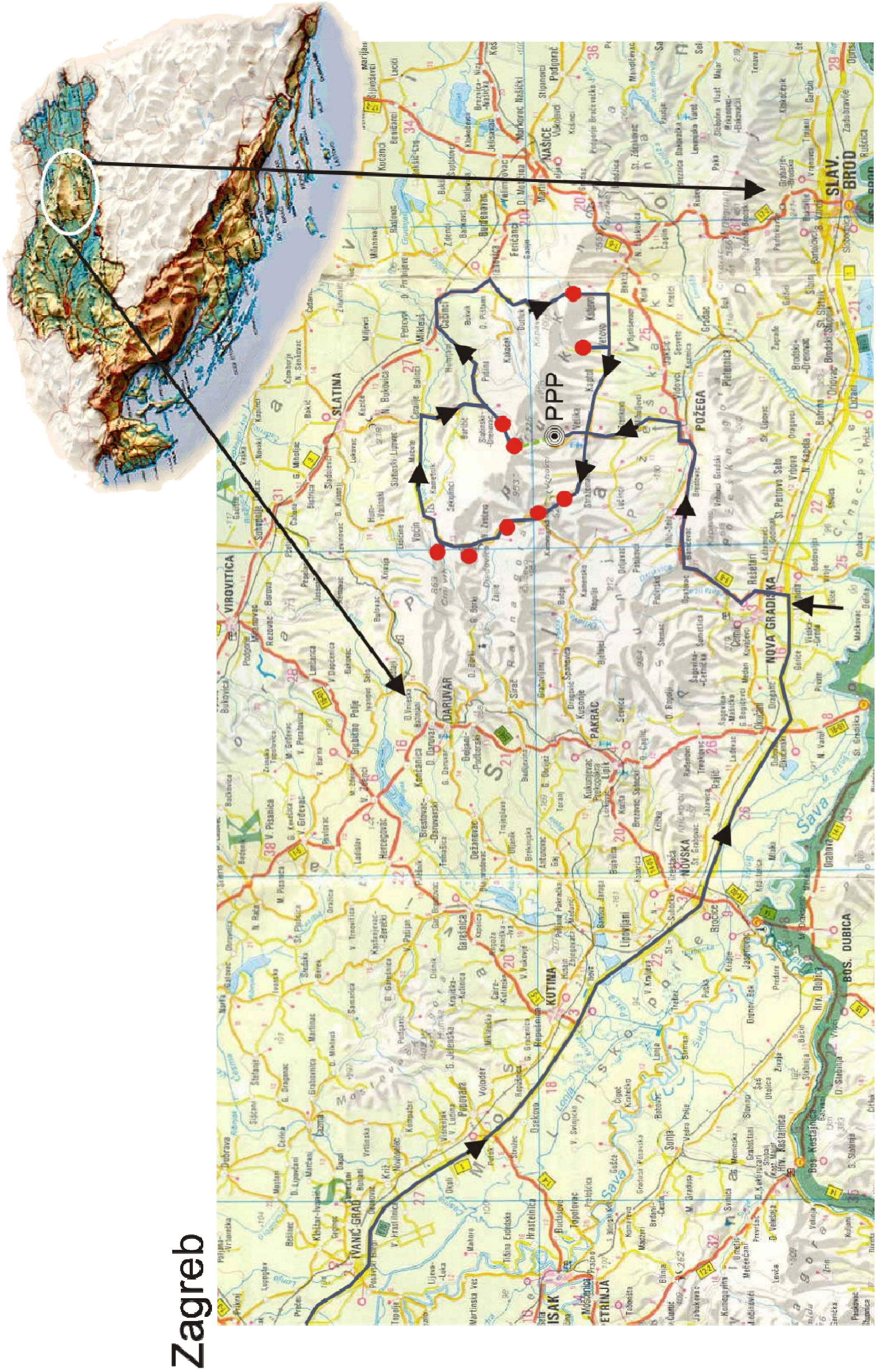
General info for participants

Weather forecast

http://prognoza.hr/sedam.php?id=sedam&param=Hrvatska&code=14999

The field trip stops are meant to illustrate the type localities or key points for understanding the geology of the Slavonian Mts. At each stop we will perform a short overview of geology, than divide ourselves to subgroups. The goal is to consider these outcrops in different contexts (mineralogy, petrology, textural and structural relations, tectonics, etc.). Use all equipment that you have, hammering a lot (*Mente et maleo*), make your own notes and support your ideas with detail sketches – and do not hesitate to ask questions! Every kind of question is welcome and warmly encouraged. We will bring some additional “heavy artillery” and geological maps.

With a hand lens it is possible to see most of the tiny mineralogical features including garnet trails. From tiny detail we can have a clearer understanding of the larger picture. We will have subgroup discussions and the whole group discussions at the end of work on outcrop and possible at the end of the day.



Road map with approximate position of stops

Introduction (Geology of the Slavonian Mts.)

Source: Balen et al (2006) and references therein

The Slavonian Mts. comprise four up to 1000 m high hills of Psunj, Ravna Gora, Papuk and Krndija located along the southern edge of the Pannonian Basin (PB) in the northeastern Croatia. In the course of the Neogene to recent tectonic history these hills are seen as a structural assemblage of the pre-Neogene tectonic units, composing a complex WNW-ESE trending positive flower structure formed within a transpressive corridor between the Drava and Sava dextral strike-slip faults (Jamičić, 1995). In their central parts they expose metamorphic and igneous pre-Alpine rocks considered to build up the crystalline basement of the southern part of Tisia Unit (e.g. Csontos, 1995; Pamić and Jurković, 2002; Pamić et al., 2002). This crystalline basement was firstly covered by Permian–Mesozoic sediments, recently only locally preserved in cores of map-scale synclines, and then by Neogene–Quaternary fill of the Pannonian Basin (Jamičić and Brkić, 1987; Jamičić, 1989). Later inversions, however, obliterated original contacts, which are largely overprinted by younger faults of reverse, normal and strike-slip character.

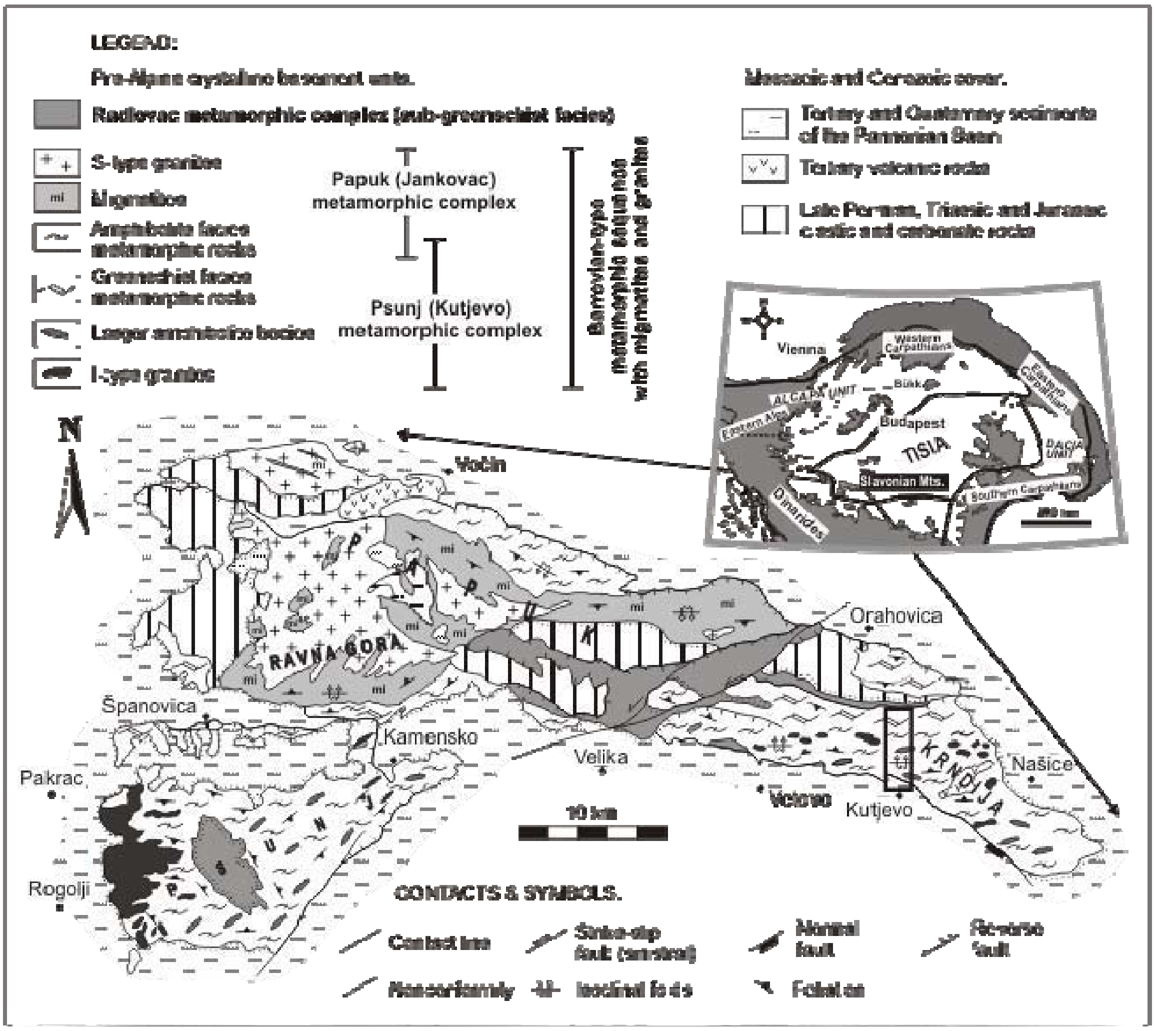
Separation of the major tectonic units of the crystalline pre-Alpine basement of the Slavonian Mts. and particularly the timing of their metamorphic-deformational history are still controversial. According to the subdivision of Jamičić (1983, 1988) this basement comprises the following tectonic and metamorphic units: (1) the Psunj metamorphic complex (also named as the Kutjevo metamorphic series) originated from a progressive metamorphism during the Baikalian orogeny, later overprinted and retrogressed by younger metamorphic events; (2) the Papuk metamorphic complex (also named as the Jankovac metamorphic series) originated from progressive metamorphism and migmatitization during the Caledonian orogeny, and (3) the Radlovac metamorphic complex originated from a very low-grade metamorphism during the Variscan orogeny.

The **Psunj metamorphic complex** consists of (a) low-grade (greenschist facies) metamorphic sequences composed of metapelites, chlorite schists and micaschists, and (b) medium-grade (amphibolite facies) metamorphic sequences composed of paragneisses, garnetiferous micaschists, amphibolites, metagabbros and marbles, locally intruded by discordant granodiorites and plagiogranites (i.e. I-type granites according to Pamić, 1986; Pamić et al., 1988a; Pamić and Lanphere, 1991).

The **Papuk metamorphic complex** largely consists of (a) granites (S-type granites according to Pamić, 1986; Pamić et al., 1988a; Pamić and Lanphere, 1991) surrounded by (b) migmatites and migmatitic gneisses that grade into (c) medium-grade (amphibolite facies) metamorphic sequences composed of garnetiferous amphibolites, paragneisses and micaschists.

The **Radlovac metamorphic complex** consists of very low-grade (sub-greenschist facies) metamorphic sequences largely composed of slates, metagreywackes, metaconglomerates and subordinate phyllites, locally invaded by metadiabases and metagabbros (Pamić and Jamičić, 1986). According to Jamičić (1983, 1988) and Jamičić and Brkić (1987) this complex occupies the highest position in the pre-Alpine structural assemblage of the Slavonian Mts., originally representing a sedimentary cover of the Carboniferous (Brkić et al., 1974) or Late Silurian to Early Permian age (Jerinić et al., 1994) over the Psunj

(Kutjevo) metamorphic complex. In turn, it is nonconformably covered by a clastic-carbonate succession of Late Permian and Triassic age, not affected by the Alpine metamorphism (Jamičić and Brkić, 1987).



Simplified geological map of the Slavonian Mts. (after Jamičić et al. 1986; Jamičić and Brkić, 1987; Jamičić, 1988; Pamić and Lanphere, 1991; modified and partly reinterpreted) with index-map showing position of the Tisia Unit inside the Pannonian Basin. Black-box shows the approximate position of the Kutjevo River (Kutjevačka rijeka) transect through progressive metamorphic complex.

Based on extensive petrological analysis combined with radiometric age determinations of plutonic and metamorphic rocks of the Slavonian Mts. Pamić and Lanphere (1991) put forward an alternative subdivision of major tectonic units and timing of major metamorphic events (see also Pamić and Jurković, 2002 and references therein). They proposed that the Psunj (Kutjevo) and the Papuk (Jankovac) complexes defined by Jamičić (1983, 1988) compose one plutonic and metamorphic complex comprising the E–W trending Barrovian-type metamorphic sequences, which following a roughly N–S oriented sections grade into migmatites and granitoids. These sequences are characterized by zoned distribution of index-minerals of chlorite–biotite–almandine–staurolite–sillimanite (Raffaelli, 1965), ± kyanite (Jamičić, 1983) or andalusite (Pamić et al., 1988b). This uniform complex is interpreted as a part of a low-pressure/high temperature metamorphic belt of Variscan age inferred from geochronological results which include (Pamić and Jurković, 2002 and references therein): (1) a 333±1.7 to 324.7±1.5 Ma $^{40}Ar/^{39}Ar$ plateau ages for muscovite concentrates from paragneisses and micaschists; (2) a 376.4±11.5 to 352.6±8.5 Ma K–Ar ages for hornblende concentrates from orthoamphibolites; (3) a 314 ± 16 to 317 ± 17 Ma Rb/Sr-isochrone ages for whole-rock samples of S-type granites and migmatites (Pamić et al. 1996), and (4) a 423.7±12.9 to 336.3±8.4 Ma K–Ar ages for muscovite concentrates from I-type granites (Pamić et al., 1988a). Besides these, however, Pamić et al. (1996) reported older K–Ar and Ar–Ar ages grouped around 430 Ma obtained on muscovite concentrates from micaschists of the same complex, which possibly imply a presence of some relict pre-Variscan mineral parageneses observed by Jamičić (1983, 1988). In accordance with subdivision of Jamičić (1983, 1988), they also separated the semimetamorphic complex with metadiabases and metagabbros, i.e. the Radlovac complex, which they interpreted as to originate from a very low-grade metamorphism of Variscan age, too.

For additional overviews on geology of Slavonian Mts. see:
Pamić and Jurković (2002), Pamić (1998), Tomljenović (1998), Pamić and Tomljenović (2000), Jamičić (2003), Pamić et al. (2003), Balen et al. (2006).

Geology of Tisia

Source: Balen et al (2006), Horváth et al. (Contrasting P-T-t paths from the Variscan basement of the Slavonian Mts. (Tisia Unit, NE Croatia): application of quantitative phase diagrams and monazite age dating, in prep.) and references therein.

The Tisia Unit, which comprises the pre-Neogene basement of the central and southeastern Pannonian Basin is commonly regarded as a lithospheric fragment broken off from the southern margin of the European plate during the Middle Jurassic (cf. Géczy, 1973; Csontos, 1995; Pamić et al., 2002 and references therein). It reached its present day position after a complex movement history and multiple rotations during Mesozoic and Cenozoic times (e.g. Csontos, 1995; Fodor et al., 1999; Csontos and Vörös, 2004), being surrounded by the regional-scale tectonic zones, most of them representing oceanic sutures (Schmid et al. 2008). The Slavonian Mts. in northeastern Croatia are considered as the largest outcropping area of pre-Mesozoic crystalline basement in the southern part of Tisia Unit (e.g. Pamić et al., 1996; Pamić and Jurković, 2002). According to Schmid et al. (2008) this crystalline basement and its Mesozoic cover belong to the Bihor nappe system, stacked between the Mecsek (the lowermost) and Codru (the uppermost) nappe systems of Tisia. The southern tectonic contact between the Bihor nappe system and the ophiolite-bearing Sava Zone suture (Ustaszewski et al. 2008) or the Sava–Vardar Zone (Pamić, 2002) is approximately located south of the Slavonian Mts., inferred as a N-dipping thrust of Paleogene age, recently covered by Neogene deposits of the Sava Depression (Ustaszewski et al. 2008). North of the Slavonian Mts. the crystalline basement and the Mesozoic cover of Tisia is largely covered by Neogene deposits of the Pannonian Basin and only sporadically crop out in the Mecsek–Villany Mts. of southern Hungary and in the North Apuseni Mts. of Romania (e.g. Schmid et al. 2008). Combined geochronological and thermobarometric data obtained from the crystalline rocks of Tisia in southern Hungary indicate that these rocks underwent Permian and Alpine metamorphic overprints (Árkai et al., 2000; Horváth and Árkai, 2002; Lelkes–Felvári et al., 2003; Horváth, 2007). In the Slavonian Mts. a polyphase pre-Variscan and Variscan tectono-metamorphic evolution of the crystalline rocks has been documented by structural, geochronological and thermobarometric studies, too (Jamičić, 1983, 1988; Pamić and Lanphere, 1991; Balen, 2005; Balen et al., 2006), recently supplemented by data indicating the youngest thermal overprint during the Cretaceous (Balen et al., 2007). Due to generally poor outcropping conditions many details in the metamorphic-deformational history are still open and need further refinement.

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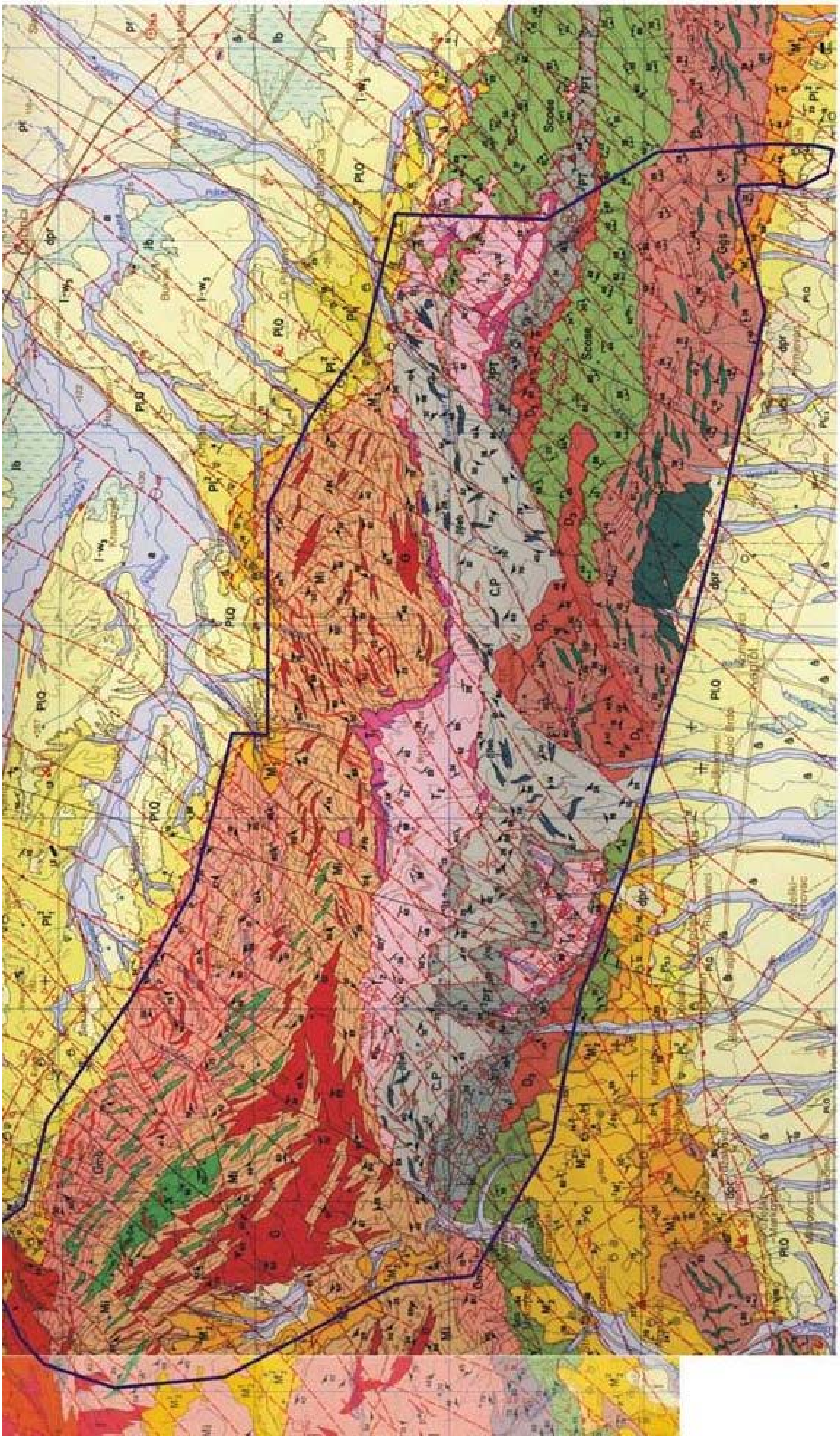


Basic geological map with boundary of Nature Park Papuk (geological background after OGK M 1:100000, sheet Orahovica - Jamičić and Brkić (1987) and sheet Daruvar - Jamičić (1989)).

Legend:

	1	Quaternary sediments
	2	Tertiary sediments (Late Miocene and Pliocene)
	3	Tertiary sediments (Early Miocene)
	4	Cretaceous volcanic rocks
	5	Triassic Carbonates
	6	Very low grade metam. rocks – Radlovac metam. complex
	7	Low grade metamorphic rocks – Psunj metamorphic complex
	8	Medium grade metamorphic rocks – Psunj metamorphic complex
	9	Amphibolite
	10	Migmatite
	11	S-type granite
	12	I-type granite

STOP 1: VELIKA - Nature Park Papuk / Papuk Geopark

Source:
http://www.pp-papuk.hr/
http://www.papukgeopark.com

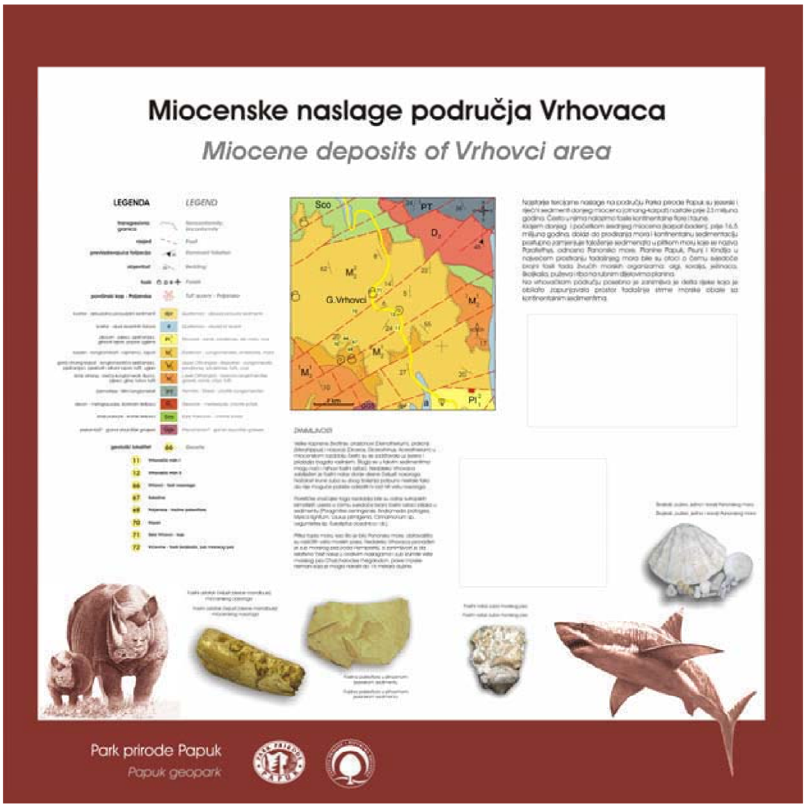
Generally speaking, the main feature of the eastern part of Croatia is flat lowland which was once the bottom of the Pannonian Lake. Driving from Zagreb toward the east, one can notice mountains that rise on the horizon to almost a thousand meters above sea level. Most remarkable among these mountains is Papuk – for the Slavonians the most beautiful mountain. Papuk is from the geological point of view the most diverse mountain in Croatia and that was the main reason for proclamation of Nature Park. Since 23rd April 1999 Papuk was designated as a protected Nature Park on the basis of its extraordinary geological and biological diversity and valuable cultural heritage. In 2007 Papuk became the first area in Croatia to be awarded Geopark status and became the member of European Geopark Network.

The main building of Nature Park Papuk (Velika)

One of the several main entrances into Papuk Geopark area

STOP 2: GORNJI VRHOVCI

Source: Papuk Nature Park Application dossier for nomination as a European Geopark, Pavelić (2001), Pavelić et al.(2003) and references therein.



Papuk Geopark table

This site is sedimentologically and palaeontologically important area situated on southern edge of the Papuk Mt. representing evolution of the Pannonian Basin from the Miocene to the Quaternary. Outcrops reveal the continental development of the Ottnangian–Karpatian period with fossils and terrestrial flora, freshwater fish ant tuff deposits. Visible is continuous crossing into the Badenian strata with different facies: river delta (*Rhinoceros* remnants), coastal and reef facies sediments (*Bryozoa*, corals, bivalves, gastropods, echinoderms, fish and shark teeth). Site also allows insight into process of Paratethys closing in Sarmatian, and forming of brackish Pannonian Lake at the beginning of Pannonian. The Pannonian and Pontian sediments contain numerous fossils of *Ostracoda, Gastropoda* and bivalves.

The land areas generated by the Laramian uplift remained preserved until the Early Miocene when fresh water sedimentary basins formed in the Slavonian Mountains with sedimentation of conglomerates, sandstones and siltstones in alluvial and lacustrine environments. Lacustrine conditions were replaced by marine environments during the Karpatian times, characterized by sedimentation of mainly marls and silts with impermanent input of clastic material into the basin by gravity flows. Marine environments continued into the Badenian when the last Miocene marine transgression occurred. Dominant deposits are algal banks and biocalcarenites with important fossil remains (bivalves, gastropods, echinoids). In the early Sarmatian the salinity of the sea decreased, and a brachyhaline fauna developed. A general trend of decreasing salinity continued in the Late Miocene and final infilling of the lake took place in the Late Pontian. The Late Miocene deposits are conformably overlain by the Pliocene siliciclastic deposits accumulated in small fresh-water lakes.

STOP 3: VRANOVO

Source: Papuk Nature Park Application dossier for nomination as a European Geopark, Jamičić (1979), Jamičić (1983) and references therein.

Phyllonite at Vranovo locality

Retrograde metamorphosed and sheared gneisses (phyllonite - see below*). The rocks passed through repeated cycles of deformations and metamorphism which finally lead to assemblage metamorphosed and equilibrated at greenschist facies conditions.
The phyllonite forming processes were accompanied with new foliation formation and strong crenulation that is obvious through several centimeters thick folds. Formation of new cleavage occurred during the youngest tectonic processes. Presence of unique record of main orogenic events during the Slavonian Mountains formation makes this site so important.

*

- A rock that macroscopically resembles phyllite but that is formed by mechanical degradation (mylonization) of initially coarser rocks (e.g., graywacke, granite, or gneiss). Silky films of recrystallized mica or chlorite, smeared out along schistosity surfaces, and formation by dislocation metamorphism are characteristic. (**Webster's dictionary**)
- Phyllonites are like mylonites in that they are fine-grained and are shaped by deformation, but in phyllonites there has been a reconstitution of the minerals.

Some of the parent-rock minerals are re-formed with a different orientation, and new minerals are formed in response to the metamorphic conditions. (**Encyclopedia Britannica**).

STOP 4: BRZAJA - ČARUGIN KAMEN / ZVEČEVO

***Source**:* Raffaelli (1965), Papuk Nature Park Application dossier for nomination as a European Geopark, Pamić and Lanphere (1991), Horvat (2004), Balen and Tomljenović (2005) and references therein.

Brzaja - Čarugin kamen

Čaruga (real name Jovan Stanisavljević) was a famous outlaw who robbed rich peasants and travelers in the area of Papuk. Legends say that his favorite location was near this stone, where a local railway was bringing salaries for workers.

Migmatite and/or porphyroblastic biotite – muscovite gneiss with quartz veins are part of the Papuk metamorphic complex which comprises different varieties of such metamorphic rocks. The age according to the authors of the Basic Geological Map (Jamičić, 1989; Jamičić and Brkić, 1987) is Early Paleozoic.
The rock is light gray to gray microcline porphyroblastic gneiss, with layered texture comprising thin dark layers with biotite and thick leucocratic layers with plagioclase, quartz and microcline. The microcline occurs as porphyroblast elongated parallel with schistosity plane. The younger granite veins cut foliation plane of metamorphic rocks.

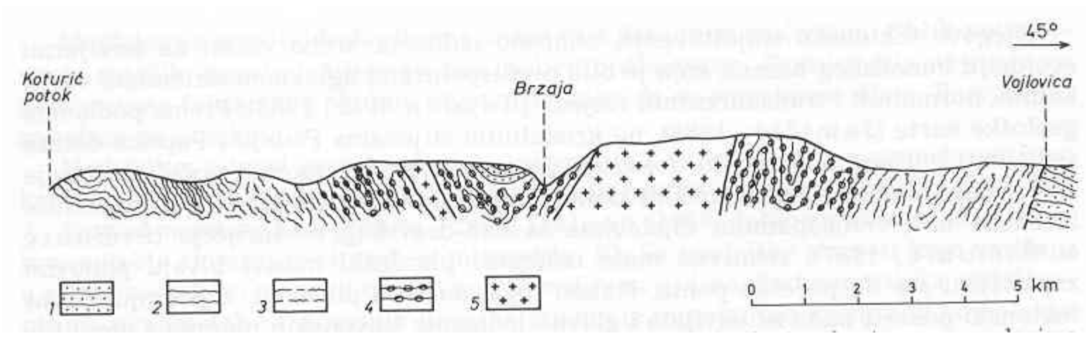
Brzaja Creek valley, Papuk Mountain (slightly modified after Horvat, 2004)
At the road Vučjak Kamenski–Voćin, in the canyon of Brzaja Creek we follow a porphyroblastic gneiss zone (according to the Basic Geological Map 1:100 000, Jamičić and Brkić (1987), this zone is marked as a migmatite zone). The north-south striking valley itself is a big fold (fold axis striking east-west), and locality „Čarugin kamen" (Čaruga´s stone), where gneisses crop out with occasional granitoid veins is situated on its wing. The granitoid is a fine-grained, light rock containing quartz and feldspar grains and biotite leaves. The gneiss has heteroblastic texture and foliated („folded") structure. Porphyroblasts (3–5 cm) are white feldspars and sometimes quartz. They are elongated parallel to foliation. Other mineral components are biotite leaves and fine quartz and feldspar grains. Cracks are parallel to foliation direction.
Further sampling points along Brzaja canyon represent migmatitic zone offered the exchanging and/or mixing of porphyroblastic gneiss and granitoids (granitic-pegmatitic-aplitic material) in the form of veins, augen forms, bands and/or dispersed spots/stains by injection or differentiation. Representative types are muscovite-biotite granitoid with poorly porphyritic structure and fine- to medium-grained texture and slightly augen gneiss. The main mineral components of the granitoids are: grey, sometimes bluish quartz grains with greasy luster, white grains of feldspar with glassy luster (alkali feldspar), muddy white grains of feldspar (plagioclase) and black leaves of biotite. Muscovite is also present. The

rocks have the transitional texture between grained and slightly porphyritic type. Coarse-grained varietites similar to pegmatites (coarse quartz and feldspar grains but without large mica leaves), are frequent. Megacrysts are white feldspars and their grain size is variable. Maximum grain size is 0.5 cm. Their colour in pegmatites and aplites is also white. Gneisses are finefolded gneisses, eyed embreschite and anatexites. According to the classification they are homogeneous migmatites with augen, amygdaloidal to partially banded structure.

Zvečevo

S-type granites

S-type granites and associated intermediate rocks occur as large or small bodies within the migmatitic complex. Texture of S-type granites is commonly xenomorphic, medium- (1-3 mm) to coarse-grained (5-6 mm); porphyroid varieties are subordinate. Structure is mostly massive whereas foliated varieties are rare. Mineral composition comprises quartz and plagioclase, biotite as the most common mafic mineral, with muscovite, hornblende and accessory minerals (apatite, zircon). Biotite and secondary muscovite are commonly found in nest-like aggregates which are similar to lensoid mica agglomeration in migmatites. Classification based on modes shows that most of these rocks are monzogranites and granodiorites. Pamić and Lanphere (1991) interpreted that both the migmatites and the S-type granites occurred simultaneously and are related to the Variscan orogeny.



Sketch cross-section Koturić potok – Brzaja – Vojlovica based on geological map of Jamičić (1988); 1 Neogene sediments; 2 low-grade metamorphic rocks; 3 medium-grade metamorphic rocks; 4 migmatites; 5 S-type granites (from Pamić and Lanphere, 1991)

STOP 5: TREŠNJEVICA (DJEDOVICA) QUARRY

Source: Papuk Nature Park Application dossier for nomination as a European Geopark, Pamić and Lanphere (1991), Pamić et al. (2003), Horvat (2004), Balen and Tomljenović (2005) and references therein.

Up to 1 m thick volcanic rock dike intrud ed in granitic rocks.

Detail shows granitoid xenolith and chilled margins at volcanic rock - granitoid contact.

Trešnjevica quarry is placed inside leucocratic granitoid rock mass which is penetrated by numerous veins of volcanic rocks that vary in composition from basaltic to andesitic and up to rhyolitic (Kišpatić, 1887; Tajder, 1956; 1960; Pamić, 1991). The granitoid rocks are strongly tectonized. The mineral assemblage of granitoid rocks (Variscan in age, mostly 336–324 Ma - Pamić and Lanphere, 1991; Horvat, 2004; Finger et al., 2005) comprises quartz and feldspar, as the predominant minerals, micas (biotite) with subordinate chlorite, and various accessory minerals (garnet, titanite, zircon, apatite). Most of the analyzed rocks fall into the fields of granodiorites and monzogranites. Swarms of volcanic rocks veins comprising gray to green and dark porphyritic rocks with plagioclase, sanidine, quartz, pyroxene, amphibole, biotite and volcanic glass.
In the basalts near Voćin, plagioclase phenocrysts are zoned; average composition An_{74-61}, while in groundmass plagioclase is more sodic An_{57}, clinopyroxene is augite. The K–Ar ages of basalts are in range 72–62 Ma (Pamić et al., 2000). However, authors of geological map interpreted volcanic rocks as Miocene in age (ca. 16 Ma) – Jamičić and Brkić (1987).

Trešnjevica (Djedovica) Quarry, Papuk Mt. (description slightly modified after Horvat, 2004)

Viewed from the distance, there is a huge amount of crystalline rocks, cracked by reverse faults. The pale green gneiss consists of: quartz, feldspars – both alkali feldspar and plagioclase, and biotite that is completely altered to chlorite. Quartz grains are gray and have greasy luster. Alkali feldspar is white with glassy luster, while plagioclase has muddy white to yellowish colour. Plagioclase grains are bigger than other minerals. Their size achieves 1 cm, so due to this feature the texture is “augen”. The second rock type at the same locality is the medium-grained, light gneiss type without mafic minerals. Only quartz and feldspar are present. The greenish colour of the rock suggests that some mafic minerals could have existed in the primary paragenesis but they were not preserved.

Trešnjevica (Djedovica) quarry – NW part.

Trešnjevica (Djedovica) quarry – central part.

STOP 6: RUPNICA – protected geological monument, columnar jointing in volcanic rocks

Source: Papuk Nature Park Application dossier for nomination as a European Geopark, Jamičić (2003), Pamić et al. (2003), Balen and Tomljenović (2005) and references therein.
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Rupnica locality is situated in the valley of Djedovica creek, a few km from Voćin in the northwestern part of the Nature Park Papuk. This is one amongst the very few protected geological monuments in Croatia. In fact, Rupnica was the first proclaimed geological monument of nature in Croatia (protected since 14th October 1948.).
Its geological importance is the unique geomorphological appearance of the columnar jointing in volcanic rocks and folding of volcanic rock columns. Characteristically, the joints are shrinkage cracks formed by cooling of volcanic mass and form 4–6 sided polygons i.e. columns. The columns were made as a consequence of creation of crack-systems during the solidifying of magma. They are mostly vertical, but also folding of columns can be noticed in central parts.
These rocks are part of heterogeneous volcanic body composed of different varieties of basalt, andesite (augite andesite), rhyolite (albite rhyolite), ignimbrite, tuff and pyroclastic agglomerate (Kišpatić, 1887; Tajder, 1956, 1957, 1960, 1969; Jamičić et al., 1986; Pamić, 1991). There is a difference in opinion about the age of the volcanic rocks. According to different interpretation some geologists set volcanic mass as Late Cretaceous (ca. 70 Ma –Pamić, (1991)), while others have opinion that Rupnica rocks are Miocene (ca. 16 Ma) – Jamičić and Brkić (1987), created through evolution of the Pannonian Basin.

This year - it's 60 years since Rupnica was granted a protected status as the first geological monument of nature in Croatia.

Rupnica, columnar jointing, side view

Rupnica, columns, view from above

Rupnica, folding of volcanic rock columns

Rupnica columnar jointing

Columnar jointing can be used as indicator of cooling: “Much evidence exists that column diameter and stria width of columnar joints in lava flows vary inversely with cooling rate and thermal gradient at the point of fracture as the flow cools. Some evidence suggests that lava flows cool conductively. A conductive cooling model yields cooling rate and thermal gradient through space and time for cooling igneous bodies, both for extrusive and intrusive settings. Thermal gradient and cooling rate are then linked to stria width and column diameter, with faster cooling leading to narrower columns, and steeper gradients to narrower striae. This model shows large regions within a body where the ratio of thermal gradient to cooling rate is nearly constant, and predicts that the ratio of stria width to column diameter is also nearly constant. This prediction is consistent with field observations, both in this and other works. The model also suggests that if conductive cooling dominates, then joint spacing (i.e., column diameter) should increase inward from the margins of the body, as should stria width.” (abstract from Kenneth A. Grossenbacher, Stephen M. McDuffie (1995): Conductive cooling of lava: columnar joint diameter and stria width as functions of cooling rate and thermal gradient. Journal of Volcanology and Geothermal Research 69, 95-103).

See also: Weinberger, Ram (2001): Evolution of polygonal patterns in stratified mud during desiccation: The role of flaw distribution and layer boundaries. GSA Bulletin 113, 20–31.

STOP 7: JANKOVAC – transect from Paleozoic to Quaternary

Source: Papuk Nature Park Application dossier for nomination as a European Geopark, Jamičić (2003; 2003b), Pamić et al. (2003), Horvat (2004), Balen and Tomljenović (2005) and references therein.

This locality exposes tufa barrier at the 30 m high Skakavac waterfall. In the surrounding area, numerous springs formed along the contact between carbonate and less permeable Paleozoic crystalline rocks are present.
One of the most beautiful is the spring of Jankovac creek.

Geological column of Jankovac area
'400 million years in 400 meters'

Skakavac waterfall

In the small valley of Jankovac creek from its spring and up to footwall of Skakavac waterfall (which enter into Kovačica creek) there is a popular expression among geologists that 400 million years of geological past can be found in only 400 meters distance. In deed, six different lithologies can be found in that small area (Jamičić, 2003b):

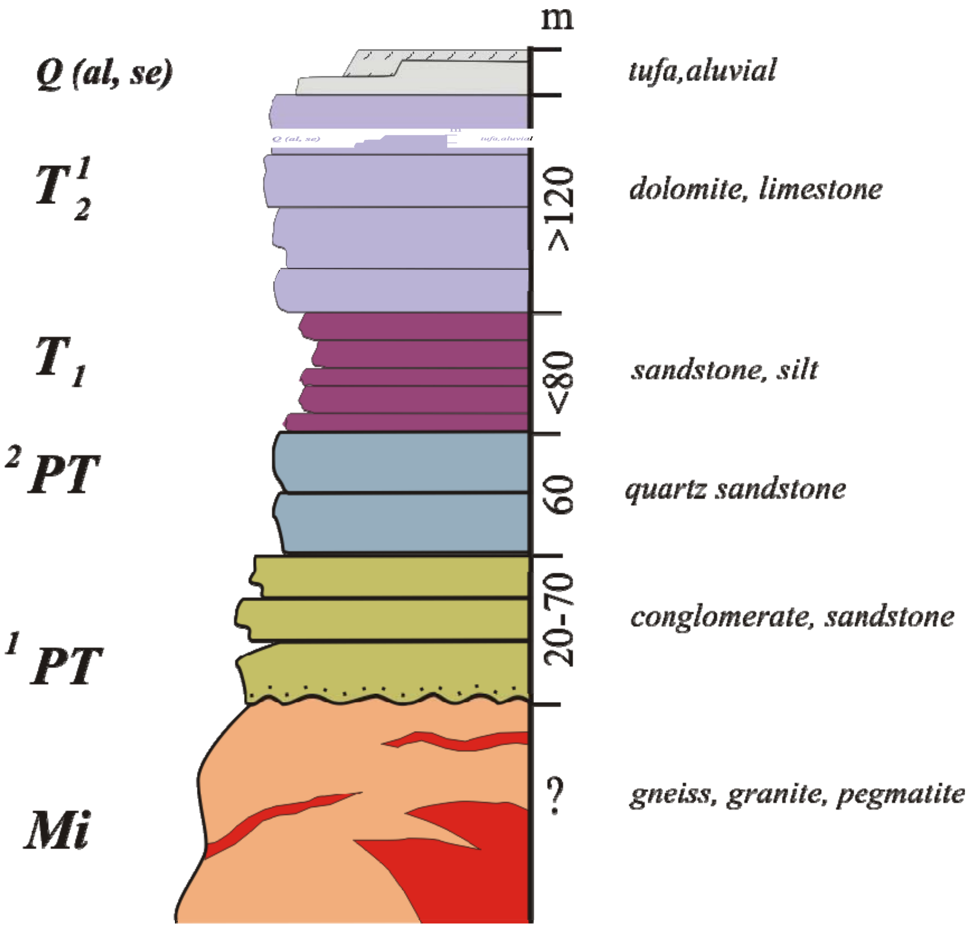
- The oldest rock of Jankovac is migmatite also described as porphyroblastic gneiss. Mainly comprise K-feldspar (microcline) but also plagioclase can be found as a few centimeter large grains in 'augen' texture enveloped by dark mica (biotite). Structure of rock is parallel with well defined schistosity marked also with laminas and lenses of quartz and feldspars. Beside K-feldspar, quartz, plagioclase and biotite, subordinate are muscovite and accessory minerals. The age is Early Paleozoic and rock belongs to Papuk metamorphic complex.
- Layered conglomerate to coarsegrained sandstone are Permo–Triassic (^{1}PT) in age, disconformably overlie migmatites and comprise fragments and pebbles of quartz (up to 5 cm in diameter) which origins from rocks of Papuk metamorphic complex. Beside quartz, lithic fragments together with mica and feldspar occur.
- Quartz sandstone (^{2}PT) belongs to upper parts of Permo–Triassic, comprising mainly quartz, lithic fragments with subordinate muscovite and biotite and sericite matrix.
- Early Triassic (T_1) brown sandstone and greenish silts. Age is determined on the basis of paleontological findings of shells *Myophoria laevigata, Myophoria costata, Anodontophora (Myacites) fassaensis* and *Gervilleia* sp.

- Dolomites and dolomitic limestones near the Jankovac spring are Anisian (T_2^1) in age. Rocks are gray, coarse-grained, tectonized and often with visible traces of karstification processes and phenomena with caves, sinkholes and abysses. Spring is on contact of permeable carbonates and impermeable clastic rocks.
- The youngest sediments of Jankovac area is tufa. During the past 6000 years (according to ^{14}C isotope analysis) 30 m high and 100 m wide tufa barrier has been formed above which Skakavac waterfall today drops. Tufa barrier occur also at Skakavac waterfall and near the spring. The tufa barrier changes its position due to Quaternary tectonic movements which through time shifted Skakavac waterfall toward the east.

Mountain hut Jankovac 485 m a.s.l.

Jankovac Creek, Papuk Mountain (description slightly modified from Horvat, 2004)

In Jankovac Creek valley (northeastern part of Papuk Mt.) we can follow a series of muscovite-biotite gneiss outcrops. Gneiss has granolepidoblastic texture. The main salic mineral components are feldspar and quartz. Feldspar size goes up to 3 cm. In some variaties feldspars have white in the other pink colour. Very often they include oval quartz grains. In general, gray quartz grains are much smaller than the feldspar grains. Black biotite flakes surround the blasts of both the white and pink feldspars making the structure foliated. Small biotite flakes can be found inside of the feldspar grains, too. Muscovite flakes are rare.



Geological column of Jankovac area (Jamičić, 2003b)

STOP 8: SLATINSKI DRENOVAC

The mineral assemblage of migmatites comprises quartz and feldspar, as the predominant leucosome minerals, micas (biotite) with subordinate hornblende and garnet as melanosome constituents, and various secondary and accessory minerals. Most of the migmatites fall into the fields of granodiorites and monzogranites (Pamić and Lanphere, 1991).

Migmatite on the road from Jankovac to Slatinski Drenovac

STOP 9: KUTJEVAČKA RIJEKA - transect

Source: Balen and Horváth (2003), Balen et al. (2005; 2006) and references therein.

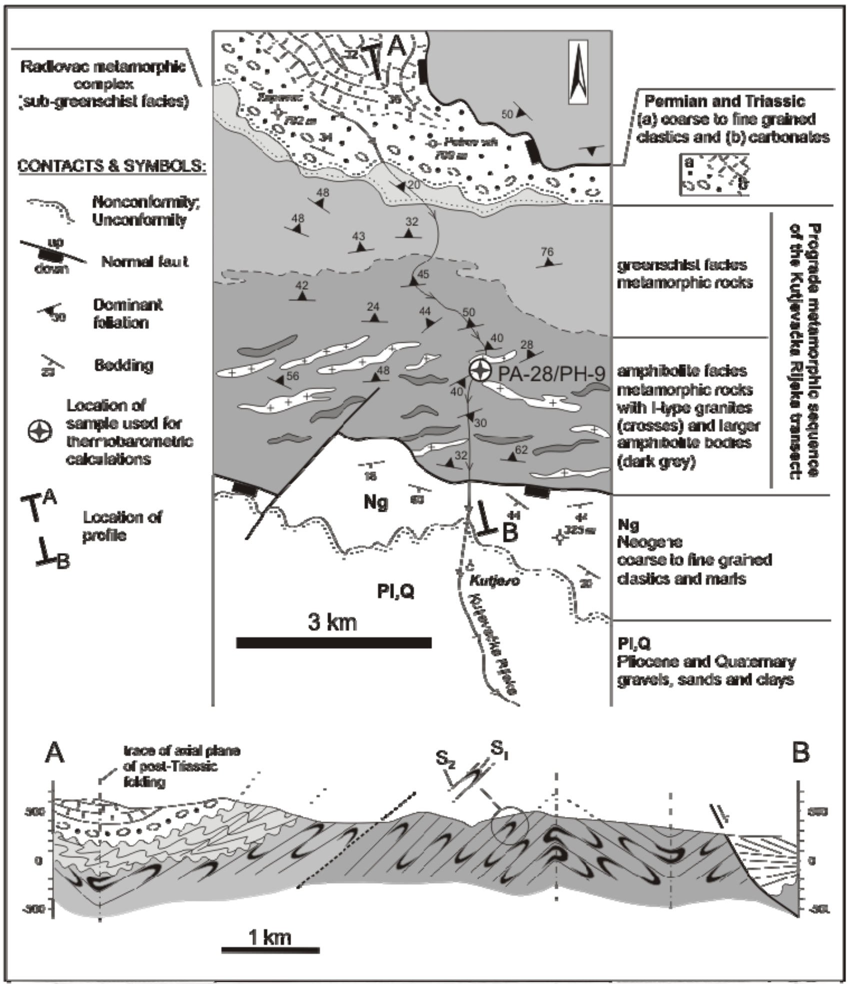
Prograde metamorphic sequence along the Kutjevačka Rijeka transect

Beside the N–S striking transect in the central part of the Slavonian Mts. where Raffaelli (1965) firstly described a zoned distribution of index minerals within the prograde metamorphic sequence, a parallel, more to the east located transect along the Kutjevačka Rijeka valley is another section where the same unit can be studied in great detail. Along this transect heading north, the prograde metamorphic sequence is firstly represented by its medium-grade (amphibolite facies) part largely composed of garnet-bearing micaschists and paragneisses with subordinate orthoamphibolite intercalations and granitoid intrusions. Further north, this grades into greenschists facies schists comprising the low-grade part (chlorite zone) of the prograde metamorphic sequence, which is firstly covered by sub-greenschist facies rocks of the Radlovac metamorphic complex and then by a clastic-carbonate succession of Permian and Triassic age. Mesoscopic observations in the prograde metamorphic sequence reveal evidence of two foliations that predate Alpine deformation. An older (S_1) foliation is only locally recognized within F_2 fold closures where it is folded around F_2 fold axes. Here, S_1 is marked by a metamorphic layering characterized by a cm-scale alternation of micaschist, paragneiss and amphibolite, all containing mm-scale garnet trails parallel to the metamorphic layering. This relationship indicates that amphibolite facies conditions took place during formation of S_1 foliation. By passing from F_2 fold hinges into strongly attenuated limbs S_1 becomes sub-parallel and parallel to a younger (S_2) planar fabric, which is the most evident mesoscopic foliation in these rocks. This foliation is either parallel or show consistent geometrical relationship with the axial planes of predominantly E-W trending, isoclinal F_2 folds. Hence, it is interpreted as to represent an axial plane cleavage of F_2 folds related to D2 deformational event, which resulted in greenschist facies retrogression of the prograde metamorphic sequence. Sporadically along the transect, S_2 is found to dip in opposite directions, which is interpreted as a result of a subsequent post-D_2 folding event attributed to Alpine deformation.

Micaschists have a well preserved metamorphic fabric (S_1) with a peak metamorphic assemblage of garnet, biotite, muscovite, plagioclase and quartz corresponding to amphibolite facies conditions. This foliation is predominantly marked by preferentially oriented biotite, muscovite and abundant garnet trails. Plagioclase is elongated and together with quartz occurs in layers parallel to S_1 foliation. Garnets are hypidioblastic and partly fractured, and typically surrounded by asymmetric pressure shadows filled with chlorite, biotite, muscovite, epidote and quartz. Regarding the grain size garnets form two distinct groups comprising relatively larger- and smaller-sized population, respectively. Large-sized garnet population clearly preserves a complex growth history.

Paragneiss assemblage comprises garnets with slightly different core and rim composition, suggesting prograde character. Peak assemblage includes biotite, amphibole, plagioclase (~28 % An) and quartz. Apatite, ilmenite, zircon, amphibole and quartz are inclusions in garnets.

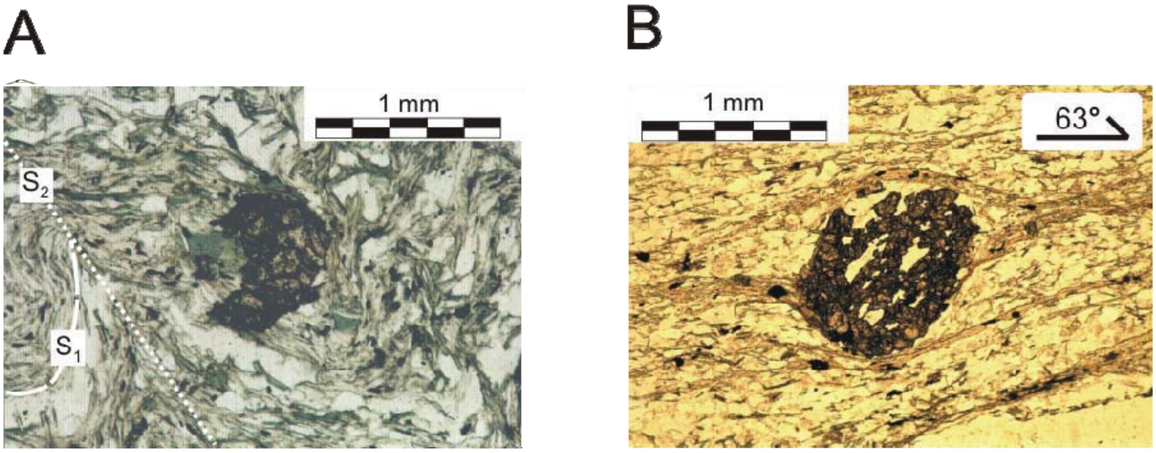
Amphibolites also contain garnets with slightly different core and rim compositon. Cation distribution suggests prograde character. Peak assemblage also includes amphibole, plagioclase (20-30 % An) and quartz, with minor ilmenite, apatite, titanite, epidote-clinozoisite.



Geological map in the area of the Kutjevačka Rijeka transect
(based on data from Jamičić and Brkić (1987), partly modified and reinterpreted).

A detailed investigation of compositional variation in garnet combined with monazite dating of the medium grade metamorphic rocks exposed along the Kutjevačka Rijeka transect in the Slavonian Mts. (NE Croatia) has been undertaken in order to decipher the metamorphic history of the crystalline basement of the southern part of Tisia Unit. Microstructural observations, together with the interpretation of preserved garnet chemistry, point to a complex metamorphic history reaching amphibolite facies peak conditions of ca. 600-650 °C and 8-11 kbar. Compositional variation in garnet from micaschists is interpreted as a change in reaction assemblage involving breakdown of calcium-rich phase during a prograde P-T path. Th, U, Pb contents of yttrium-rich accessory monazites indicate a pre-Variscan, i.e. Silurian (428±25 and 444±19 Ma) age for the medium-grade metamorphism of garnet-bearing micaschists exposed along the Kutjevačka Rijeka transect.

Greenschist facies rocks comprise greenschists (s. str.), as the most common, composed of quartz, chlorite and muscovite with subordinate feldspar (commonly albite) and clinozoisite, and in the higher garde parts with epidote, garnet and biotite.
Phyllites alternate with greenschists. In many places they show microfolding. Quartz and “white mica” (most commonly muscovite) predominate, with subordinate feldspar and chlorite and opaques and zircon as accessories.



Microstructural relations in garnet-bearing micaschists from the Kutjevačka Rijeka transect, PPL, N-. A Microscale isoclinal folding of older foliation (S1) overprinted by a younger S2 foliation. B mylonitic microstructure around garnet grain.

Chloritoid schists comprise metapelites and metapsammites which contain chloritoid as a major or subordinate mineral. As a rule, these rocks occur along the contact zone between anchimetamorphic complex and the lower-grade parts of the progressively metamorphosed complex. However, the exact relations are not clearly defined yet. Chloritoid phyllites and schistose chloritoid metasandstones are the most common rocks.

Chloritoid schists

I-type granites

I-type granites occur within the progressively metamorphosed complex. These are mostly small, up to few hundreds or km long bodies. The largest one is known as Omanovac granitic body (Psunj Mt.). Mineral assemblage comprises quartz, feldspar, biotite, muscovite, hornblende, garnet. Primary texture is xenomorphic. Majority of rocks are classified as tonalite, granodiorite, and monzogranite. Garnet-bearing tonalite varieties are common in granitic bodies of Krndija Mt. (Pamić and Lanphere, 1991).

Sedimentary rocks at Kutjevo River transect

The Permo–Triassic rocks are coarse- to medium grained terrigeneous clastics, i.e. conglomerates and sandstones that unconformably overlie the metamorphic complex. Composition of detrital components indicates magmatic and metamorphic rocks as the nearby source region. Permo–Triassic rocks crop out as elongate narrow zones dividing crystalline complex from the Triassic, predominately carbonate rocks.

“Phyllitic conglomerates” pinky to violet colored, poorly sorted, composed of granite derived pebbles grade into more fine-grained violet sandstones. Quartz sandstones (arkose and subarkose) concordantly overlie coarse-grained rocks and are considered as a transition to Lower Triassic clastic sequence represented by sandstones and siltstones. The Middle Triassic is represented by carbonate rocks (dolomite and subordinate limestone) - Jamičić and Brkić (1987), Tomljenović (1998).

STOP 10: VETOVO

Source: Balen and Tomljenović (2005) and references therein.

Psunj (Kutjevo) metamorphic complex, gneiss, amphibolite, sulphide mineralization, goethite

The Psunj (Kutjevo) metamorphic complex is formed under the P-T conditions of greenschists and amphibolite facies. Higher grade, amphibolite facies rocks are paragneisses and mica schists commonly interlayered together with amphibolites and subordinate marbles. The lower-grade, greenschist facies rocks are mostly phyllites, quartz schists and greenschists.

The Psunj (Kutjevo) metamorphic complex

Paragneiss, the most common rock type, shows lepidogranoblastic and lepidoblastic, rarely porphyroblastic texture. Modal, compositional and granulometric layering is common, together with internal foliation and microfolding. Mineral composition comprises biotite, quartz, subordinate muscovite, plagioclase, garnet, hornblende.
Amphibolites occur as few decimeter thick interlayers in paragneisses and also as larger bodies. Textures are fine-grained nematogranoblastic, lepidogranoblastic and relic ophitic. Foliation and lineation are strongly developed. Mineral assemblage includes predominately hornblende and plagioclase with garnet, quartz, biotite. Geochemical data suggest that amphibolites originate from tholeiitic basalts (Pamić and Marci, 1990; Pamić et al, 2002).
In the huge Vetovo quarry occurrences of sulfide and goethite mineralization in the veins and along fault planes are quite common.

One of the wine-cellars in Kutjevo area (Enjingi)

Vineyard on the southern flank of Mt. Papuk (Enjingi)

“Kutjevo and Kutjevo’s wines, cultivated in ancient wine-cellar, built in 1232 by the clerical order of cistercits, are one of the symbols of the wine culture of Croatia.
About 1000 ha of modern vineyards have been spread on the southern slopes of archaic mountains of Papuk and Krndija, of rolling middle Slavonia, at 250-350 m height above sea-level.
The varieties are modern, European and have an excellent genetic potential. But, Kutjevo wine-cellar are also their people, a skilled cellarers, technologists, enologists and agronomists in vineyards, all of them with the same goal; to achieve the top-level quality of Kutjevo wines.” (Tourist map of Republic of Croatia)

Some of the wines from the Kutjevo area are: Graševina, Rheinriesling, Chardonnay, Pinot Gris, Pinot Noir, Pinot Blanc, Sauvignon, Traminer …

Reference list (see also at stop descriptions)

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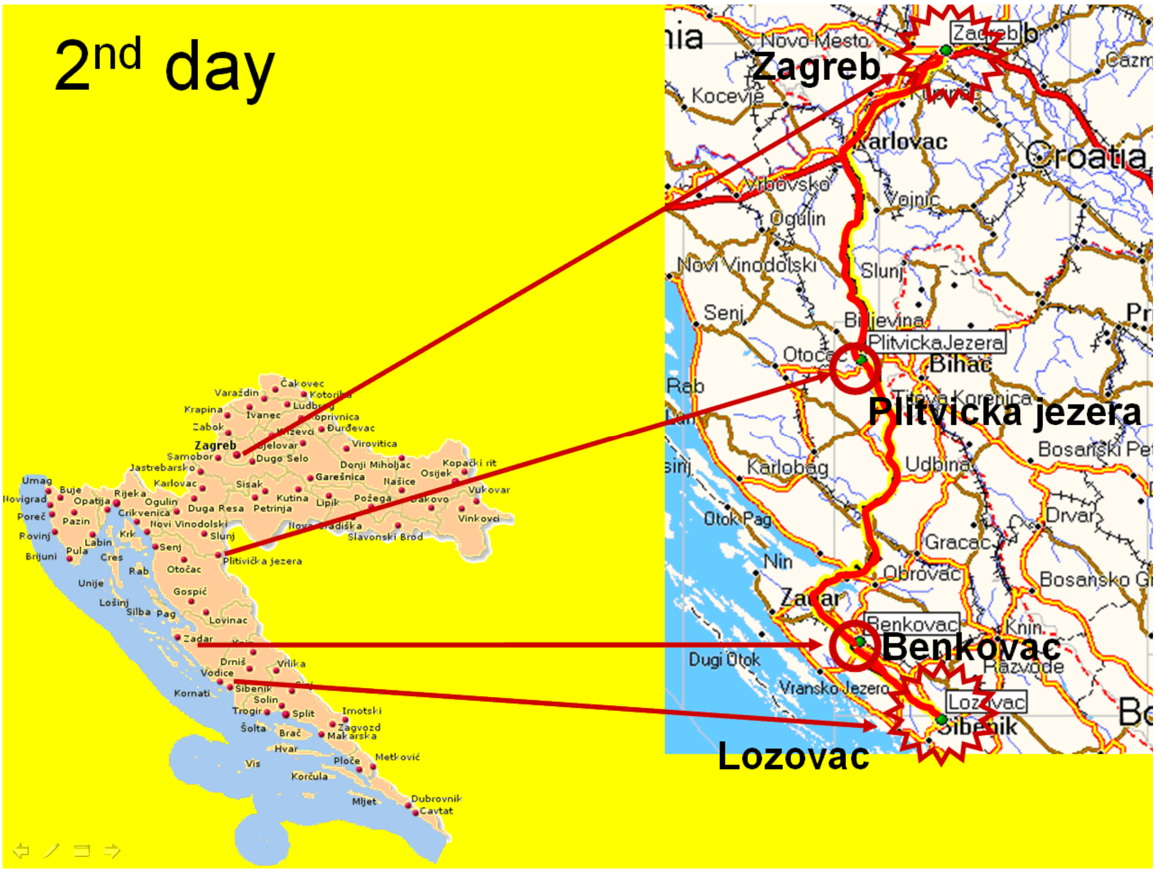
5. DAY 2

A transect through the Karst Dinarides

Plitvička jezera lakes. Benkovac stone.



ROAD ZAGREB – KARLOVAC – SLUNJ

Karmen Fio

The capital of Croatia, **Zagreb**, is situated in the NW part of the Panonian plain with the Medvednica Mt. at north. It is set on the alluvial terace of the Sava river, with mostly unbanded sediments: pebbles, sands and clays of the Holocene epoch (Šikić et al., 1979).

Going to the south, towards Karlovac, we drive through the Pliocene and Pleistocene sediments, mostly pebbles, sands and clays.

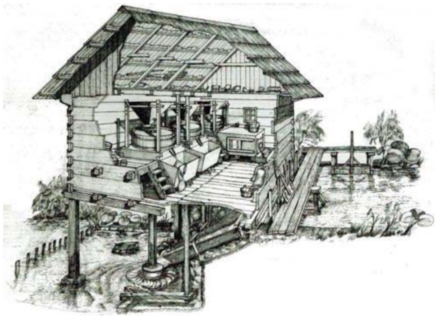
Karlovac, the city on four rivers (Korana, Kupa, Mrežnica, Dobra) is also set on the Pliocene and Pleistocene sediments. It is situated on the Dinaric edge of the Panonian plain, and it marks the transition to the mountainous part towards the Mediterannean. Going more to the south, towards Slunj, we encounter mostly limestones, dolomites and clastites of the Middle and Upper Triassic, Lower Jurassic and Lower Cretaceous. The part around Nikšić is represented by the Lower and Upper Cretaceous limestones, dolomites and clastites. The area of city **Slunj** is represented by the Lower and Middle Jurassic limestones, often with hornfels, and Lower and Upper Cretaceous limestones, dolomites and clastites (Korolija et al., 1981). From Slunj towards Rakovica we continue through mostly Cretaceous sediments.

STOP 1: SLUNJ – RASTOKE

City of Slunj is situated above the rivers Slunjčica and Korana in a pitoresque area by the main road to Plitvica lakes and Dalmatia. It takes position of 401 square km, and according to the Inventory in 2001. has 6096 inhabitants.

Slunj was mentioned for the frst time in 12th century. Fortress on a rocky hill above the river Slunjčica belonged to aristocratic familiy Frankopan, Dukes of the Krk island, and is known from from the 15th century. Under their protection town on the other bank of river Slunjčica with franciscan monastery grows. During the 16th century place was destroyed by Turks, and Slunj became a border defend fort. At the end of the 17th century town was rebuilt in a modern style. During the short Napoleon ocupation (1809 –1813) it was the easternmost part of Napoleon impery.

Although Napoleons wars had ocupation character, they also helped spreading of western ideas that impacted the economy and social life of this area. New roads, new bridges, and warehouses for grains were built in those time. Some of those water-mills and warehouses were preserved till today.

In summer river Korana is a paradise for swimmers. In some parts it is wild and suitable for watersports - kayaking and canooing. It is also rich with all sorts of fish. River Slunjčica with its spring looks like a blue-green small lake under the high cliffs. Its very atrctive to fishermen because of the best quality of creek trout. Area of Slunj also offers the possibility of hunting. From wild animals most of them are wild boars, rabbits, partridges and game like deers and fawns. Those who stop in Slunj during the travel, will find pleasure which can be given just by the untouched nature.

http://www.tz-slunj.hr/eindex.html

STOP 2: PLITVICE LAKES

***Source*:**

Marjanac, T. (2008): Plitvice lakes, outline of geomorphology and geology. 5th International ProGEO Symposium on Conservation of the Geological Heritage and ProGEO Working Group I Annual Meeting GUIDEBOOK, 1st – 5th October 2008, Rab Island, Croatia, 19–22. Zagreb, September 2008.

DAY 2

LEADER:
Jasenka Sremac

Drive from Korenica to Starigrad-Paklenica where the excurion will overnight. Visits to the Plitvice Lakes National Park and Cerovačke Pećine show caves.

PLITVICE LAKES,
OUTLINE OF GEOMPORPHOLOGY AND GEOLOGY
Tihomir Marjanac

LEGAL STATUS

The Plitvice Lakes National Park was declared in 1949, and currently covers area of 29.685 ha. However, the Plitvice Lakes area was proclaimed a national park already in 1928, but the continuous formal protection and maintenance was missing (because of the need for annual renewal of the park status - which was not done), so that the national park was not finally established until 1949. The aesthetic, ecological and cultural value of the Plitvice Lakes was finally recognized in 1979 when UNESCO included them into World Heritage List.

The park basic phenomena are geological and hydrogeological, as well as karst phenomena, preserved primeval forest communities, and lake biocenosis.

The Plitvice Lakes National Park is administrated by the Plitvice Lakes National Park public institution which is located in the park area.

The national park is a popular destination of many tourists, mainly in transit, and the number of visitors is more than 860.000 per year. The Plitvice Lakes homepage is: http://www.np-plitvicka-jezera.hr/

GEOMORPHOLOGY

The Plitvice Lakes are located in Dinaric karst, on the contact of Kapela and Lička Plješivica mountains. Their modern shape is a result of long-lasting interaction of various natural processes, and their geological substrate.

The Plitvice Lakes are a chain of 16 travertine (tufa, sedra in Croatian)-dammed lakes which cover the area of about 2 km2 (Fig. 3). The Plitvice Lakes are supplied by waters provided by two small rivers, the Bijela Rijeka (White River) and Crna Rijeka (Black River), and several ephemeral streams. The outflow from the lakes forms the Korana River which flows to

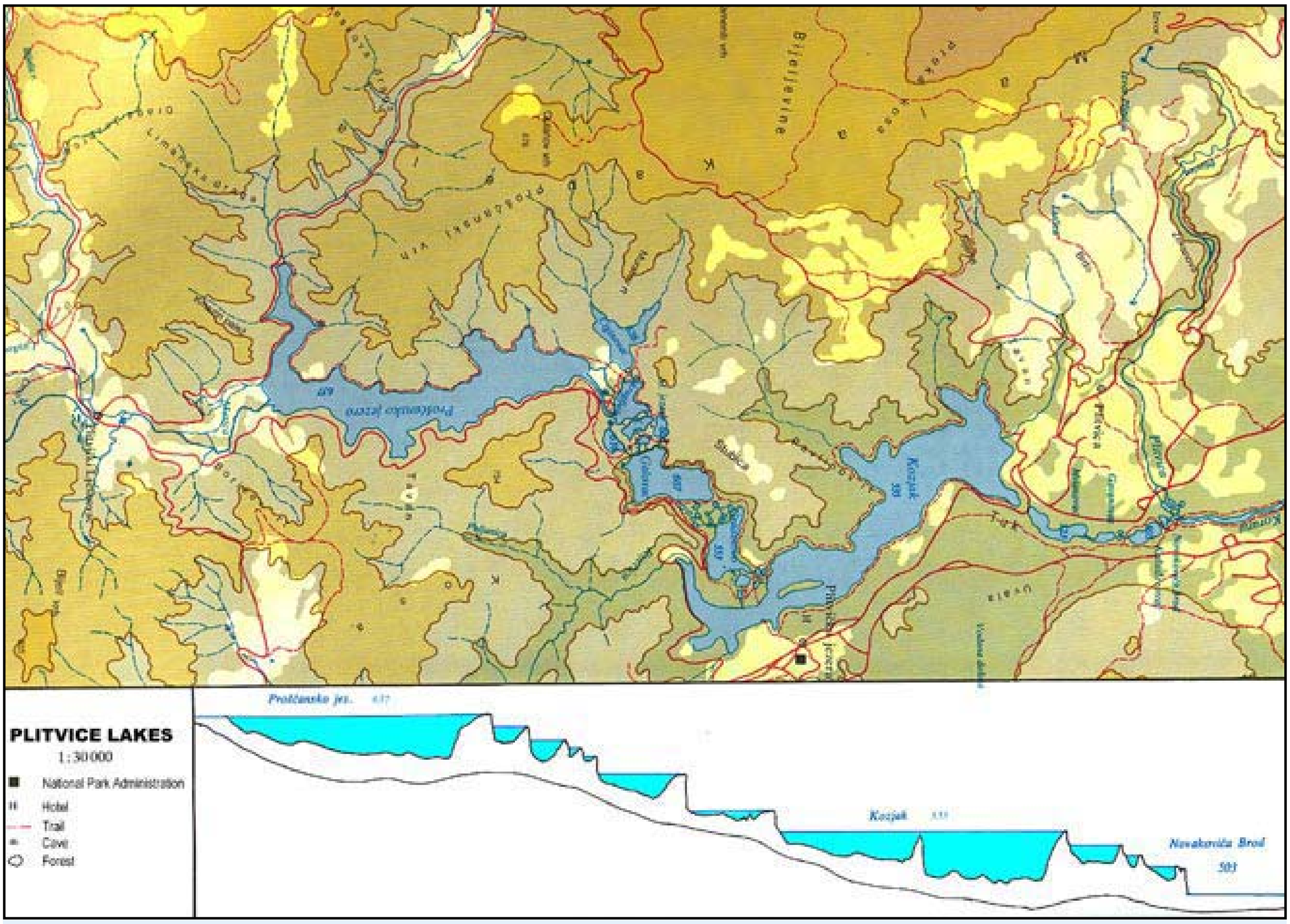


Fig. 3: Map and topographic cross-section of the Plitvice Lakes

the north, as a part of the Black Sea drainage basin.

Travertine cascades host numerous waterfalls, the highest reaching 25 m. However, the highest waterfall in the Plitvice National Park area is the Plitvice brook waterfall, which is 72 m high. The Plitvice brook flows through a hanging valley, and at the Sastavci amphiteatre-shaped rock wall, in plunges down into the Korana River.

Two groups of lakes, geomorphologically different, can be differentiated and are referred to as the Upper, and the Lower Lakes, respectively. The group of Upper Lakes occupies a wide alluvial valley, and consists of 12 lakes which make 2/3 of the total lake area, amongst of which lakes Prošće and Kozjak are being largest (Fig. 3). The group of Lower Lakes are confined to the 70-80 m deep canyon, and consists of 4 smaller lakes with vertical limestone walls (Fig. 4). This geomorphological difference is lithologically conditioned; the Upper Lakes are developed on Triassic dolomites, whereas the Lower Lakes are developed in Cretaceous limestones (Fig. 5). The Korana River flows through canyon which is incised in karstified Cretaceous limestones, and periodically dries-out, although the Plitvice Lakes continue to supply the water.

The Upper Lakes area is anthropogenically altered to a various degree. Some lakes were filled and dried in the 19th century in order to provide space for water-mills and settlements, whereas some barriers were severely damaged by logging. Today, major threat to the lakes is eutrofication, particulary in the lake Kozjak.

Fig. 4: Plitvice panorama

GEOLOGY

The area of the Plitvice Lakes is composed of Upper Triassic, Jurassic, Lower Cretaceous, Upper Cretaceous and Quaternary deposits (Polšak 1969, 1974, Polšak et al. 1977). These are predominantly carbonates; limestones and dolomites, with only subordinate role of other lithologies.

Upper Triassic deposits are late-diagenetic dolomites, light-grey in colour and well bedded. They frequently comprise stromatolites, as the only macroscopically visible fossils.

Lower Jurassic, Liassic, deposits are almost exclusively carbonates, with limestones prevailing. Dolomites occur in alternation with limestones, but they are more frequent in lower part of the Liassic succession. The Liassic limestones are typically grey-coloured and thin-bedded. The lithogenic bivalve Lithiotis problematica locally forms Lithiotis-limestones.

Middle Jurassic, Dogger, succession is characterized by prevailing detrital micritic limestones with frequent oncoides. Dolomites occur as thicker poorly-bedded interbeds.

Lower Malmian succession comprises bedded limestones with sporadic interbeds of late-diagenetic dolomites. The Upper Malmian succession predominantly comprise poorly-bedded, massive, light-grey to white dolomites. These are commonly coarse-crystalline, and porous. Locally, dolomites are silicified and comprise quartz nodules, exceptionally also chert interbeds. This dolomites are being weathered into fine-grained dolomite “sand”.

Lower Cretaceous deposits are represented by a monotonous succession of micritic limestones, of grey to grey-brownish colour. Dolomite interbeds are rare. Locally the succession comprises poorly sorted intrabasinal breccia of Late Albian age. Deposits of Cenomanian and Turonian age are represented by well-bedded limestones with occasional dolomite interbeds. Well bedded, platy, laminated slightly marly limestones of the Late Turonian age are widespread, and represent an important hydrogeological barrier. Limestones of Senonian age are thick-bedded or massive. They commonly contain biostromes of rudist fauna. The uppermost part of the succession locally comprises platy, laminated, dark-grey to black bituminous limestones with interbeds and lenses of black-coloured cherts.

The most important sediment of Quaternary age are travertines (tufa), which form lake-damming barriers. The travertine is grey-yellowish coloured, extremely porous and cavernous (Fig. 6). It is formed by calcification of travertine-producing mosses and algae. The growth rate of barriers is 1-3 cm per year, although significant variations exist between even very close dams. Travertine dames are up to 20 m thick, some are drowned, and some are dry (uplifted). Their age is radiometrically dated as ca. 4.000 years old, but the remnants of dry barriers above the modern lake system was dated as 40.000 years old. It is worth noting that it seems that between 22.000 y. and 6.000 y. there has been no travertine deposition in the Plitvice Lakes area, providing an indirect evidence of cold Late Pleistocene climate.

The Plitvice Lakes area is strongly tectonized, faulted. Major structural units strike NW-SE. Block-tectonics predominates, forming apparent autochthonous structural framework.

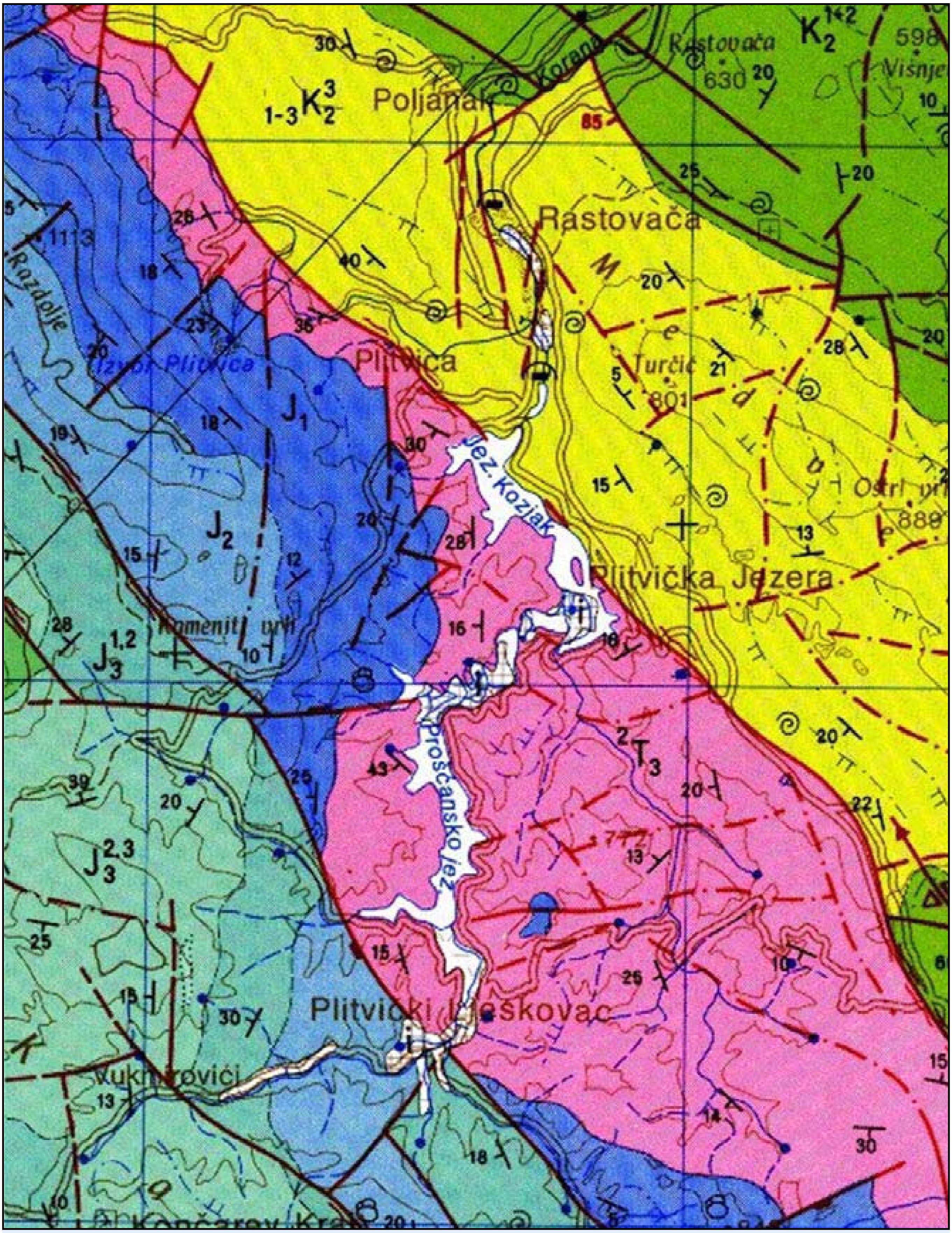


Fig. 5: Geological map of the Plitvice Lakes area (Polšak et al. 1977)

Fig. 6: Plitvice Lakes travertine, in a travertine-barrier cave.

Hydrologically, barrier is represented by Upper Triassic clastics (unexposed in the Plitvice Lakes area) and dolomites, as well as the overlying Lower and Middle Liassic limestones. This deep barrier forms "hanging" hydrological conditions (Fig. 7), allowing surficial drainage over its hanging-wall rocks, which is far detached from the water-table. This Triassic-Jurassic barrier allowed formation of the Upper Plitvice Lakes. The second important hydrological barrier are impermeable thin-bedded marly limestones of the Late Turonian age, which are responsible for the formation of the Lower Plitvice Lakes. Other lithostratigraphic units are permeable, and represent a drainage basin which resupplies the Lakes with water, apparently without any significant fluvial contribution.

There are several speleological objects in the Plitvice National Park area; several caves are open by lateral erosional processes along the canyon walls, and several deep pits (ponors, swallow-holes) are found in the wider lake area. The largest cave is Golubnjača, which is mere 165 m long, and the deepest is 203 m deep Čudinka Ponor. Interesting feature are small caves developed in travertine dams, which are easily accessible by the public, and document vivid growth history of the travertine.

The origin of the Plitvice Lakes is poorly understood, primarily due to insufficient research, and one recent discussion is published by Markowska (2004).

More detailed description of the Plitvice Lakes is provided by Bratulić (1995).

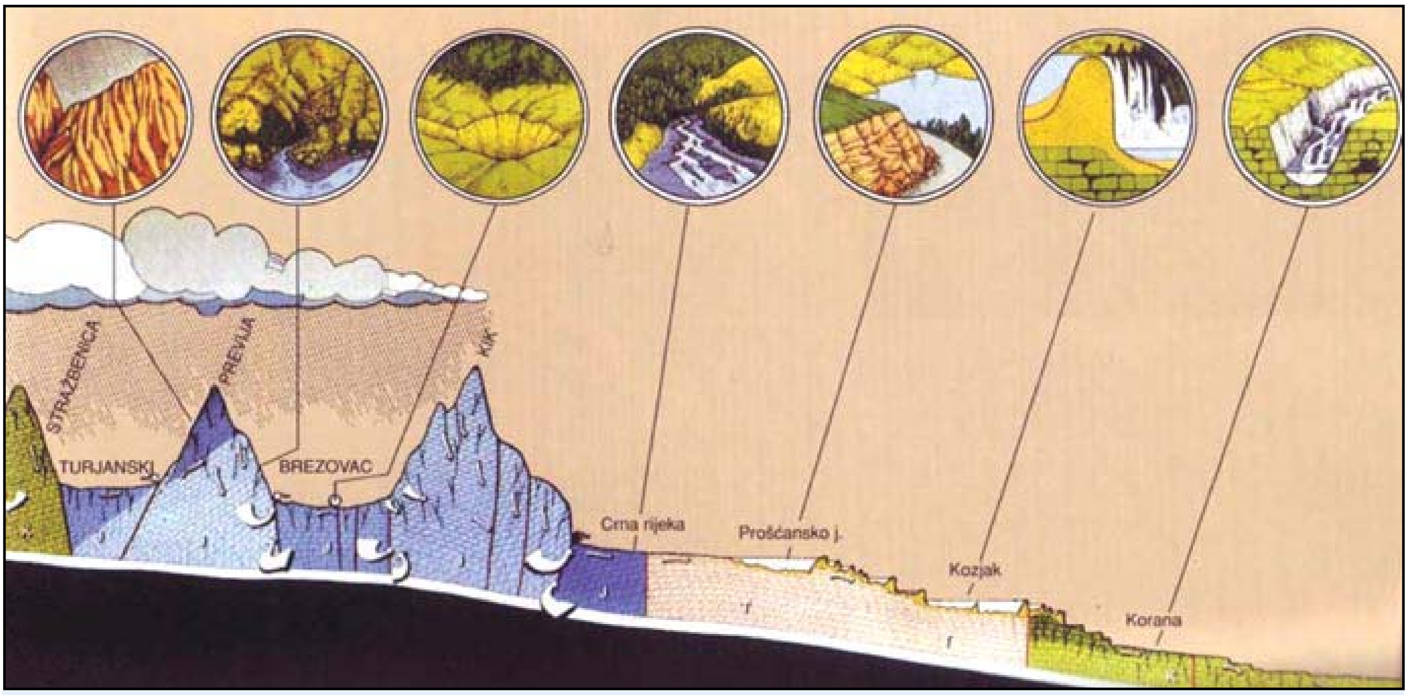


Fig. 7: Hydrogeological profile with source area composed of karstified limestones with dolomite intercalations of the Jurassic age. White arrows represent the flows of the underground waters towards the Bijela Rijeka and Crna Rijeka springs. Lakes between the Prošćansko Lake and Kozjak are located on Triassic dolomites, whereas the Lower lakes and Korana River are located on Cretaceous karstified limestones (Božičević 1998a).

ROAD PLITVICE – UDBINA – GRAČAC

Karmen Fio

After the structure in which Plitvice lakes are set, we pass through Lower Triassic (Campilian) limestones, dolomites and clastites; Upper Jurassic limestones, dolomites and hornfels, and come to the **Krbavsko field** which is a tipical Karst field, built of Pliocene (white marls rich in microfaunal communities, and marly clays), Pleistocene (gravels and sands) and Holocene (organic ponds) unconsolidatet sediments. **Udbina** is situated on the southeastern edge of the field, in contact with the Triassic sediments. Here we can find Lower Triassic rocks, represented by: Seissian beds – mostly mica sandstones and schists, with characteristic fossils *Adontophora fassaensis* and *Claraia* sp.; Campilian beds – well bedded limestones, dolomites and marls, and Middle Triassic (Anizian) beds, limestones and dolomites which are continuous on the Campilian beds (Sokač et al., 1976).

Going on, we come to the anticlinal structure in the area of **Bruvno**, with the sequence of beds from Middle Triassic to Upper Jurassic. Middle Triassic (Anisian) beds are transgressive on older beds and here we have some Anisian calcareous algae: *Diplopora*, *Physoporella*, *Teutloporella*, *Macroporella* which indicate sedimentation in the dinamic shallow water areas. In Ladinian, carbonate sedimentation continues, and at the end of the Ladinian there was an emersion in this area by which starts the paleorelief formation. In the basal parts of the Upper Triassic there are some bauxites in depressions, which are characterized by the terrestrial influence. Continuous on bauxites with the advancing transgression we found dolomites of the rest of the Upper Triassic.

Jurassic sediments are continuous on the Upper Triassic, and the transition is marked by different limestone types which age is documented by the different types of algae. Middle part of the Lower Jurassic is characterized by the limestones and dolomites in exchange, and the upper part by the thin-bedded Fleckenkalk (limestones with spots). **Gračac** is situated in Middle Jurassic area at the outer part of the anticlinal structure Bruvno.Tectonic structural unit Bruvno is at the southern part divided by the Lika fault from the structural unit of Velebit.

On the part between Gračac and Starigrad we pass first through the southeastern edge of the Paklenica structure (explained later) and after that through Eocene and Oligocene conglomerates, limestones and marly limestones, and some Cretaceous limestones and carbonate breccias (Ivanović et al., 1976; Sokač et al., 1976). These Eocene and Oligocene carbonate breccias and conglomerates are called *Jelar breccias*, or *Jelar formation*, and are built from carbonate macroclasts of different size. They are a result of the Paleogene tectonic movements, and here you can find clasts of different periods, from Triassic to Paleogene, and they are often in reverse order, since the parts at the surface were first wasted. This kind of beds are common throughout all of this part of the Adriatic coast (SW Velebit), all the way up to island Rab.

Lower Cretaceous limestones follow after the emersion at the end of the Upper Jurassic, and originate from the shallow water basins with dinstinct relief. In the Upper Cretaceous started a stabilization of the area, till the next emersion in Paleogene.

Starigrad is situated in area of the Jelar beds, and underneath the Paklenica structure.

UDBINA

Udbina is a small town situated in Krbavsko polje in Lika region, along the regional road Zagreb–Split.
Udbina, together with the surrounding small settlements, has 1.649 inhabitants, according to the official data from 2001.
Krbavsko polje is a karst field, 21 kilometres long and 5 kilometres wide, cca. 100 km^2 large, with Dinaric strike (NW-SE). It is surrounded with the mountains Lička Plješivica and Mala Kapela.
“Laudon forrest” near Bunić village is an UNESCO‘s protected park-forrest since 1960. It consists of 554 oak trees, planted on live-sands 260 years ago by the Austrian army officer, Ernest Gideon baron of Laudon.
Krbavsko polje is also a historical locality, where a famous battle with Turks took place in 1493, and more than 10 000 Croats were killed.

http://hr.wikipedia.org/wiki/Udbina
http://www.lickosenjska.com/?page=grad&mjesto=20

STOP 3: BENKOVAC AND BENKOVAC STONE

Source:
Mrinjek, E. & Pencinger, V. (2008): The Benkovac Stone – a building stone from the Promina Beds: A Late Eocene heterolithic succession of storm-dominated shelf deposits with highly diverse trace fossils. 5th International ProGEO Symposium on Conservation of the Geological Heritage and ProGEO Working Group I Annual Meeting GUIDEBOOK, 1st – 5th October 2008, Rab Island, Croatia, 105–125. Zagreb, September 2008.

The contemporary centre of Ravni kotari, Benkovac, is proud of its mighty fortress with an old church standing beside it. Benkovac was in ancient times an important seat of power, which is confirmed by the presence of the nearby ruins of the city of Asseria dated to the Antique period, with its beginnings in the Iron Age period. Old forts Klicevica and Karin are to be found in the neighborhood of Benkovac. Beneath the Fort Karin, by the shores of the deepest Adriatic gulf - the Karin Sea, a Franciscan monastery from the 15th – 18th century is situated. Benkovac is also famous for the production of the Benkovac stone, a building and decorative stone of Palaeogene age with numerous ichnofossils.

http://www.zadar.hr/English/Zupanija/Kulturne.aspx

EXCURSION 3B
Rab-Split

The Benkovac Stone – a building stone from the Promina Beds: A Late Eocene heterolithic succession of storm-dominated shelf deposits with highly diverse trace fossils

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Synopsis

The excursion will visit the peculiar part of the Promina Beds - a Late Eocene thinly bedded succession of alternating carbonate sandstones and calcareous mudstones that crop out as a narrow, NW-SE trending belt near the the town of Benkovac. The succession is well known as Benkovac Stone since has long been an important local source of building stone. Their sedimentary structures and wide range of recognizable trace fossils indicate deposition in the shoreface and the offshore transition zones of storm-dominated, microtidal shelf of the Promina foreland basin.

Stop 1

The locality is a small, very indented and abandoned excavation pit of platy-bedded Benkovac Stone at the left side of Obrovac-Benkovac road. The former excavation enables exposing of the sedimentary structures and various trace fossils. The Benkovac Stone succession in this pit is proposed for the protected geolocality by the authors of this guide.

Stop 2

The participants will visit "Kamen Benkovac" company quarry that exploits and prepares the platy-like Benkovac Stone for a market place as well. An exploited field contains three long and narrow excavation pits orientated along the beds strike direction. The longish pits enable to note a persistent sheet-like geometry of numerous sandstone beds. The exposed bed surfaces display various ripples, hummocky forms, sand volcanoes and dykes, and surprising great number of various trace fossils.

Stop 3

The locality is on a small Mejanica hill (414 m) near Lisièiæ village. Containing numerous illegal excavation pits Me-

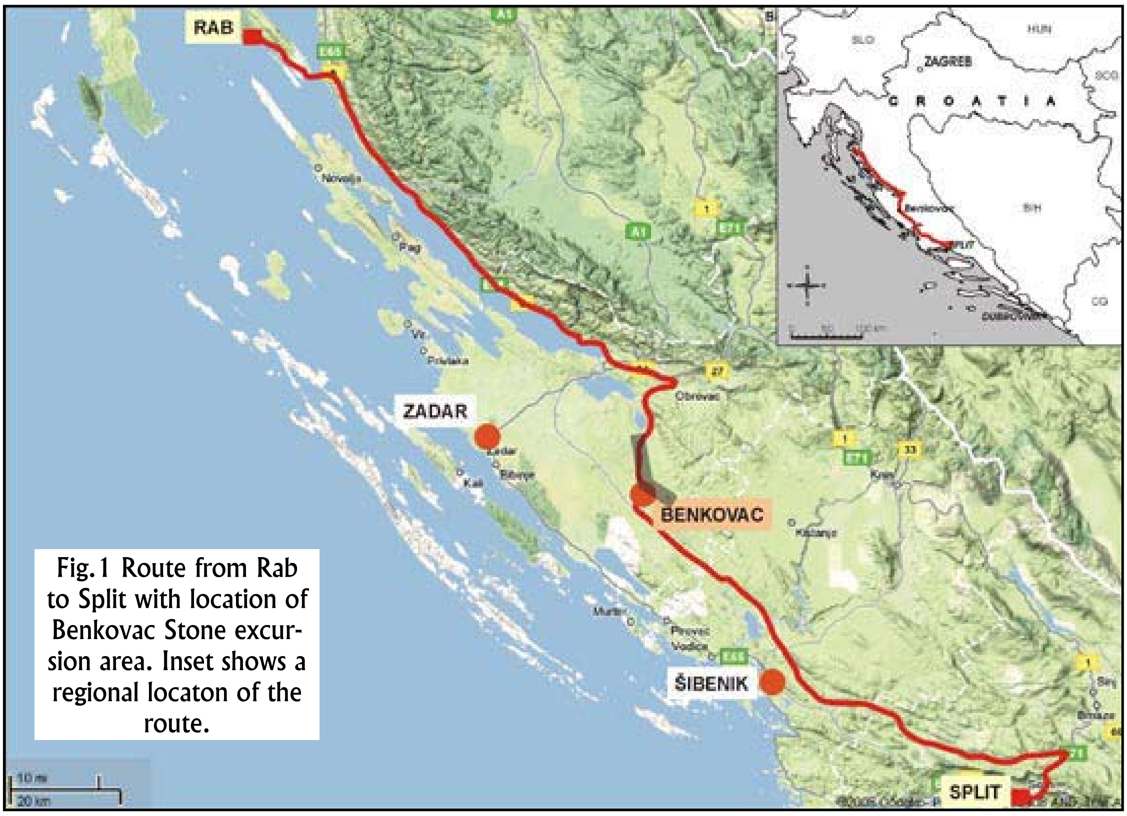

Fig.1 Route from Rab to Split with location of Benkovac Stone excursion area. Inset shows a regional locaton of the route.

janica looks like a "huge mol-hill" but such exploitation and as well as weathering enabled to perfectly see various sedimentary structures in detail. In the same time many exposed bed surfaces are a paradise for "ichnologists".

ACKNOWLEDGEMENTS

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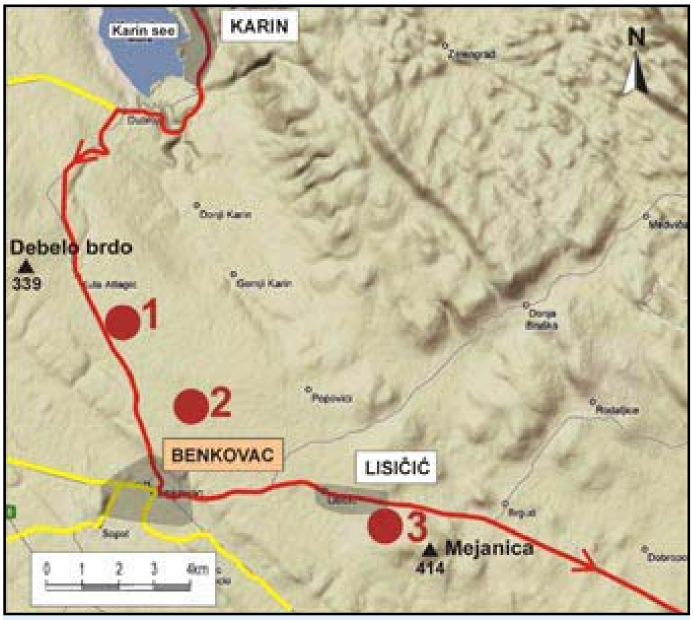


Fig. 2 Excursion route with numbered stops.

Karst Dinarides and Promina Beds

Geological history of the Karst Dinarides, a mountain belt connecting Southern Calcareous Alps with Albanides, Helenides and Taurides along the NE Adriatic Coast, is very complex. A very thick sequence of mostly shallow marine carbonates was deposited since Carboniferous, mostly within the vast Adriatic Carbonate Platform which lasted from the end of the Early Jurassic to the end of Cretaceous on the foundation of the Adria Microplate (Vlahović et al. 2005). After gradual tectonic disintegration during the Late Cretaceous followed by shorter or longer hiatus at the K/T boundary, more or less continuous shallow-marine deposition was recorded only in the northwesternmost (Ogorelec et al. 2007) and southern part of the platform (Steuber et al. 2005). Increasing compression caused formation of the NW–SE oriented foreland basins in front of the uplifting mountain belt. These were characterized by gradual deepening evidenced by continuous succession from foraminiferal limestones (including miliolids, alveolinids, nummulitids and discocyclinids), transitional marls with glauconite and crabs to "flysch" deposits; stratigraphic span of this succession is mostly from earliest to Middle/Late Eocene.

Only in few places infilling of newly formed foreland basins is visible, and the best example is the Promina Basin in the northern Dalmatia. In this area approximately 900 m thick succession of deeper-marine deposits (usually referred to as "flysch") is followed by generally regressive, approximately 2.000 m thick deposits of late Middle Eocene to Oligocene Promina Beds (also informally referred to as Promina fm.) indicating a very significant, predominantly tectonically induced formation of the accomodation space.

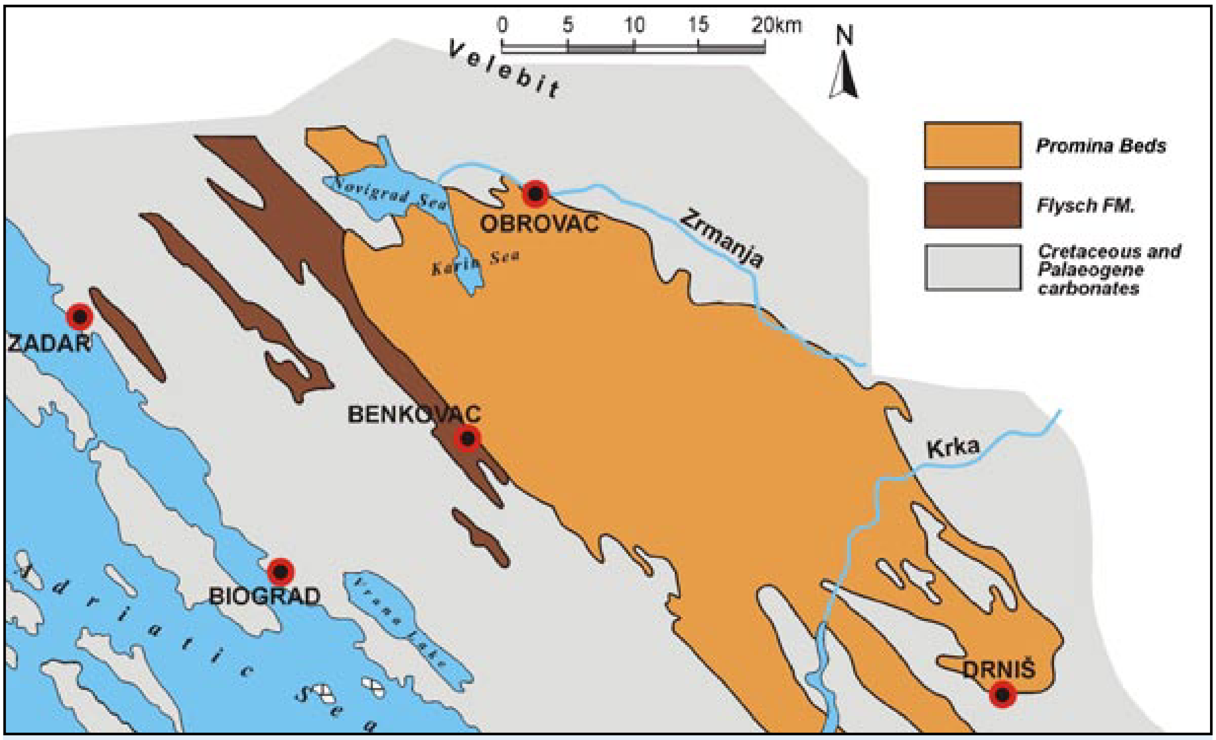


Fig. 3: Regional location of the Promina Beds in the Northern Dalmatia.

Introduction to the Promina Beds in Northern Dalmatia

The Promina Beds cover more than 80 km long, and up to 20 km wide area of northern Dalmatia in the Adriatic coastal zone which is a part of the Outer Dinarides. The Promina Beds (or so-called Promina Fm.) are approximately 2.000 m thick succession represented by various calciclastic deposits. They include various shelf deposits, delta/coast deposits and alluvial deposits. The oldest, late Middle Eocene Promina Beds represented by more or less shallow ramp, delta-front and coastal deposits (paper in preparation) overlyes conformably the so-called Flysch fm. in the southwestern margin of Promina Beds area. Towards the northeastern margin the youngest, Late Eocene to Oligocene alluvial Promina Beds (mostly braid-plain conglomerates) onlap deformed Paleogene and Createaceous carbonates with local bauxite deposits at their base (Babić & Zupanič 1988, Mrinjek 1993 a,b, 1994).

Tari-Kovačić & Mrinjek (1994) interpreted the Palaeogene clastic succession ("Flysch" and Promina Beds) of northern Dalmatia as "tectogenic" deposits, formed concurrently with regional tectonic deformation. In their polyphase tectonic interpretation of the Promina basin, the authors consider the Promina Beds as "proximal" deposits linked to an early (Lutetian–Bartonian) compressional deformation of the carbonate platform, and the Flysch Formation to be their "distal" equivalent. The next phase of tectonic compression (Bartonian to possibly Oligocene) is thought to have caused folding and thrusting of the underlying platform carbonates, together with the tectonic transport and cannibalization of the flysch which led to the development of a new elongate foreland basin, trending NW–SE and filled by the shallowing-upward Promina Formation. In their seismic interpretation, Tari-Kovačić & Mrinjek (1994) consider the final tectonic structure of northern Dalmatia to be a result of the duplexing of internal thrusts and basin-edge thrusting, which caused uplift and considerable erosion of the Promina Formation.

The common opinion on the Promina Beds as succession with a prominant shallowing-upward trend from deep- to shallow-marine and alluvial facies appeared as incorrect (Mrinjek et al. 2005). The last two years comprehensive field-work in the northwestern part of basin revealed four transgressive

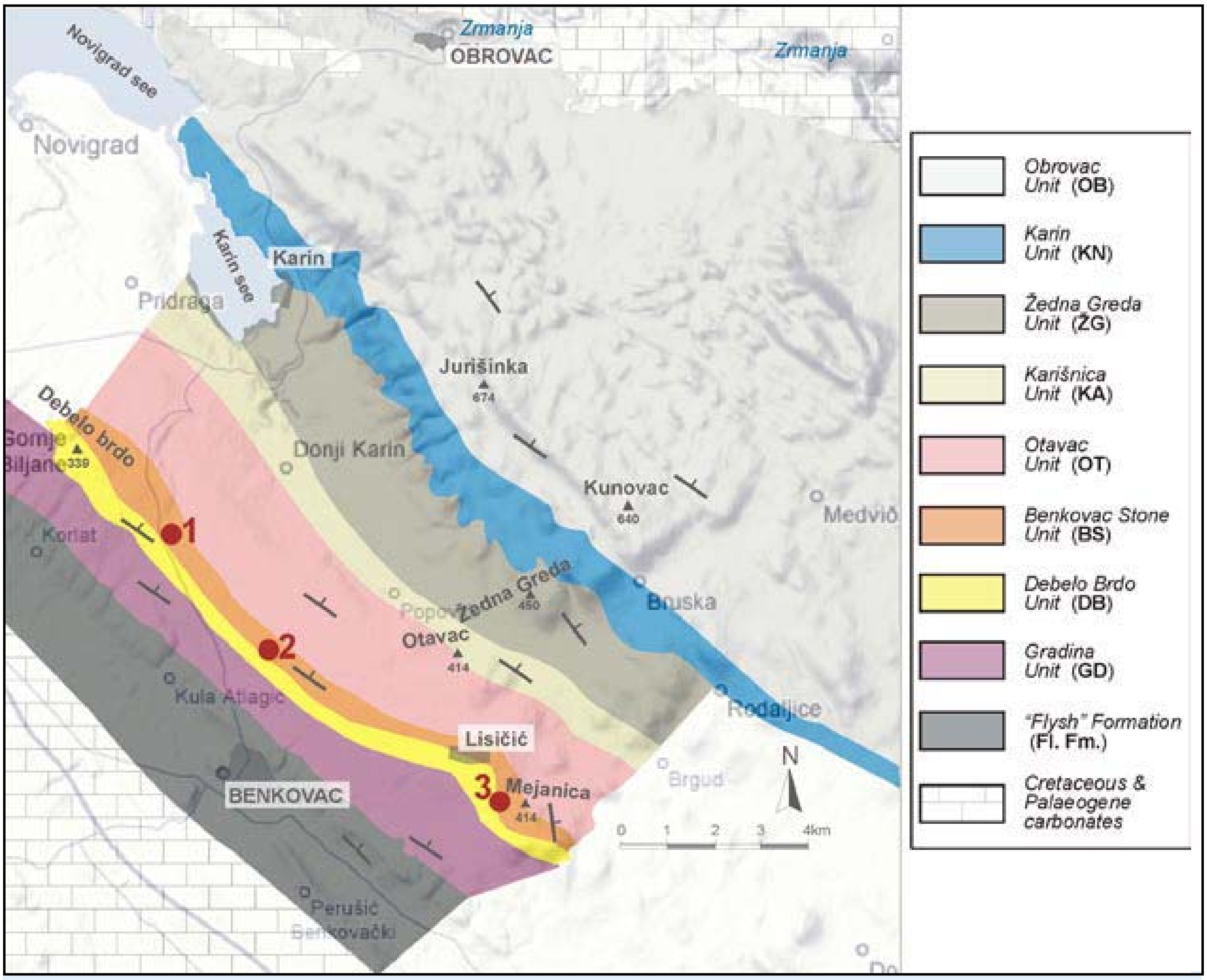


Fig. 4: Litostratigraphic map of the northwest part of the Promina Basin with the excursion stops.

and five regressive systems tracts during underfilled and fulfilled phases is and one low- and one high- accommodation systems tracts during overfilled phase. The regressive systems tracts are composed of various gravely delta to braided-plain facies and sandy to gravely beach and shoreface facies whereas fine-sandy inner shelf and muddy outer shelf facies are dominant characteristics of transgressive systems tracts. The low- and one high- accommodation systems tracts are exclusively composed of gravelly to sandy channel braided and flood plain facies. The systems tracts show significant facies changes in their strike direction as well (paper in preparation).

Litostratigraphy and Sequence Stratigraphy

Promina Beds in the northwest part of basin can be divided into seven litostratigraphic units. With the exception of minor tilting to northeast direction the units have undergone none of the contractional deformation and structural discontinuites that is typical of foreland basin. This lucky occurrance should enable tracing of bed surfaces and sediment bodies for many kilometers but is rather reduced with cover of dense vegetation in the lower part of succession ("Flysh" Fm., Gradina, Debelo Brdo, Benkovac Stone and Otavac Units).

Gradina Unit characterised by various shelf and delta front facies (very frequent alternation of carbonate conglomerate and sandstone beds), gradually overlies "Flysch" Fm. "Flysch" contains various sheet-like sandstone bodies and marls beds frequently deformed by slumping in its lower part and isolated and amalmagated channel-fill sandstone bodies in the upper part. According to earlier interpretation (Babić & Zupanič 1983) "Flysch" represents deep-marine, slope to basin deposits (submarine fan deposits). Nowadays this interpretation is under the question and deposits can be also interpreted as prodelta facies of the slope-type fan deltas (paper in preparation). **Debelo Brdo Unit** consisting of calcareous mudstones and rare, thin interlayers of very fine-grained sandstones or siltstones indicating deposition in offshore zone. Unit is in transitional contact with **Benkovac Stone Unit** - succession of very fine to fine grained calcareous sandstones interbeded with bioturbated siltstones and mudstones deposited in shoreface zone. **Otavac Unit** is composed of carbonate conglomerates, sandstones and subordinate mudstones. The three component facies tend to form recognizable coarsening-upward cyclothems comprising either mudstone-sandstone-conglomerate or more rarely mudstone-conglomerate. At least 10 such cyclothems, each several metres thick, have been recognized as stacked upon one another in the succession. The facies assemblage of the Otavac Unit indicates an alternation of lower- to upper-shoreface environment, which was dominated by waves and supplied with gravel from a coeval beach or coarse-grained delta front. Consisting of calcareous mudstones, marls and rare, thin very fine-grained sandstones or siltstones **Karišnica Unit** is very similar to Debelo Brdo Unit and thus also represents deposition in offshore zone. On the other hand, the next succession, **Žedna Greda Unit** having about 10-20 m thick coarsening-upward cyclothems with

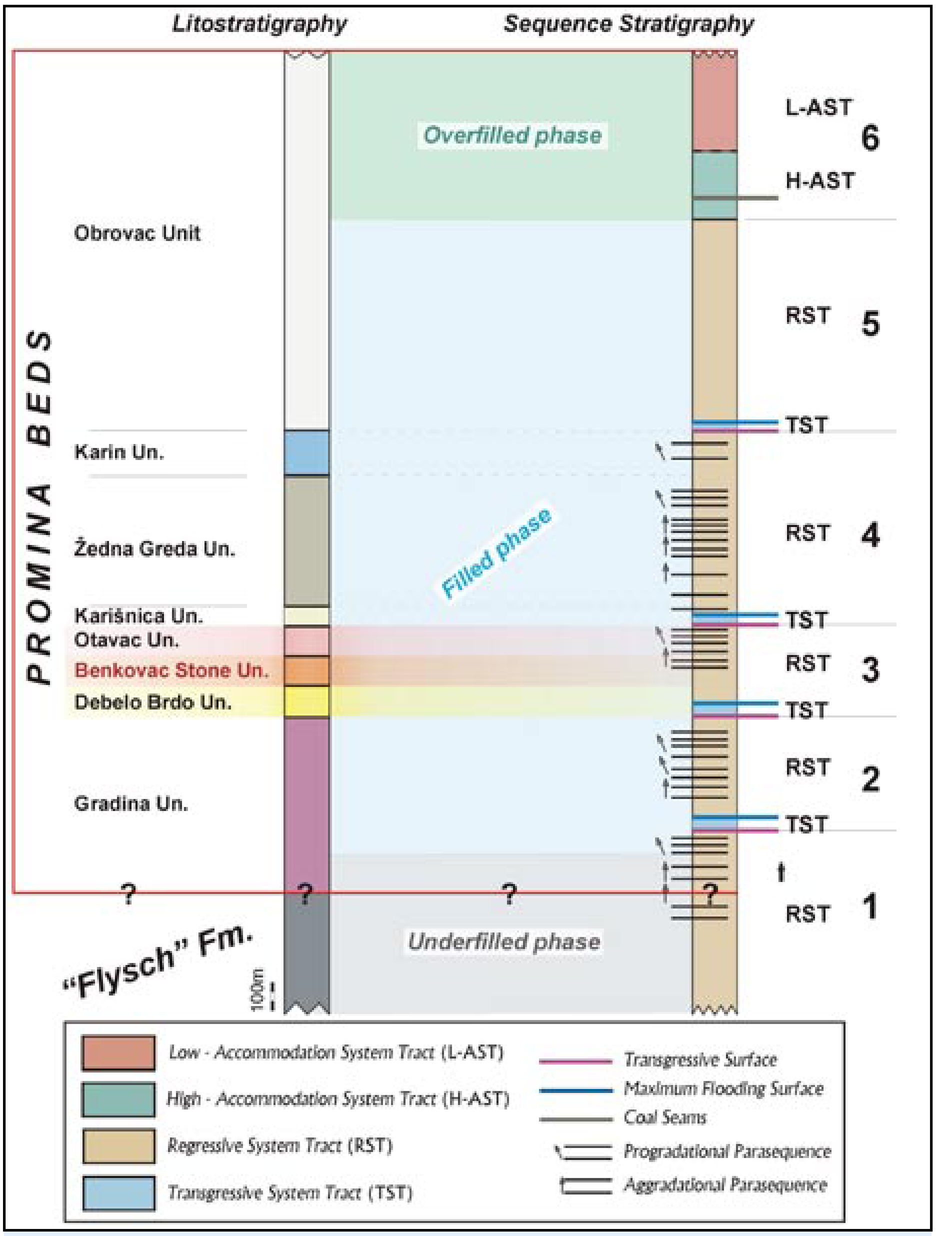


Fig. 5: Lithostratigraphy and sequence stratigraphy of the northwestern part of the Promina Beds area.

three component facies (mudstone-sandstone-conglomerate) indicates alternation of sandy lower- to upper-shoreface and gravely beachface and the mouth bars environments similar to Otavac Unit. **Karin Unit** consists of vertically stacked and prograding coarsening-upward cyclothems (parasequences). The top of the each parasequences is outstanding, thick foreset conglomerates comparable to Gilbert-type bodies. Conglomerate are underlien by mudstones (outer shelf facies) and sandstone (inner shelf facies) and overlien by relatively thin pebbly conglomerates with boring clast and bentic foramineferas. Obrovac Unit is the thickest (>800 m) and most complex unit of higher rang than described ones and even could be interpreted as a formation. The unit entirely consists of alluvial carbonate clastics. Temporal alternation of wide and amalmagated gravel channels and sandy, mostly isolated channels embraced by flood-plain deposits is outstanding characteristic of this unit.

The four transgressive and the five regressive systems tracts during underfilled and fulfilled phases and one low- and one high- accommodation systems tracts during overfilled phase can be seen on the right side of the next figure. (***Transgressive-regressive sequence model*** *uses maximum regressive surface as sequence boundary and maximum flooding surface to subdivide the T-R sequence into transgressive and regressive systems tract (Embry & Johannessen 1992). The amalgamation of all regressive deposits (highstand normal regressive, forced regressive and lowstand normal regressive) into one single regressive systems track seems to be appropriate where stratigraphic cyclicity developed during continous base-level-rise or where data are insufficient for separation between different types of regressive deposits. On the other hand, where sedimentary basins are dominated by the nonmarine deposits (overfilled basin phase) or where only the nonmarine deposits are not available for analysis, the solution to this problem is introduction of* ***low- and high-accommodation systems tracts*** *(Olsen et al. 1995). These systems tracts are defined primarily on the basis of fluvial architectural elements, including the relative rate of channel fills and overbank deposits which allows inference of the amounts of fluvial accommodation (low vs. high). The correlation between low-accommodation and lowstand systems tracts, and also between high-accommodation and transgressve to highstand systems tract can be only tentative, based on similarities in fluvial architecture. Thus, "maximum regressive surface" should not be used as boundary between the low- and high-accommodation systems tracts. It is common that he change from the low- to the overlying high-accommodation systems tract is gradational rather than abrubt*).

Quite naturally, the sequence surfaces are not in correspondence with the units boundaries. For example, the third T-R sequence is compound of Debelo Brdo, Benkovac Stone and Otavac Units. The lower part of Debelo Brdo Units is trangressive systems tract whereas the upper part belongs to regressive systems tract of the same sequence.

The Benkovac Stone and Contiguous Units

The Benkovac Stone is relatively thin unit of the lower Promina Beds in northwestern part of the basin.The Benkovac Stone consists of thinly bedded, shallow-marine calciclastic deposits that crop out as a narrow, SE-trending belt between the Debelo Brdo hill about 10 km northwest of Benkovac and the Mejanica hill about 1 km southeast of the village of Lisičić. The area has a low topographic relief covered with short vegetation and the general rock bedding here is gently inclined towards the northeast. The Benkovac Stone, with its tabular bedding and platy splitting pattern, has long been an important local source of building stone (hence the unit's name), and the numerous small quarries allow detailed study of this calciclastic succession. This sandstone-rich heterolithic succession is readily distinguishable from the underlying and overlying units.

The Benkovac Stone Unit is about 80 m thick and consists of carbonate sandstones (up to 35 cm thick, but mainly thinner) interbedded with finer-grained calcareous deposits. Its Late Eocene age was established on the basis of large benthic foraminifera (nummulitids, discocyclinids) and small pelagic globigerinids.

The sandstones are very fine- to fine-grained calcarenites, sporadically medium-grained, and consist mainly of various sparitic and micritic grains. Quartz grains are subor-

Fig. 6: Broad view from the Mejanica hill, looking towards the northwest. The occurrence of the Benkovac Stone Member is marked by numerous small quarries and other local excavation pits.

dinate (less than 10 vol. %). The sand grains are subrounded to rounded and generally well to very well sorted, forming a grain-supported framework with mostly point or planar grain contacts. Interstitial spaces are filled with a microcrystalline carbonate cement and/or fine-grained calcareous sediment.

The finer-grained interbeds are carbonate siltstones and mudstones, moderately to strongly burrowed.

The siltstones are calcisiltites composed mainly of medium to coarse silt-sized carbonate grains and up to 10 vol. % quartz grains. The calcareous mudstones are slightly clayey micrites with scattered silt-sized carbonate and quartz grains.

The carbonate sandstone beds are predominantly tabular and separated by mudstone layers, with relatively few beds amalgamated, stacked directly upon one another. The light-brown to grey sandstones are readily distinguishable from the pale yellowish–grey mudstones, even though their weathering patterns are not necessarily dissimilar. The sandstone beds vary considerably in thickness. The thicker beds have been characterised by planar parallel stratification, hummocky cross-lamination and flat parallel lamination or slightly undulatory ("wavy") laminations on their tops. They are very slightly normal graded. Some beds show convolute stratification. The thinner beds have slightly erosional and uneven bases, whereas the tops are slightly undulatory ("wavy") and occasionally transitional to the overlying silty mudstone. The thinnest sandy to silty beds (0,5–3 cm) are characterized by gently undulatory erosional bases and an undulatory, pinch-and-swell internal lamination.

The numbers of sand volcanoes and dykes occur locally on isololated bedding surfaces and in vertical beds section. This sinsedimetary deformation structures occurrance can be relatively frequent seen in the Benkovac Stone Un. profiles.

The contiguous Debelo Brdo and Otavac units occur in areas also covered with dense vegetation, where their exposure is generally poor. Field observations suggest conformable, transitional boundaries of these units with the Benkovac Stone Member.

The Debelo Brdo Unit is about 100 m thick and consists of calcarous mudstones with rare, thin interlayers of very fine-grained sandstone and/or siltstone.

The Otavac Unit is also about 100 m thick and composed of carbonate conglomerates, sandstones and subordinate mudstones. The conglomerates are clast-supported and typically have a bimodal grain-size distribution, with a pebble framework and sand- to granule-size matrix. Gravel clasts are subrounded to rounded, derived from Cretaceous limestones and subordinately also from rocks, of Palaeogene, Jurassic and Triassic age. Rare fragments of sandstone, marl, chert, dolomite and rudist molluscs aaare also present. The conglomerates form sheet-like beds 0,3–2,5 m thick, with uneven erosional bases, crude planar or gently inclined stratification. Their lateral extent is estimated to be at least several hundred metres. The conglomerate sheets are most often isolated, both underlain and overlain by sandstones or occasionally mudstone facies.

The calcareous sandstones are mainly coarse-grained, but include also fine- and medium-grained varieties, and are similar in their mineral composition to the sandstone facies of

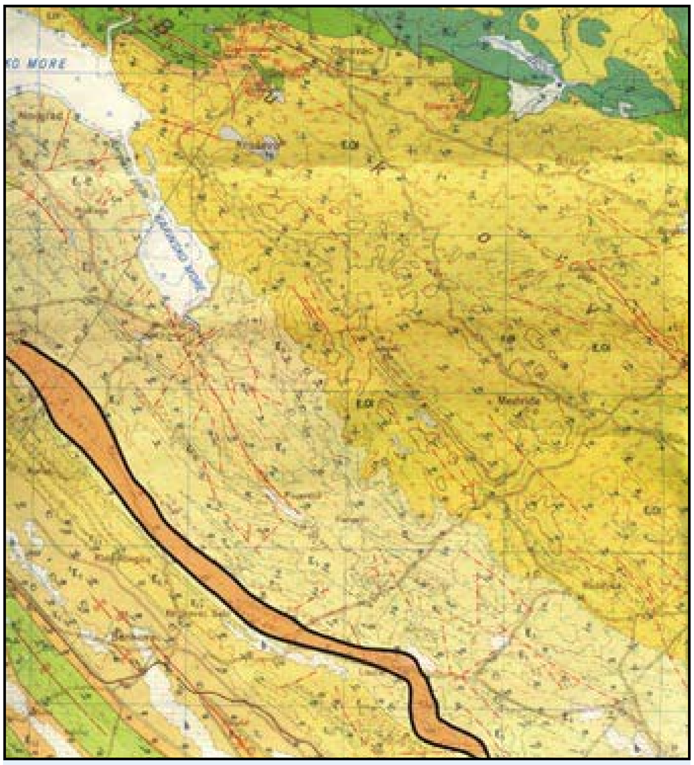


Fig. 7: Geological map of NW part of the Promina basin and Benkovac Stone Unit. Modified from Ivanović et al. (1973).

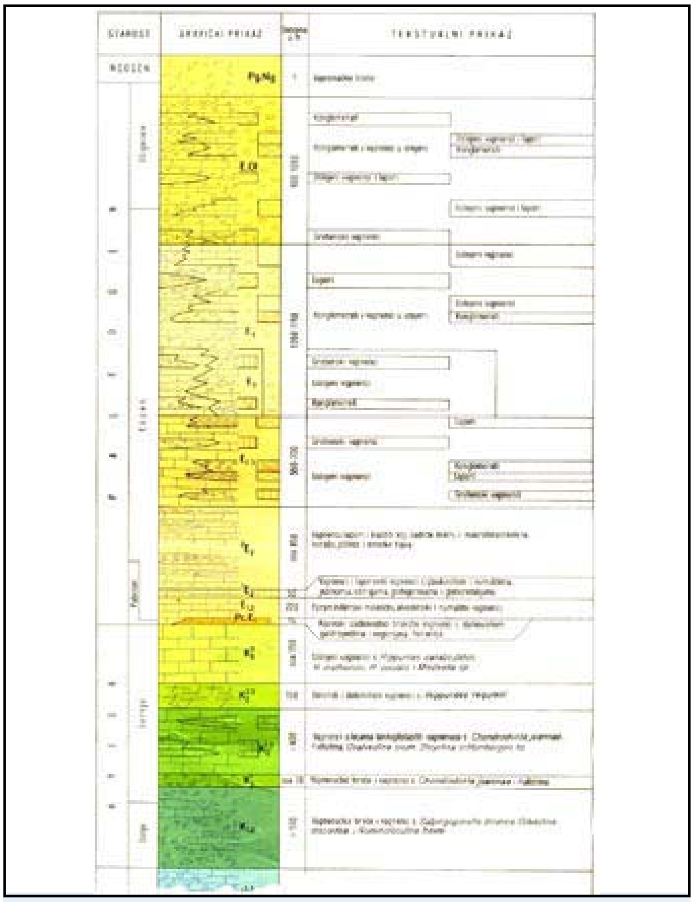


Fig. 8: Geological column of NW part of the Promina basin. From Ivanović et al. (1973).

the Benkovac Stone Member. Granules are commonly scattered in coarse-grained sandstones. Sandstone beds are 0,5–1,5 m thick and show planar parallel, low-angle inclined and locally hummocky or swaley cross-stratification. Some beds are nearly massive ("structureless") and amalgamated into units 3–4 m thick.

The calcareous mudstones are silt-streaked and similar to those in the Benkovac Stone and Debelo Brdo members. They form isolated layers 10–40 cm thick, with moderate to abundant bioturbation.

The terms carbonate sandstone, siltstone and mudstone are used for deposits containing a considerable amount of calcareous grains and composed of predominantly sand, silt and mud fractions, respectivelly, regardless of the actual proportion of calciclastic and siliciclastic components.

Description of the Benkovac Stone Facies

The Benkovac Stone Unit consists of carbonate sandstones interbedded with finer-grained calcareous deposits.

Carbonate Sandstone Facies

The carbonate sandstone beds are predominantly tabular and separated by mudstone layers, with relatively few beds amalgamated, stacked directly upon one another. The light-brown to grey sandstones are readily distinguishable from the pale yellowish-grey mudstones, even though their weathering patterns are not necessarily dissimilar. The sandstone beds vary considerably in thickness and have been classified into six facies and three subfacies, which are described in the present section.

Facies S1: tripartite sandstone beds with planar parallel stratification, hummocky cross-lamination and flat parallel lamination

These are the thickest sandstone beds, with average thicknesses in the range of 5 to 25 cm. Their basal surfaces are sharp and erosional, with an irregular relief of 1 to 7 cm, whereas their tops are slightly uneven or undulatory, with a relief of 2 to 6 cm. The beds are normally graded, with the particle size ranging from medium to fine or very fine sand. Even the thicker beds most often consist of fine to very fine sand and commonly coarse silt at the top. The basal surfaces locally show load casts, which are bulbous or irregularly-shaped features lacking preferred orientation. Basal mudstone injections in the form of load-flame structures occur in places .

Gutter casts and prode marks are sporadically found at the bases of the thickest beds. These isolated grooves are 12 cm deep and 45 cm wide, filled with sand and occasionally bearing mudstone intraclasts. The groove and prod orientation shows a NE-SW to N-S trend.

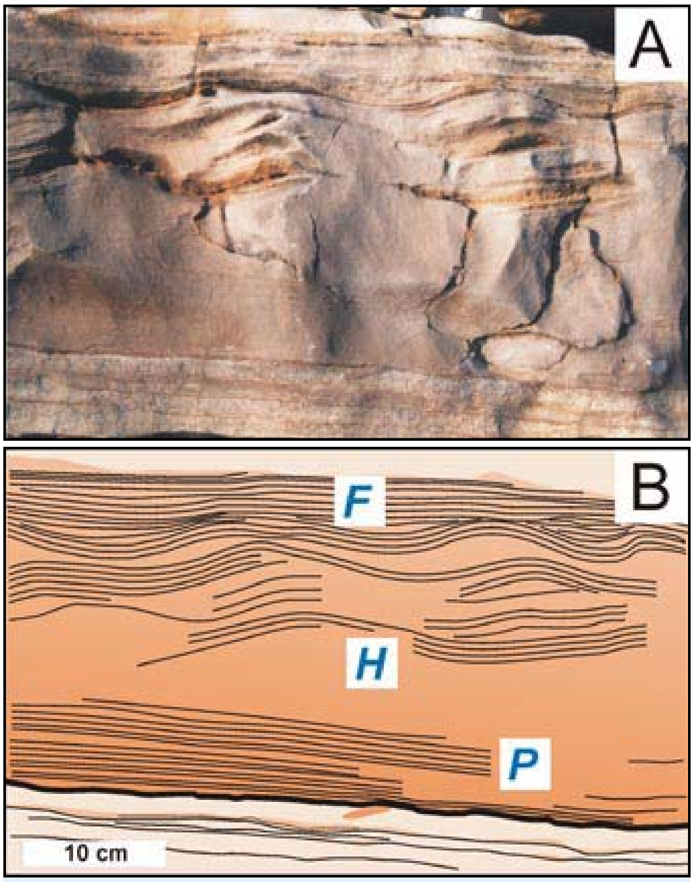


Fig. 9: Close-up view of a carbonate sandstone bed of facies S1 (A) and a corresponding sketch (B). Note that the sandstone bed has a sharp, erosional base and consists of a planar parallel-stratified division P (6 cm thick) overlain by a hummocky cross-stratified division H (15 cm) and capped with an undulatory to flat laminated division F (34 cm). The underlying and overlying deposits are silt-streaked calcareous mudstones of facies M.

Internally, these sandstone beds characteristically consist of three divisions. The lower division (P) is 3 to 20 cm thick and shows planar parallel stratification, although it is locally poorly recognizable in some beds. The strata are 0,2-0,4 cm thick, almost perfectly flat in the lower part and slightly undulatory in the upper part. Grain size varies from fine or medium to very fine sand. In the thickest beds of this facies, the parallel-stratified division is often underlain by a medium-grained sand horizon, 1 to 3 cm thick, which is rich in mudstone intraclasts. The mudclasts are angular, 0,5 to 6 cm long and flat-lying, parallel to the basal surface and sandstone strata.

The overlying, middle division (H) is 4 to 15 cm thick and shows medium- to small-scale hummocky cross-stratification (Harms et al. 1975); the latter is here referred to as hummocky cross-lamination. Grain size varies between fine and very fine sand on a bed to bed basis, but the division itself shows little internal grading. The strata are gently undulating, typically $<10°$, varying between convex- (hummocky) and concave-upward (swaley) in shape. The lateral spacing (wavelength) of the hummocks is mainly from 15 to 20 cm, and their relief (amplitude) is 1 to 2 cm. The strata are only 0,1 to 0,3 cm in thickness, which also varies laterally with their inclination. These small-scale structures are similar to the "micro-hummocky" cross-lamination of Kreisa (1981), attributed to 3D vortex ripples (Harms et al. 1982, their Figs. 214 and 316). Some beds show larger-scale hummocky structures at the transition of division P to H, which have a wavelength in excess of 50-60 cm and can be regarded as "true" hummocky cross-stratification, representing combined-flow conditions (Harms et al. 1975, Dott & Bourgeois 1982, Myrow & Southard 1996). In most cases, at least two or three superimposed sets of hummocky strata are recognizable in division H. The strata within the sets (first-order bounding surface sensu Dott & Bourgeois 1982) are concordant with the set's lower bounding surface (second-order bounding surface), which itself is slightly erosional. The transition from division P to H is either gradual or sharp and slightly erosional.

The upper division (F) is 1 to 3 cm thick, consists of very fine sand or coarse silt and shows planar parallel lamination. In contrast to the lower division, the strata here are only 0,1-0,2 cm in thickness and commonly show an upward change from slightly undulatory to flat, which renders their lower boundary transitional. In some cases, thin isolated intrasets of asymmetrical wave-ripple cross-lamination occur in this division.

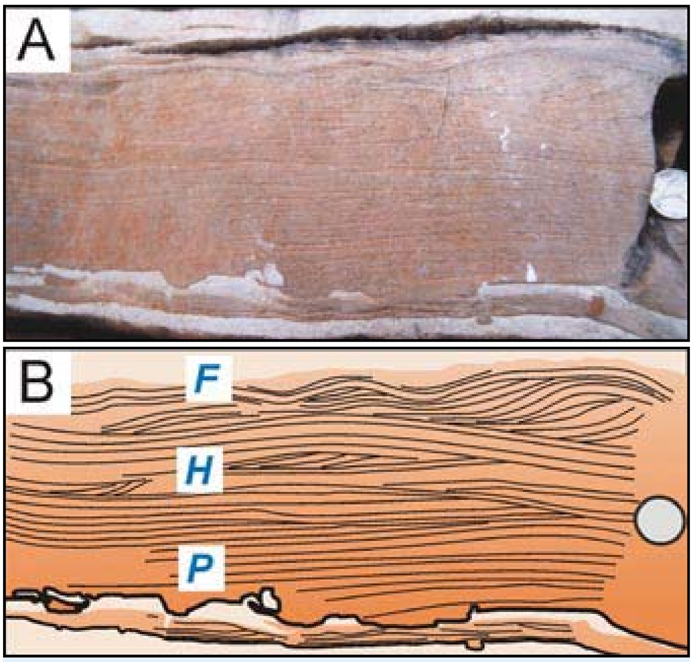


Fig. 10: Close-up view of a carbonate sandstone bed of Facies S1 (A) and a corresponding sketch (B). Note that the sandstone bed has a sharp, loaded base and consists of a planar parallel-stratified division P (5 cm thick) overlain by hummocky cross-laminated division H (45 cm) and capped with an undulatory to flat laminated division F (23 cm). The wavelength of hummock forms is about 20 cm, but is considerably greater at the transition of divisions P to H, where medium-scale hummocky cross-stratification (HCS) is recognizable. The underlying deposits are mudstones of facies M with a thin interbed of facies S5c sandstone. The coin (scale) is 2,2 cm.

Facies S2: bipartite sandstone beds with hummocky cross-lamination and flat parallel lamination

The beds of this sandstone facies are similar to those of the previous one, but are generally thinner (average thicknesses of 410 cm) and show only two component divisions. The basal surfaces are sharp and erosional, with a relief of 2 to 3 cm and local load casts, and the bed tops are slightly uneven or gently undulatory. The beds show normal grading, with the grain size ranging from fine or very fine sand to very fine sand or coarse silt, respectively.

The lower bed division (H) consists of hummocky cross-lamination, similar to the previous facies, but this division here is thinner (25 cm), composed of slightly thinner strata, and the wavelength of hummocks is also somewhat smaller (1015 cm). The overlying upper division (F) is a thin (12 cm) set of slightly undulatory to planar parallel laminae composed of very fine sand to coarse silt. Division F is often indistinct, either poorly developed or virtually absent.

Facies S3: sandstone beds with convolute stratification

These are sandstone beds that show internal hydroplastic deformation in the form of convolute stratification, although could originally be similar to any of the previous sandstone facies. Average bed thicknesses are mainly in the range of 5 to 25 cm, and the deformation is often stronger in the bed's upper part or is locally limited to only this part. The convolutions typically occur as steep antiforms composed of deformed and locally disrupted or homogenized strata. The antiforms are commonly asymmetrical, but generally lack preferential orientation or a recognizable spatial pattern.

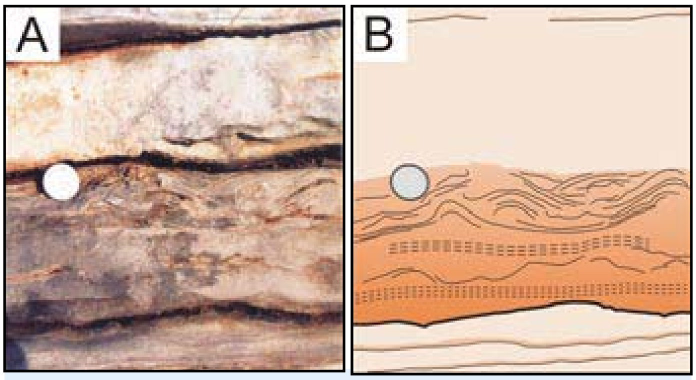


Fig. 11: Convoluted sandstone bed of facies S3 and (B) a corresponding. The underlying and overlying deposits are silt-streaked mudstones of facies M. The coin (scale) is 2,2 cm.

Facies S4: amalgamated sandstone beds

This facies is relatively rare and consists of amalgamated sandstone beds, which themselves represent one or more of the previous facies. The component beds are stacked erosionally upon one another with no intervening mudstone layers. These composite, amalgamated beds are recognizable by their greater thicknesses (up to 35 cm), multiple normal grading and a more complex vertical sequence of structural divisions.

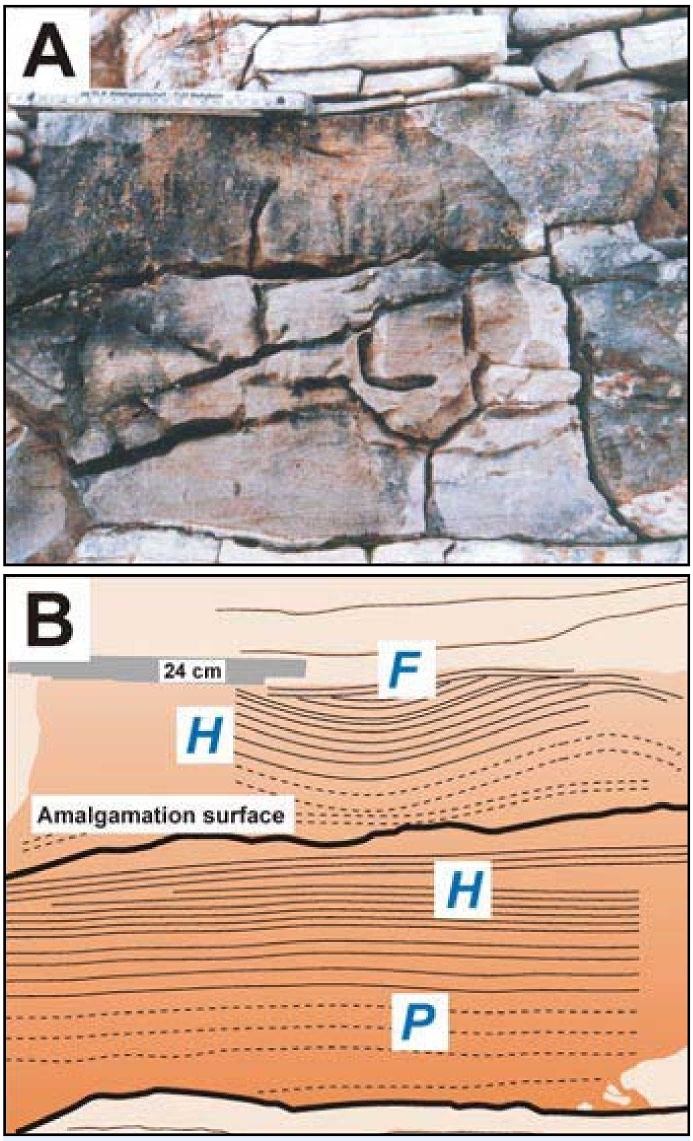


Fig. 12: A) Compound, amalgamated sandstone bed of facies S4 and (B) a corresponding sketch. Note the sequence of component bed divisions, including planar parallel stratification (P), hummocky cross-stratification (H) and undulatory to flat parallel lamination (F). The lower division H shows broader, medium-scale hummocky cross-stratification (HCS), whereas the upper division H shows hummocky cross-lamination (ripple-scale hummocks). The underlying and overlying deposits are silt-streaked mudstones of facies M.

Facies S5: cross-laminated sandstone beds

These are thin sandstone beds (25 cm), composed of very fine sand or coarse to medium silt and generally lacking any obvious grain-size grading. Their bases are slightly erosional and uneven or undulatory, whereas the tops are slightly undulatory ("wavy") and occasionally transitional to the overlying silty mudstone. Many of these sandstone beds, much like the overlying and underlying mudstone layers, are strongly burrowed. Internally, the sandstone beds show a wide range of wave-ripple cross-lamination types, which form the basis for the distinction of three subfacies. The wave-ripple cross-lamination is recognizable by the presence of uneven or undulatory basal surfaces and lower laminae sets; draped or offshooting geometry of foreset laminae; and chevron-like or form-discordant internal laminae sets.

Subfacies S5a: sandstone beds with translatory ripples - These beds have undulatory boundaries with well-preserved asymmetrical ripple forms, 13.5 cm in amplitude and 620 cm in wavelength. Some cross-sets are underlain by a set of 2 or 3 planar laminae covering the erosional basal surface. The well- developed foreset laminae, with discordant silty laminae on the stoss side and a "sweeping" drape of undulatory laminae are typical of migrating, translatory wave ripples (Allen 1982). The dip directions of foreset laminae (ripple migration azimuths) are towards the west or northwest.

Subfacies S5b: sandstone beds with climbing ripples - These beds are slightly thicker, have undulatory and slightly erosional bases, and consist of two or three superimposed sets of asymmetrical, climbing-ripple cross-lamination with preserved stoss-side laminae. The angle of climb varies from 8 to 12°. Ripple dimensions are similar to those of the previous subfacies, and the dip directions of foreset laminae are also similarly towards the west or northwest. As in the previous subfacies, a basal set of 23 flat or slightly undulatory laminae can often be seen covering the underlying erosional surface. A similar set of "sweeping" undulatory laminae occur often at the bed top.

Subfacies S5c: sandstone beds with pinch-and-swell lamination - These sandy to silty beds are the thinnest (0.53 cm), characterized by gently undulatory erosional bases and an undulatory, pinch-and-swell internal lamination (similar to the "rolling-grain" ripples of Harms et al. 1982), occasionally associated with thin, solitary lenticular cross-sets (small, sediment-starved translatory ripples; Allen 1982).

Facies S6: massive sandstone beds with normal grading

These are very common, but very thin (15 cm), fine-grained sandstone beds that lack recognizable internal lamination. Their basal surfaces are sharp and slightly erosional, with a local-scale relief of 0.5 to 1 cm, whereas the tops are flat or only slightly undulatory. The beds are normally graded, ranging in grain size from very fine sand to coarse silt. The thicker beds locally show traces of primary lamination, which suggests a secondary process of sediment homogenization. The "structureless" (massive) appearance of these deposits is thus probably a result of their bioturbation and/or subsequent pervasive weathering at outcrop.

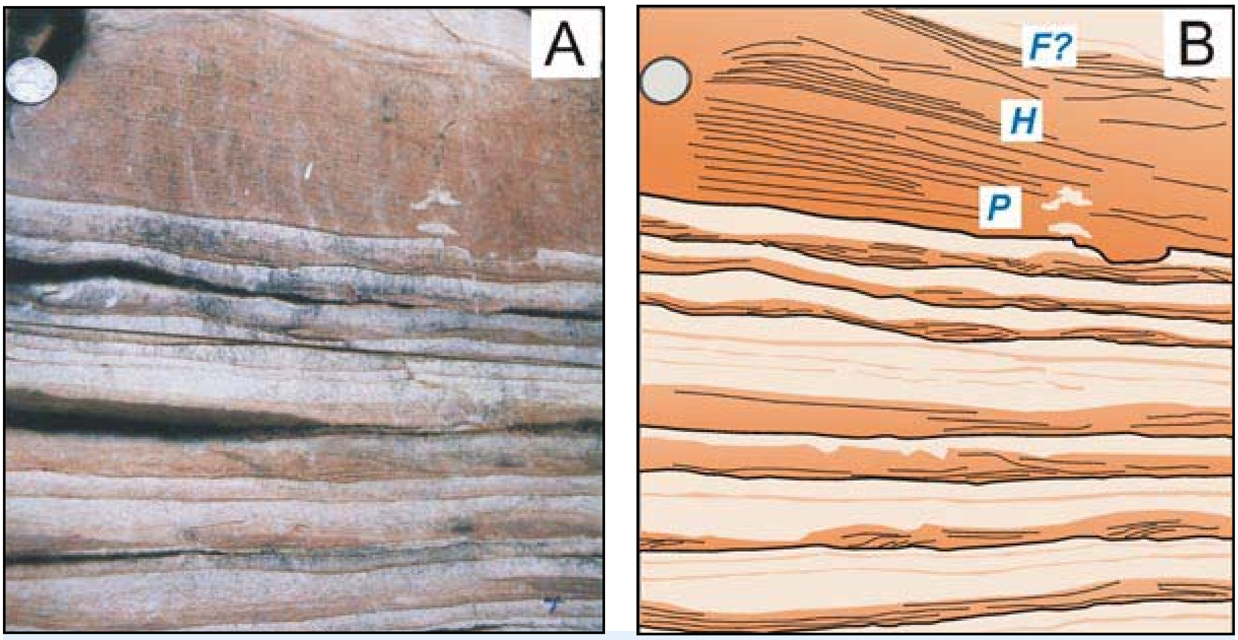


Fig. 13: (A) portion of the deposits and (B) a corresponding sketch, showing a package of the alternating beds of facies M and sandstone facies S5a (lower part) and S5c (middle part), overlain by a thicker sandstone bed of facies S1. The wavelength of hummock forms in the latter bed's division H is about 20 cm, but is considerably greater at the transition of divisions P to H, where medium-scale hummocky cross-stratification (HCS) is recognizable; note also the localized basal scour and mudstone intraclasts in the lower division P. The coin (scale) is 2,2 cm.

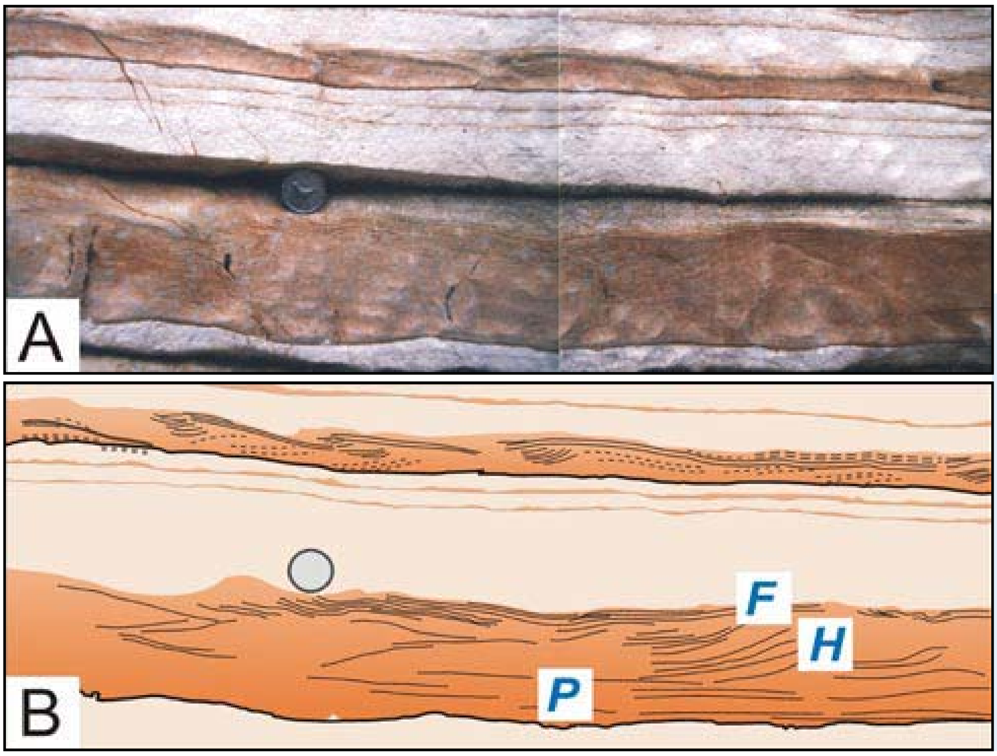


Fig. 14: (A) Some of the Benkovac Stone deposits and (B) a corresponding sketch, showing a package of alternating beds of silt-streaked mudstone facies M and sandstone facies S1 (lower bed) and S5b (upper bed). In the latter bed, the translatory ripples have an amplitude of 23 cm and wavelength of 812 cm, with an angle of climb in the range of 810°; note the preserved thin intrasets of stoss-side laminae. The coin (scale) is 2,2 cm.

Carbonate Mudstone Facies

The mudstone interbeds (facies M) are common and laterally continuous on an outcrop scale, ranging in thickness between a few mm and 30 cm. Most beds contain thin (0,21 cm) silty interlayers in the form of flat streaks and distinct lenses with signs of pinch-and-swell lamination, apparently representing sediment-starved small ripples of wave or tidal origin (see Reineck & Singh 1975; and the "rolling-grain" ripples of Harms et al. 1982). The interlayers usually show normal grading from coarse to fine silt, and many have slightly erosional bases. The vertical spacing of these interlayers varies from a

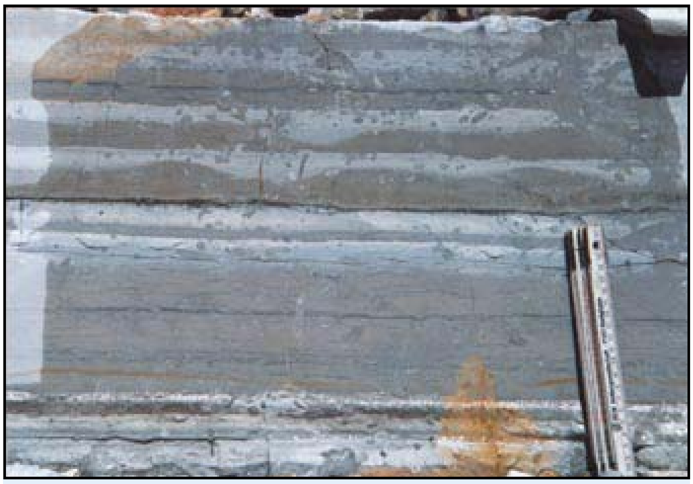


Fig. 15: Silt-streaked mudstone facies M, alternating with thin sandstone beds of facies S5a in the upper part. Ripples have amplitude of 35 cm and wavelength of 15-20 cm.

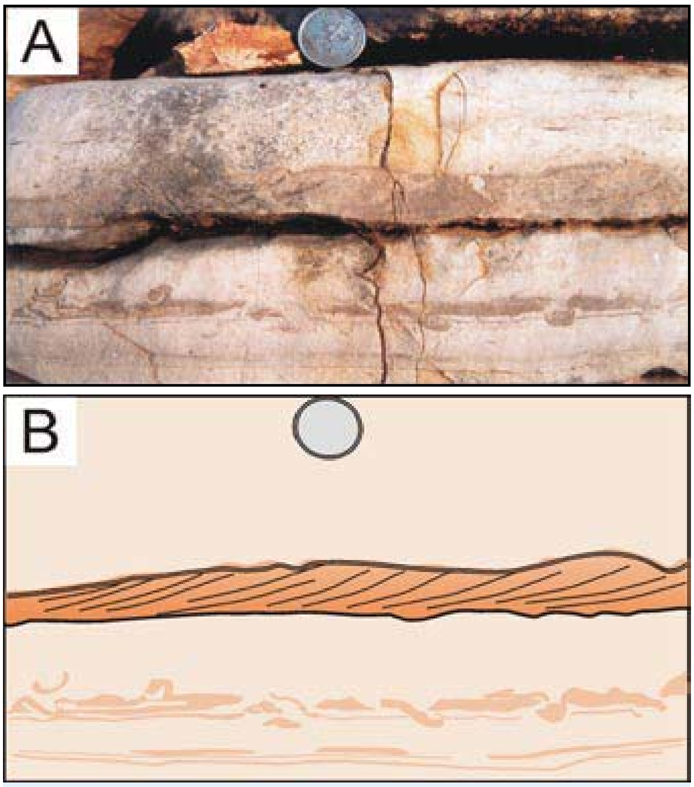


Fig. 14: (A) Photo of deposits and (B) a corresponding sketch, showing the silt-streaked mudstones of facies M with thicker (< 0,5 cm) siltstone interlayers and a sandstone interbed of facies S5a (2 cm thick) in the middle. Note that some of the interlayers are strongly disrupted by animal burrows. The coin (scale) is 2,2 cm.

few centimetres to 20 cm or more, and they are commonly disrupted and deformed by animal burrows.

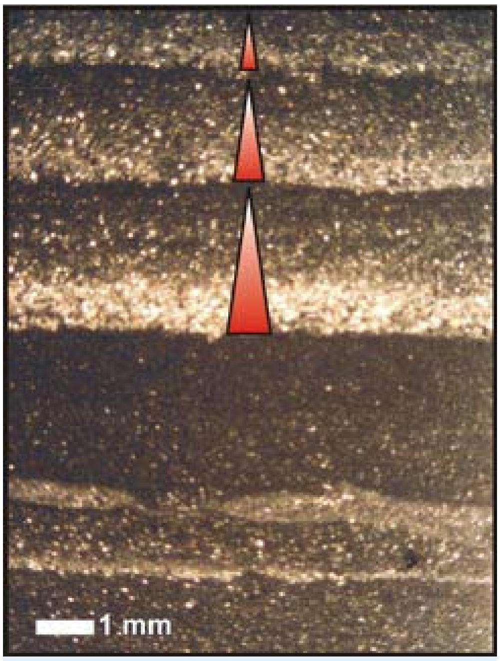


Fig. 24: Microscopic detail of a silt-streaked calcareous mudstone of facies M. Note that the silt interlayers vary from thin (12 mm) lenses and pinch-and-swell features (lower part), to thicker (23 mm), sharp-based sheets with normal grading (upper part).

Soft-sediment Deformation Structures

Two types of deformation structures probably triggered by seismic shocks are noticed in some parts of the Benkovac Stone succession.

Sand volcanoes

Small sand volcanoes, circular or elliptical in shape, occur locally on isolated bedding surfaces in the mudstone facies M. These conical features are typically 1532 cm in diameter and 36 cm in relief, and apparently represent seafloor sand extrusions buried by younger mud. A relatively a great number of such features have been found on the bed surfaces of Stop 2.

Fig. 18: Sand volcano in cal-careous mudstone facies M. This volcano has circular plan-view shape with the diam. of about 20 cm and cone relief of 4 cm.

Sand dykes

Tabular and discordant sandstone bodies caused by the injection of liquified sands from below. They show irregular forms on the mudstone bed surfaces ranging in the thickness from a few centimeters to more than 20 cm and irregularly striking on the surface from a few decimeters to more than 10 meters. In some cases mud intraclast derived from overlying and underlying mudstone by shearing stress can be noticed inside injected sands. They can be commonly seen on some bed surfaces of Stop 2.

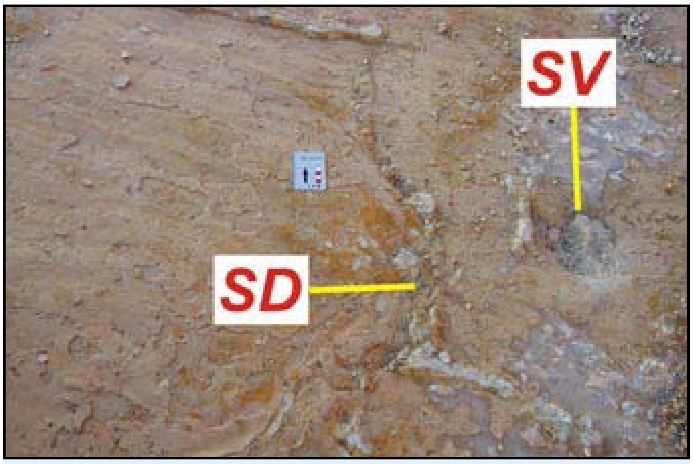


Fig. 19: A branching plan-view of sand dyke and a small elliptical sand volcanoe with the longer axis of 12 cm. SD - sand dyke; SV - sand volcano.

Trace Fossils

The sedimentary succession shows a wide range of trace fossils, which abound in the mudstone facies, but are also common in the sandstone beds. The thicker sandstone beds most often lack burrows, except for the top parts. The degree of bioturbation of the thinner bedded and muddy facies generally varies from moderate to high (grades 3-4 *sensu* REINECK, 1963).

Fig. 20: Paleodictyon.

The majority of identifiable traces belong to Nereites, Zoophycos and Cruziana ichnofacies. The grazing Helminthoida traces, produced by deposit-feeding animals, are particularly common and often show well-developed patterns. The grazing Palaeodictyon traces have been found almost at any localities.

Fig. 21: Ophiomorpha.

Fig. 22: Chondrites.

Fig. 23: Diplichnites.

Interpretation of the Benkovac Stone Facies

The internal characteristics of the sandstone facies S1S6, together with their sheet-like bedding geometry, indicate sand deposition by waves in combination with unidirectional currents (see De Raaf et al. 1977, Hamblin & Walker 1979, Dott & Bourgeois 1982, Leckie & Walker 1982, Walker et al. 1983). The intervening, silt-streaked mudstone layers of facies M indicate quiet-water conditions dominated by hemipelagic suspension fallout and biogenic activity, with the sand-starved seafloor episodically affected by very weak wave action and/or tidal currents. The intimate association of the discrete, erosional sandstone sheets rhythmically alternating with mudstone layers indicates episodic deposition from storm events in an offshore transition zone (Swift et al. 1987, Snedden et al. 1988, Leckie & Krystinik 1989, Walker & Pllnt 1992), which means a shelf bathymetric area extending between the average fair-weather wave base and the average storm wave base (Reading & Collinson 1996). The offshore transition zone thus occurs outside the shoreface zone (perennially affected by waves) and is subject to episodic incursions of sand during storm events ("event" sedimentation sensu Einsele & Seilacher 1982). The actual width, or seaward distance, of these zones depends on the local seafloor inclination and may vary from a few hundred metres to several kilometres (Reading & Collinson 1996).

Accordingly, the sandstone facies are considered to be tempestites (storm deposits), embedded in a "background" mudstone facies (fair-weather deposits). In the following part of this section, the hydrodynamic regime of the offshore transition zone is briefly reviewed as a conceptual basis for the subsequent detailed interpretation of the individual sandstone facies.

Processes in the offshore transition zone

As the storm winds push seawater against the coast as a surface current, the resulting coastal setup generates strong bottom currents of seaward-returning ("ebbing") water, such as the rip currents, ebb surges and the wide and longer-running geostrophic currents (Walker & Plint 1992, Reading & Collinson 1996). As a result, the nearshore water column divides into three internal layers: a highly turbulent surficial layer, an inviscid inner (core) flow layer and a bottom boundary layer (see Myrow & Southard 1996). This latter layer combines the boundary layers produced by waves and currents, such that its lower part is effectively a "combined-flow" boundary layer, where waves and currents interact nonlinearly to produce bot-

CARBONATE SANDSTONE

Facies S1: *tripartite sandstone beds with planar parallel stratification hummocky cross-lamination & flat parallel lamination*

Facies S2: *bipartite sandstone beds with hummocky cross-lamination & flat paral-lel lamination*

Facies S3: *sandstone beds with convolute stratification*

Facies S4: *amalgamated sandstone beds*

Facies S5: *cross-lamianted sandstone beds*
- Facies S5: *sandstone beds with translatory ripples*
- Facies S5: *sandstone beds with climbing ripples*
- Facies S5: *sandstone beds with pinch & swell lamination*

Facies S6: *massive sandstone beds with normal grading*

CARBONATE MUDSTONE & SILTSTONE

Laterally continuous mudstone interbeds (facies M), thickness between a few mm and 30 cm. Mosty contain thin (0.21 cm) silty interlayers in the form of flat streaks and distinct lenses with signs of pinch-and-swell lamination. The inter-layers are normaly graded from coarse to fine silt, and many have slightly erosional bases. They vertical spacing varies from a few centimetres to 20 cm or more, and they are commonly disrupted and deformed by animal burrows.

Summary of facies recognised in the Benkovac Stone Unit.

tom shear stresses considerably stronger than a simple sum of the two energy components. Importantly, the storm-generated current tends to be non-uniform and unsteady, which means that the relative role of waves and unidirectional flow in the boundary layer may vary in both space and time.

Four basic forces affect the geostrophic current (see Myrow & Southard 1996): (1) the seaward pressure gradient created by the coastal setup; (2) the Coriolis force that rotates the current to the right in the Earth's northern hemisphere; (3) the flow-retarding force of bottom friction; and (4) the downslope component of gravity force due to excess weight of sediment-laden water. Depending on the temporal history of these four controlling forces, the hydrodynamic regime of a storm event may theoretically represent any of the following cases (Myrow & Southard 1996): (1) a temporal increase and then decrease in the magnitude of all four forces; (2) a greater change in bottom friction than in the other forces; (3) a seaward and then landward rotation of the flow direction relative to shoreline; and (4) weak flow conditions at all times, with a predominance oscillatory waves. Another consequence of the combined forces is that weaker currents tend to be nearly shore-parallel, whereas the stronger and denser currents are directed offshore at a higher angle. Furthermore, the local hydrodynamic behaviour of the storm-agitated bottom water can vary through a whole spectrum of cases defined by the following three end-members (Myrow & Southard 1996): (1) an "ideal" combined-flow geostrophic current, (2) pure oscillatory wave action and (3) a density-driven flow somewhat analogous to a turbidity current. The various intermediate, "modified" cases are thought to be commonplace in shelf environments.

Myrow & Southard (1996) also explained as to how the relative role of waves, geostrophic flow and density-driven flow may change during the predepositional and depositional phase of a storm event, with reference to a nearshore (shoreface) site and seafloor sites above and below the storm wave base (i.e., in the offshore transition and offshore zone, respectively). Three hypothetical storm events are considered as an illustration. In an event involving relatively weak waves and a decelerating geostrophic current, the wave action increases in the shoreface zone; the relative role of a density-modified current increases and then decreases in the offshore transition zone; and only the density-driven current will be recorded in the offshore zone. In an event involving a relatively weak geostrophic current and strong waves with decreasing orbital velocities, the process record in all three zones will be nearly identical, except that the geostrophic flow may gradually prevail in the shoreface zone. In a disequilibrium event with high nearshore suspension concentration, the action of a density-driven current will predominate in all three zones.

Interpretation of sedimentary facies

The sandstone beds of facies S1 show planar parallel stratification (division P) overlain by medium- to small-scale hummocky cross-stratification (division H) and capped with undulatory to flat parallel lamination (division F). If the sporadic medium-scale hummocky cross-stratification is ignored, the sequence of stratification types can be attributed to the action of oscillatory waves (see the bedform stability diagrams in Allen, 1982 figs. 1118; Harms et al., 1982 figs. 214), with the temporal trajectory of seafloor hydraulic regime beginning in the plane-bed field and re-entering this field again after crossing the field of 3D vortex ripples (see also Walker et al. 1983; Myrow & Southard 1996). The action of a geostrophic current in such a case would be limited to supplying sand to the offshore transition zone, and to aiding briefly the development of medium-scale hummocks. Alternatively, the basal division P could partly or entirely be deposited by a geostrophic current, if the latter was sufficiently powerful, laden with sediment and characterized by high suspension fallout rate, such that tractional plane-bed transport occurred (see Lowe 1988 fig. 3). The action of waves would then directly follow that of the density-modified current. This possibility is particularly likely for beds that show medium-scale hummocky cross-stratification in the lower part of their division H, because this stratification type is widely attributed to a combined-flow regime.

The sandstone beds of facies S2 show a hummocky cross-laminated division H overlain by an undulatory to flat parallel-laminated division F, which can be attributed to oscillatory waves with the temporal trajectory of the hydraulic regime commencing in the stability field of 3D vortex ripples and passing into the plane-bed field as the sediment supplied becomes finer-grained In this case, the sand delivered to the offshore transition zone by a waning geostrophic current would be thoroughly worked by waves.

It is worth pointing out that the action of waves on the seafloor in the offshore transition zone will cease abruptly as soon as the wave base detaches itself from the seafloor. This means that the storm event of sand deposition can abruptly be terminated at a non-zero level of general wave energy; and that is why most tempostites have not only sharp bases, but also sharp tops, which are often also undulatory, showing well-preserved ripple forms.

The sandstone beds of facies S1 and S2 also stand out by their greater thicknesses, implying the strongest storm events that affected the offshore transition zone in the present case. Geostrophic currents would play a greater role in the deposition of facies S1, attributed to the strongest storm. In this context, the significance of sandstone facies S4 would be to represent strong storms that closely followed one another, such that little or no fair-weather sedimentation took place between these events.

The erosional bases and normal grading of these tempestite beds are consistent with the notion of an initial, strong ebb-surge followed by a waning geostrophic current that supplied increasingly fine-grained sediment to the offshore transition zone. The sporadic occurrence of gutter casts at the bases of facies S1 beds may theoretically be due to either oscillatory waves or combined-flow currents (Myrow & Southard 1996). However, some authors suggested that a unimodal orientation of gutter casts may indicate unidirectional currents, possibly density-modified (Hamblln & Walker 1979, Leckie & Walker 1982, Walker et al. 1983). The NE-SW to NS trend of the gutter casts in the present case is roughly perpendicular or oblique with respect to the inferred palaeoshoreline (see palaeogeographic reconstruction in subsequent section), which may support the notion of strong ebb-surges or powerful geostrophic currents. This interpretation is further supported by the occurrence of mudclast-rich horizons, considered to be lag deposits of powerful, erosive currents (Sepkoski 1982, Walker et al. 1983). The fact that the mudclast lags are uncommon may reflect either their limited preservation potential or deposition from somewhat exceptional currents.

The convoluted sandstone beds of facies S3 were apparently deposited in a similar way to those of facies S1 and S2, but underwent a late syndepositional or early post-depositional hydroplastic deformation. These deformed beds indicate partial sediment liquefaction, but are relatively rare, and hence the cause of the deformation itself can be regarded as a rare factor. The seafloor was clearly affected by sporadic shallow liquefaction, as is also indicated by the horizons of mud volcanoes. The origin of mud volcanoes is attributed to the upwelling of pore-water springs through liquefied quickmud (Reineck & Singh 1975), which may occur in response to a rapid sediment deposition, cyclic seafloor loading by storm waves or shaking by seismic "ground-roll" wave (i.e. the combined S and L shock waves propagating at ground level). The same factors, or the shearing by an overpassing current (Sanders 1965), could occasionally liquefy the seafloor when it was covered with sand (facies S1 or S2), rather than mud, and hence result in facies S3 (see Middleton & Hampton 1973). A more intense liquefaction and/or pervasive bioturbation are thought to have similarly produced facies 6, which seems to have resulted from a sporadic internal homogenization of freshly-deposited sand beds of facies S5.

The sandstone subfacies S5a and S5b indicate storm events with a prevalent role of geostrophic currents, which were sand-laden and characterized by a moderate (subfacies S5a) to high suspension fallout rate (facies S5b) (see Harms et al. 1982). These beds are thin and fine grained, which implies relatively weak, highly subcritical (Harms et al. 1975) and low-density currents (sensu Lowe 1982). The orientation of ripple cross-lamination indicates currents flowing towards the west (obliquely offshore) or northwest (alongshore).

At the other end of the whole spectrum of tempestites are the very thin and fine-grained beds of facies S5c, whose geometry and internal features indicate sand-starved vortex ripple and rolling-grain ripples, implying weak action of "pure" oscillatory waves (Allen 1982, Harms et al. 1982).

The silt-streaked calcareous mudstones of facies M represent quiet-water sedimentation during the inter-storm periods of fair-weather conditions, accompanied by widespread biogenic activity (seafloor burrowing). The fallout of hemipelagic muddy suspension was frequently interrupted by sparse incursions of silt, which can be attributed to weak tidal currents and/or minor seasonal storms.

Spatial Distribution of Facies

The sedimentary succession is characterized by tabular bedding, with the sheet-like sandstone and mudstone beds showing lateral continuity on an outcrop scale of up to several hundred metres. Two of the thickest sandstone beds of facies S1 can be correlated as markers, on an outcrop to outcrop basis, over a distance of at least 15 km parallel to the inferred palaeoshoreline.

The succession of alternating sandstone and mudstone beds shows considerable variation in their thicknesses, but little obvious vertical organization. The only recognizable trend is that the thicker beds of facies S1 are more common, and the mudstone beds of facies M are thinner and less bioturbated, in the middle part of the succession. This stratigraphic pattern may reflect a temporal change in relative sea level, sediment supply or sea-wave climate. An episode of an accelerated shoreline advance seems likely to have been the case, because it would inevitably increase the frequency and magnitude of storm events affecting the offshore transition zone, and thus increase the supply of sand to the latter. The subsequent, temporal recession of the shoreline could be due to any of the three factors mentioned above, but was most likely caused by a relative sea-level rise.

Depositional Model

The Promina Formation has previously been recognized to be the record of an overall upward transition from deep-water turbiditic facies to braid-delta and fluvial braidplain deposits (Babić & Zupanič 1990, Mrinjek 1993 a, b, 1994). The present study indicates that the Benkovac Stone Member consists of the offshore transition deposits of a storm-dominated, microtidal shelf variously affected by oscillatory waves and sediment-laden geostrophic currents. The underlying Debelo Brdo Member is considered to represent a corresponding muddy offshore zone, whereas the overlying Otavac Member represents a wave-dominated shoreface supplied with sediment; an advancing, wide braid-delta front. A somewhat similar braidplain delta, many tens of kilometres wide and passing into a storm-dominated offshore-transition zone, was described from the Lower Cretaceous of Svalbard (Nøttvedt & Kreisa 1987, Nemec et al. 1988, Nemec 992).

The palaeogeographic scenario for the stratigraphic succession of these three members takes into account the SE-trending basin margin and implies a stratigraphic model of a long-term normal regression) punctuated by minor, shorter-term relative sea-level rises. Overall, a considerable rise of relative sea level must have occurred, because the thickness of the Otavac Member (shoreface deposits) exceeds 100 m, whereas the depth of the mean fair-weather wave base is unlikely to have exceeded 15 m (Walker & Pllnt 1992). The smaller thickness of the Benkovac Stone Member (ca. 40 m) reflects a relatively low net rate of sediment accumulation in the offshore transition zone (area of episodic sand incursions), markedly different than that in the associated shoreface zone (nearshore sediment trap) and the strongly aggrading braidplain.

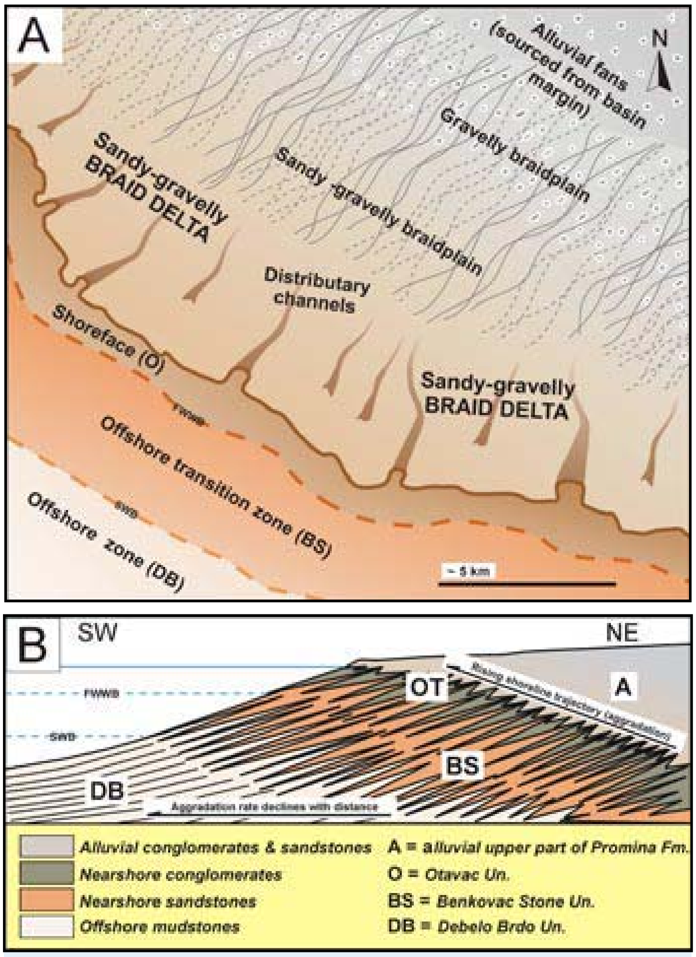


Fig. 24: A depositional model for the Benkovac Stone Member, in the form of a schematic palaeogeographic map (A) and a shore-transverse stratigraphic cross-section (B). The vertical scale and seafloor gradient in diagram B are grossly exaggerated for graphical purposes. FWWB = fair-weather wave base; SWB = storm wave base; other symbols explained in the legend.

Stop 1

The stop 1 is next to the left side of the road Obrovac-Karin-Benkovac. It is abandoned quarry outcrop. Position of the outcrop "walls" (almost perpendicular to each others) enable 3-D view of facies. The outcrop contains sandstone beds with typical facies S1 and S2. Their platy splitting enable trace fossils analysis on many bed surfaces.

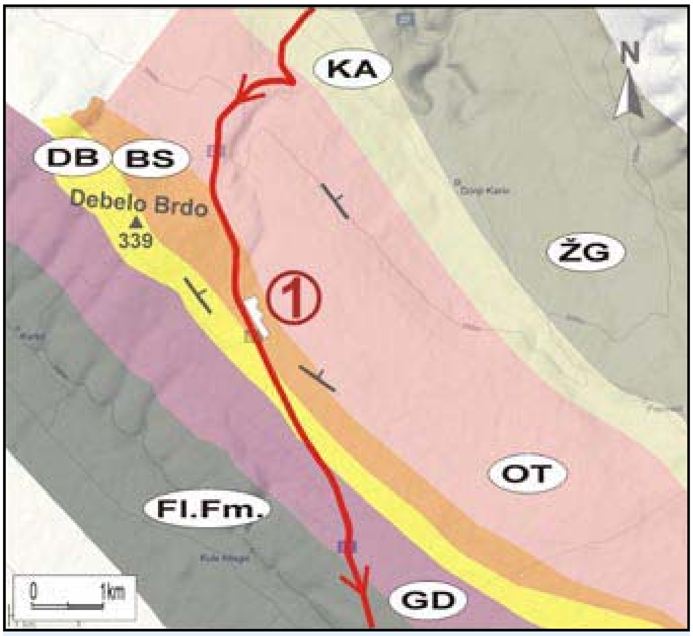


Fig. 25: The location of Stop 1 with litostratigraphic map.

Fig. 26: This outcrop is proposed for a geolocality by the authors of this guide. Approach is very easy and comfortable.

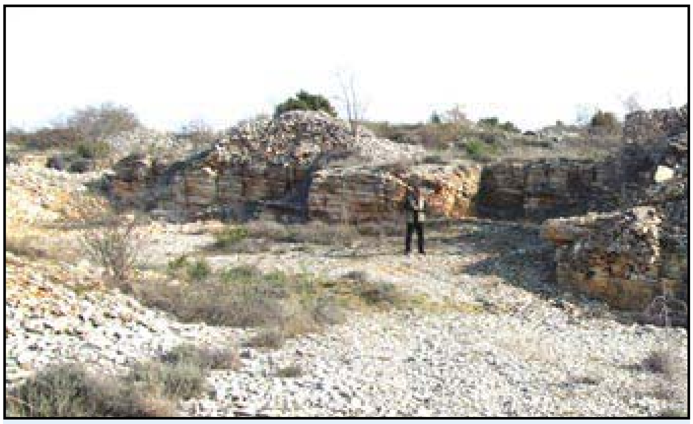


Fig. 27: The outcrop is a very suitable place for the field lectures. The photo was taken during fieldworkshop: Trace Fossils in Facies Interpretation and Sequence Stratigraphy Interpretation (leaders: S.T. Hasiotis E. Mrinjek & V. Pencinger 2007).

Stop 2

The stop is in "Kamen Benkovac" company quarry. Three long, parallel to bed strike direction outcrops enable easy approach and watching of the Benkovac Stone beds. Very extensive bed surfaces can display very nice wave ripples and small hummocky forms. Some surfaces show also sand volcanoes and sand dykes characterized by various sizes and forms.

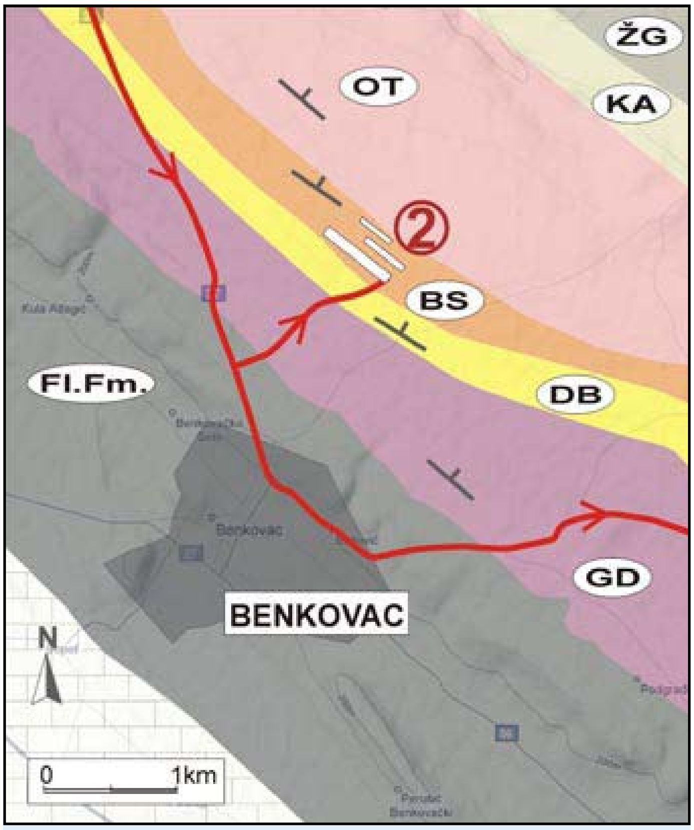


Fig. 28: The location of Stop 2 with litostratigraphic map. Stop is located inside "Kamen Benkovac" company quarry.

Fig. 29: Modern technology in "Kamen Benkovac" enables making the long vertical walls and opening the extensive bed surfaces.

Fig. 30: Small double-crested ripples. Ripple migration towards the right side of the photo. The coin is 2,6 cm in diameter.

Fig. 31: Small hummocky forms. The measuring stick is 22 cm long.

Stop 3

The stop contains numerous illegal excavation pits looking like a "huge mol-hill" but such exploitation and as well as weathering enabled to perfectly see various sedimentary structures in detail. In the same time many exposed bed surfaces are a paradise for "ichnologists". A labyrinth of walls variously orientated enable perfect 3-D view of facies.

"Caution! You can loose yourself in this outcrop labyrinth."

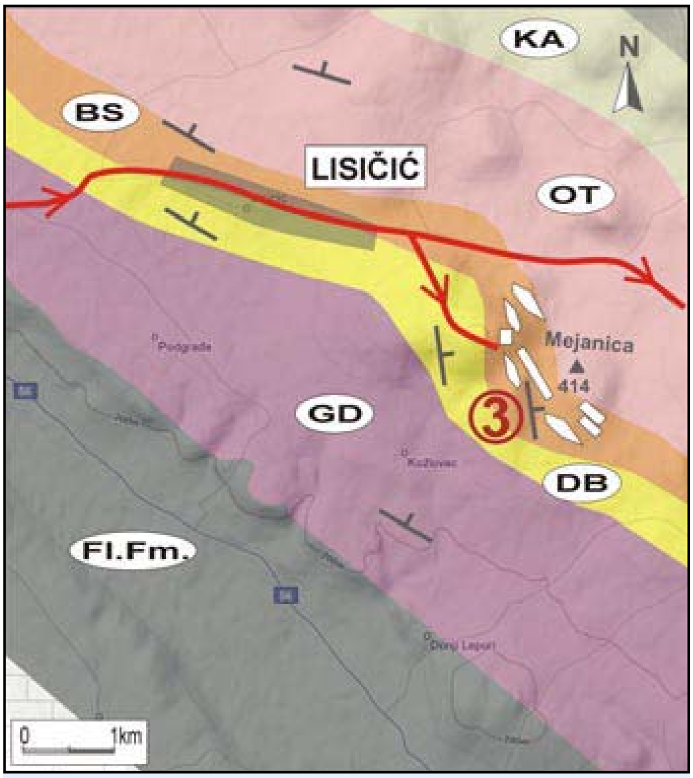


Fig. 32: The litostratigraphic map and location of Stop on Mejanica hill.

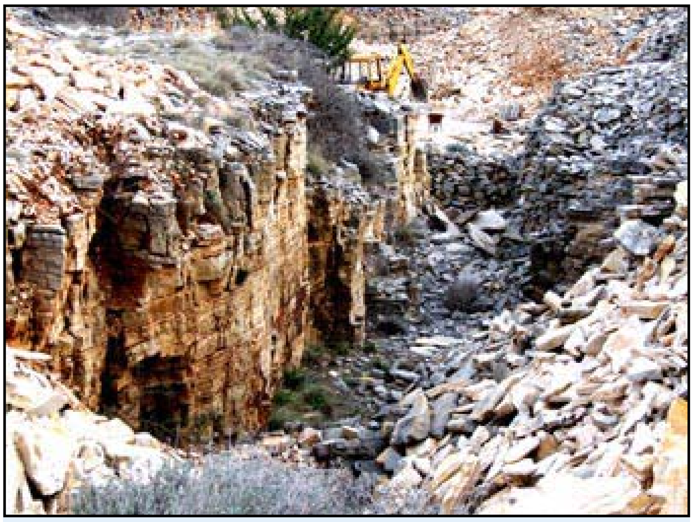


Fig. 33: The numerous outcrops in randomly position enable very nice 3-D view of facies.

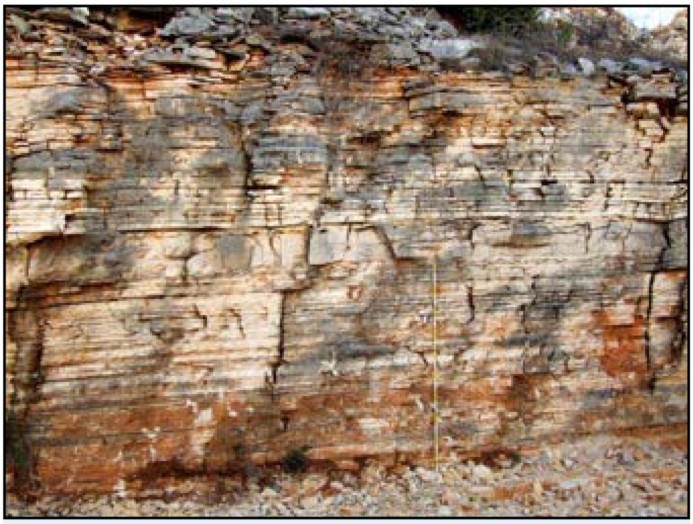
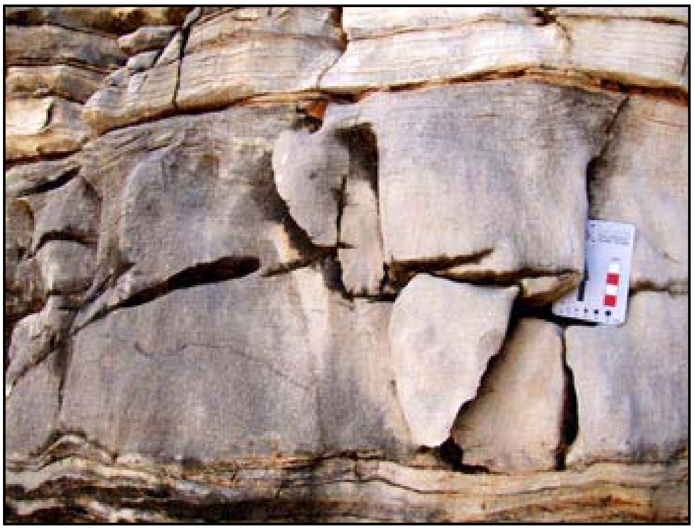


Fig. 43: Facies characteristics are nicely exposed on many vertical outcrop walls. The measuring stick is 2 m long.

"A photo gallery" of facies recognised in Benkovac Stone Unit.



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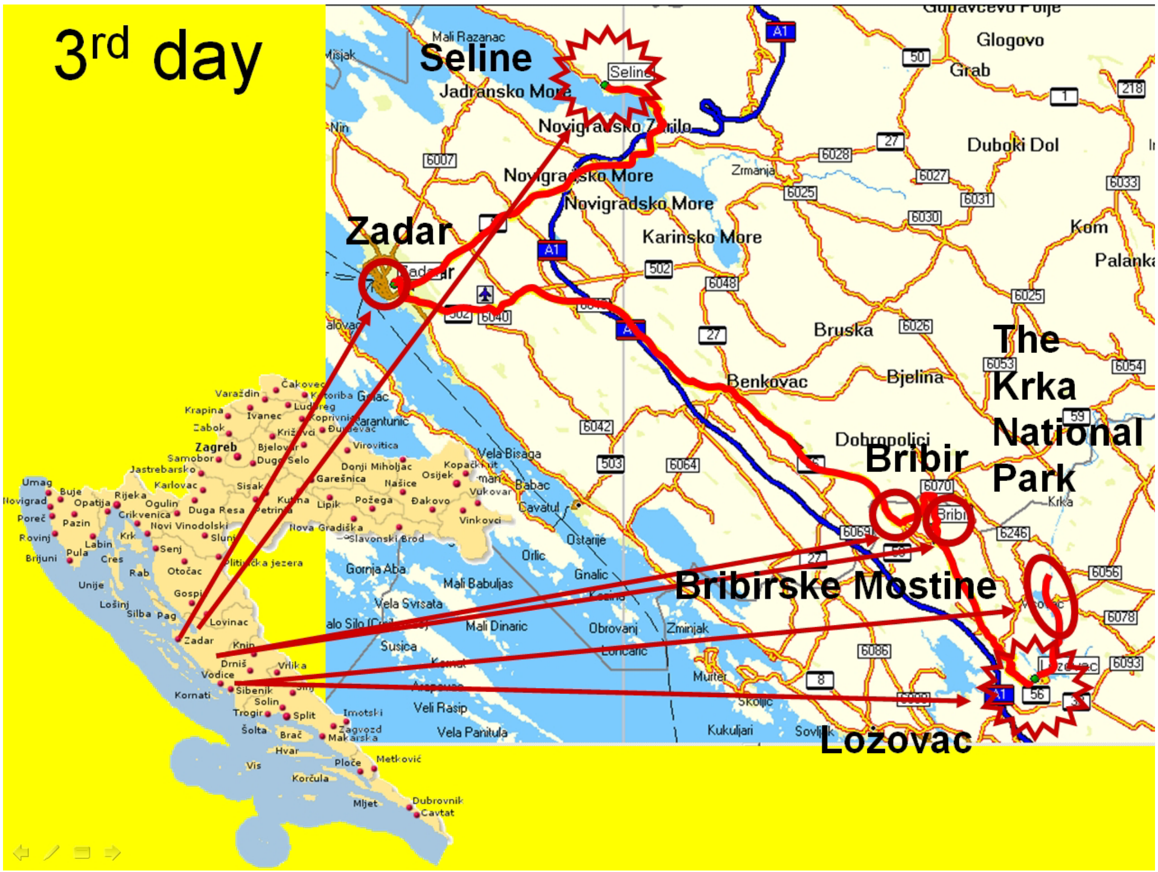
6. DAY 3

Krka National Park



Source:
Mrinjek, E. (2008): Promina beds in Krka Canyon and Bribirske Mostine areas. 5th International ProGEO Symposium on Conservation of the Geological Heritage and ProGEO Working Group I Annual Meeting GUIDEBOOK, 1st – 5th October 2008, Rab Island, Croatia, 40–77. Zagreb, September 2008.

PROMINA BEDS IN KRKA CANYON AND BRIBIRSKE MOSTINE AREAS

The Krka Canyon is frequently called "Croation Colorado Canyon". Deeply incised into the Promina Beds, Krka River made here a very precious insight to the history and anatomy of the Promina Basin. With the exception of small deformations (folds) and structural discontinuities (reverse fault without significant beds displacement) in the lower part of the Krka course, the Promina Beds are only gently tilted in the northeast direction. This lucky occurrence enable continuous tracing of the Promina succession more or less perpendicularly to its strike for more than 20 km.

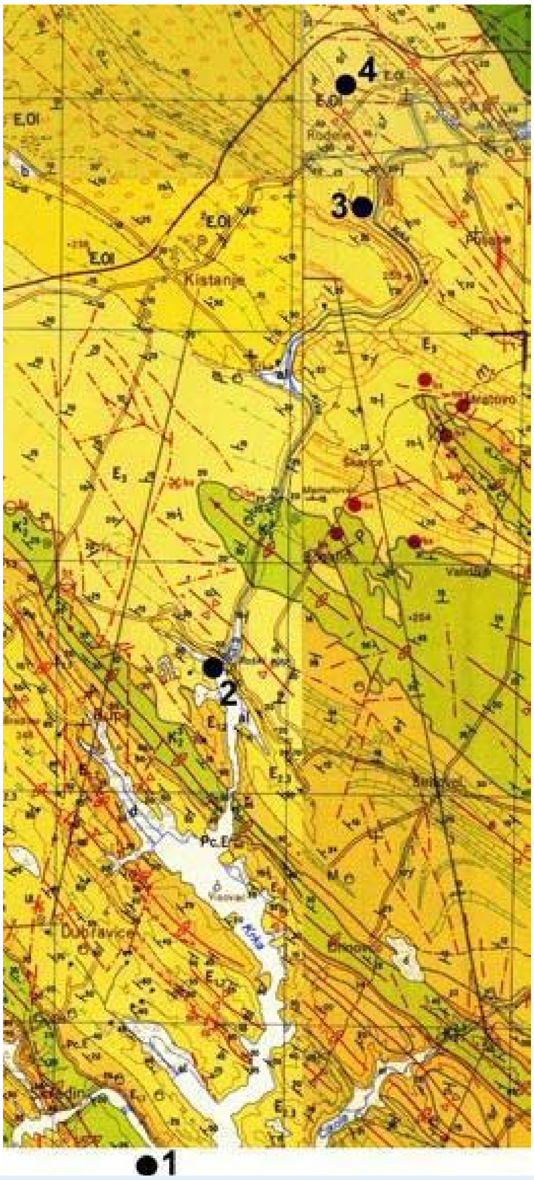


Fig. 4: Geological map of the Krka Canyon area, and the excursion stops. The map is made by merging parts of four sheets of General geological maps (Obrovac - Ivanović et al. 1973, Šibenik - Mamužić 1975, Knin - Grimani et al. 1975 and Drniš - Ivanović et al. 1977). Unfortunately, the maps differ in stratigrahic units and their boundaries.

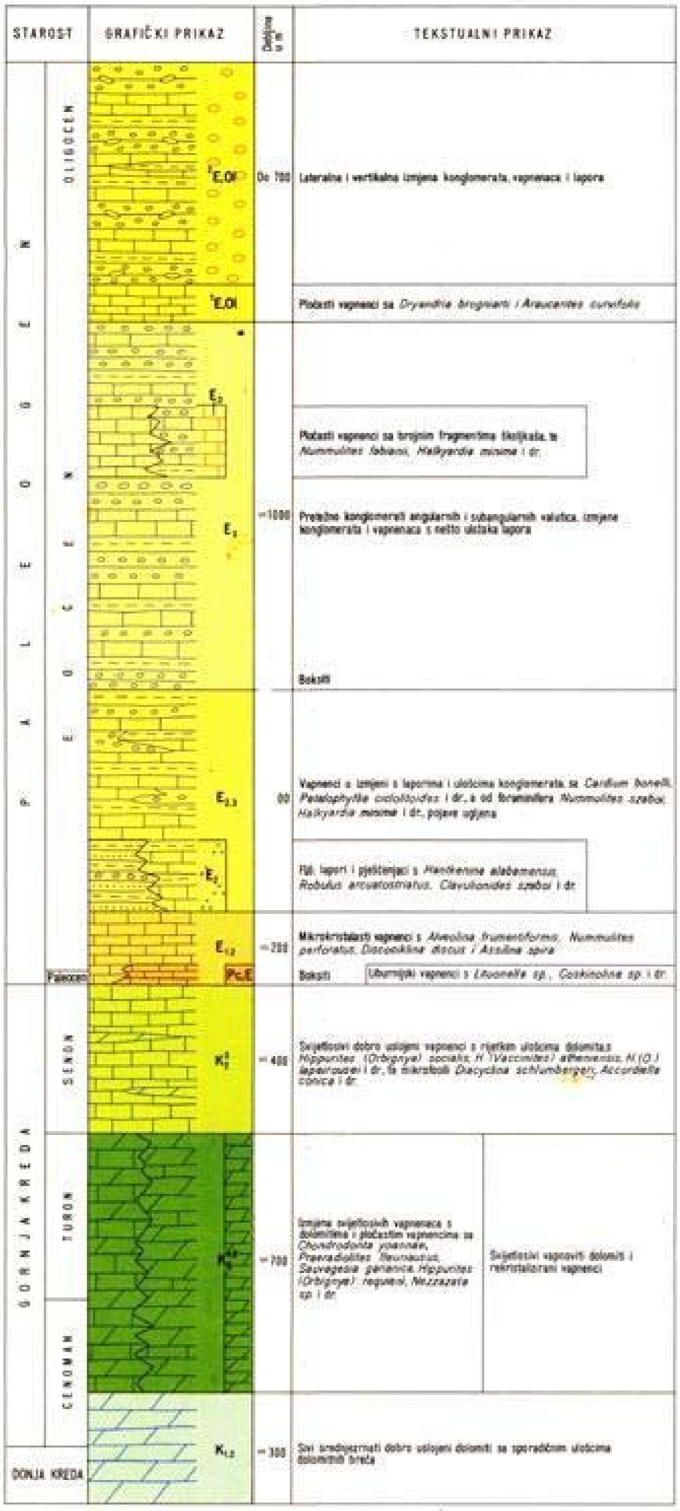


Fig. 5: The upper part of the gelogical column, from Mamužić (1975).

A time span of the Promina Beds is Middle Eocene (Lutetian) to probaly Oligocene (Rupelian or even Chattatian). The vertical alternation of shallow marine, costal and fluvial facies and domination of coarse grained deposits is the main characteristics of the Promina Beds succesion in the Krka Canyon and Bribirske Mostine areas.

The terms carbonate conglomerates sandstones, siltstones und mudstones are used for deposits containing a considerable amount of calcareous grains and composed of redominatly calciclastics and siliciclastics componets.

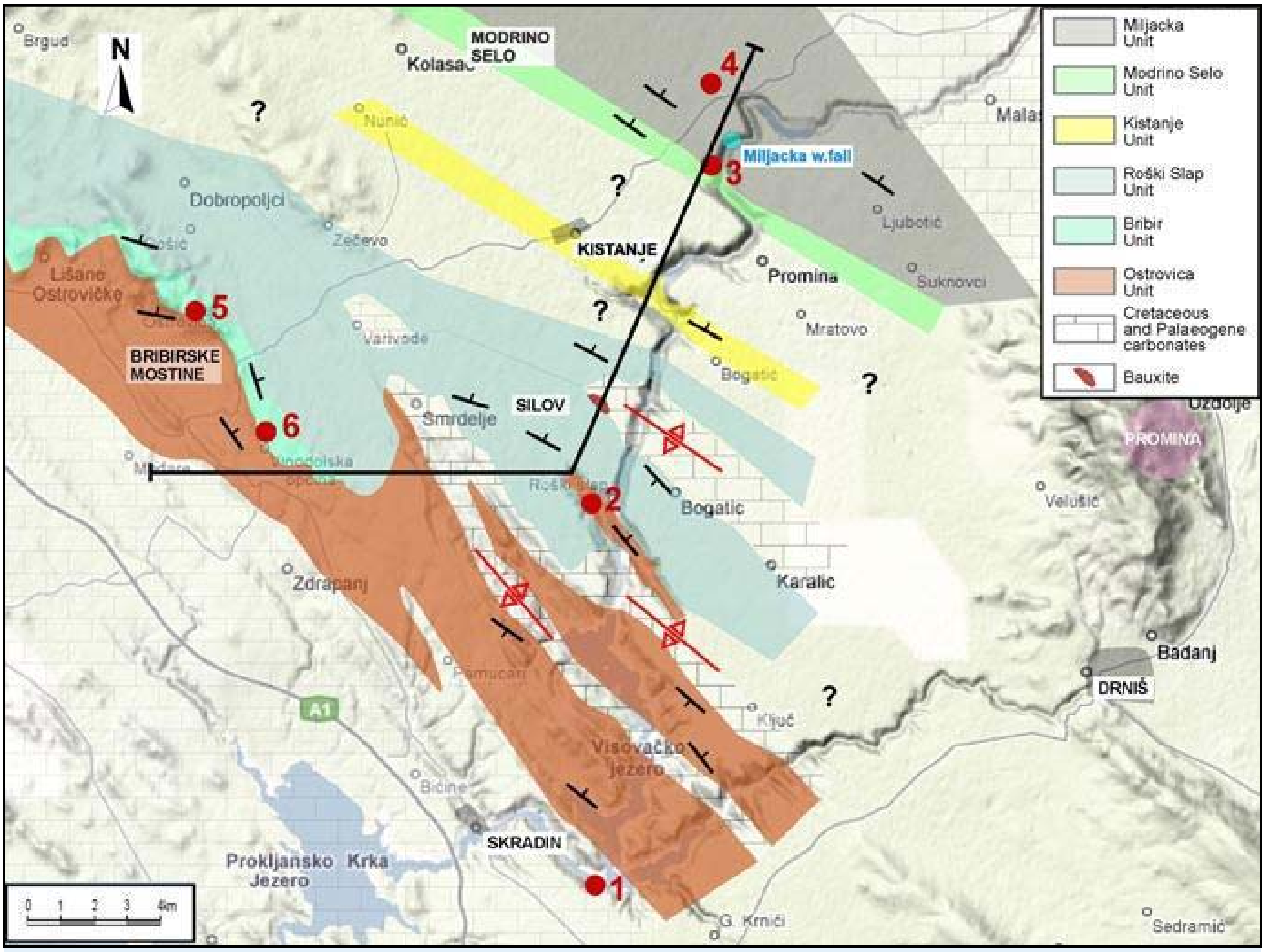


Fig. 6: Litostratigraphic map of the Krka Canyon and Bribirske Mostine areas, and the excursion stops.

The figures 6 and 7 display litostatigraphic units and sequence stratigraphy of the Promina Beds in the areas of the Krka Canyon and Bribirske Mostine. Although lito- and sequence-stratigraphy are provisional and incomplete because the field work and research are still in progress the general image of these topics is achieved.

Five informal litostratigraphic units have been determinated and their position located. The oldest is the Ostrovica Unit (named after small village Ostrovica in Bribirske Mostine area) is about 300 m thick succession characterised by monotonous alternation of sandy and marly siltstones or sandy siltstones and mudstones. The age of this unit is Middle to Upper Eocene. The lithofacies characteristics suggest deposition in the lower shoreface and offshore with general shallowing upwards trend (see Stop 5).

The Bribir Unit is about 100 m thick Upper Eocene succession, only located in Bribirske Mostine area. It conformably overlies the Ostrovica Unit. It is a deltaic complex which consists of isolated sheet-like carbonate conglomerate bodies underlain and overlain by both calcareous mudstone and sandstone beds (Mrinjek et al. 2005) (see Stop 5). The unit is named after the old town Bribir.

The Roški Slap Unit is more than 250 m thick Upper Eocene succession which unconformably overlies Senonian carbonates and Middle Eocene foraminiferal limestones (Laškovica), or conformably overlies the Ostrovica Unit (Roški Slap-Stop 2, Rupe). This Unit also conformably overlies the Bribir Unit in the area of Bribirske Mostine (Stop 5). The Unit is characterised by coarse-grained braided plain facies.

The Kistanje Unit (named after small town Kistanje) is an Upper Eocene to probably (?) Lower Oligocene succession with typical shelf facies. Unfortunaly, its very attractive outcrops are not included in the excursion because of the limited time.

The Modrino Selo Unit (Stop 3) is about 240 m thick succession of the Lower Oligocene age. The unit is characterised by lens-like single storey fluvial channels filled by sands and finer gravels. The channels are embraced by flood-plain depostis. The unit is named after small village Modrino Selo.

The Miljevac Unit (Stop 3) is about 100 m thick succession of the Lower Oligocene age, named after the Miljevac waterfall. The extensive and thick sheet-like conglomerates bodies are outstanding characteristic of this Unit. These conglomerates bodies are channel belts made of the multiple (braided) gravel channels.

Since the field work in the Krka Canyon is in progress, the sequence stratigraphy of the Promina Beds is still incomplete. The lower part of delta complex in the Bribir Unit (Stop 5) are most likely FSST deposit, while the thicker upper part and overlying braided-plain conglomerate complex (Roški Slap Unit) are LST deposits.

The Roški Slap Unit at Stop 3 (Roški Slap) is a proximal equivalent of the Bribir Unit. Thick lens- and sheet-like conglomerate bodies are incised into fluvial sandy and finer

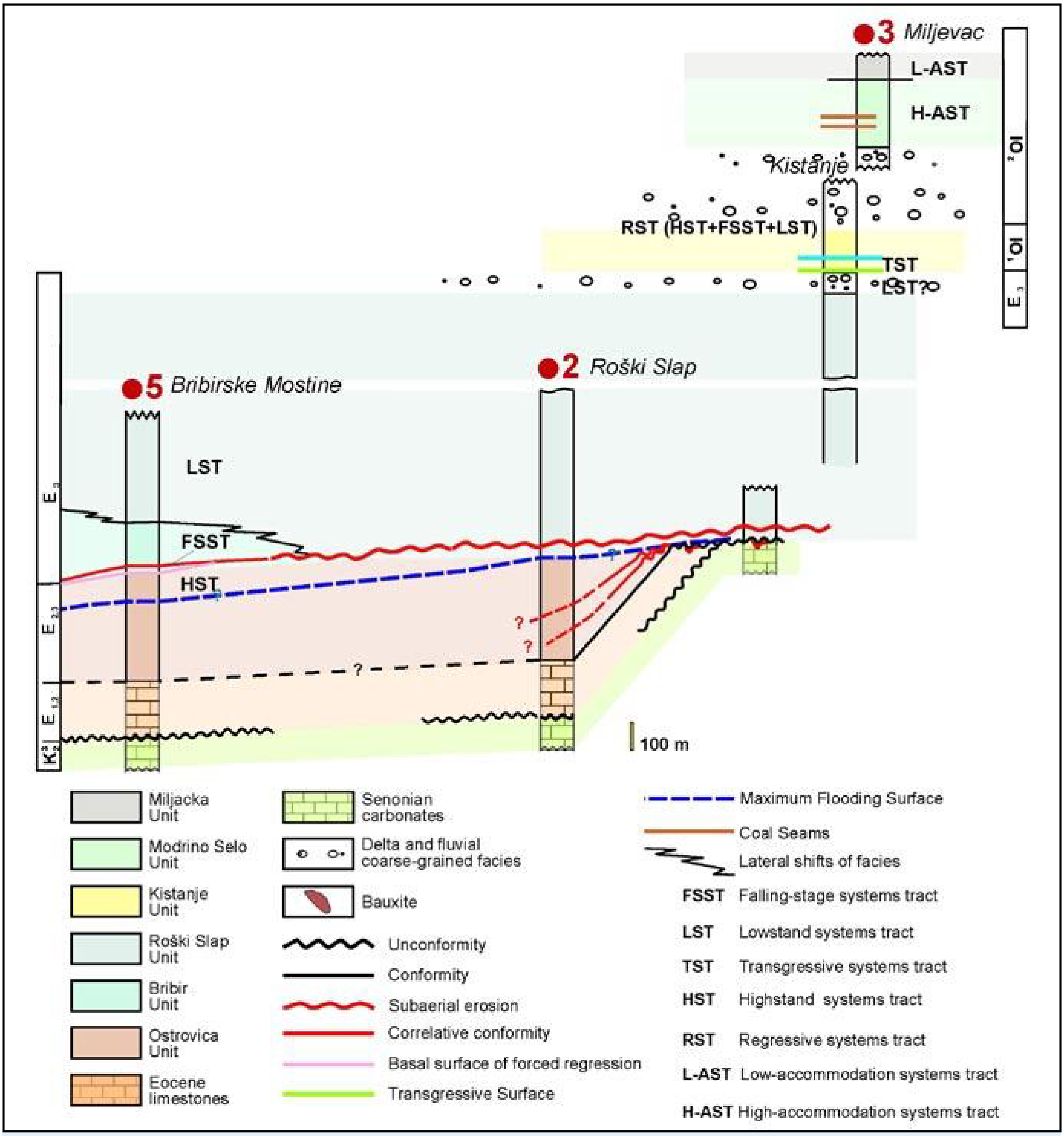


Fig. 7: Litostratigraphic profile and sequence stratigraphic interpretation of the Krka Canyon and Bribirske Mostine areas.

gravel facies (the lowest part of the Roški slap Unit). This erosive contact is most probably a sequence boundary and the outstanding conglomerate bodies are the LST deposits.

The lowest part of the Kistanje Unit is typical TST deposit and its middle and upper part belong to the subsequent HST.

The Modrino Selo and Miljeva Units are nonmarine litostratigraphic units without a marine distal equivalent and the solution to this problem is introduction of low- and high-accommodation systems tracts (Olsen et al. 1995). These systems tracts are defined primarily on the basis of fluvial architectural elements, including the relative rate of channel fills and overbank deposits which allows inference of the amounts of fluvial accommodation (low vs. high). The correlation between low-accommodation and lowstand systems tracts, and also between high-accommodation and transgressve to highstand systems tract can be only tentative, based on similarities in fluvial architecture. Thus, "maximum regressive surface" should not be used as boundary between the low- and high-accommodation systems tracts. In our case the change from the low- to the overlying high-accommodation systems tract is gradational rather than abrubt.

NATIONAL PARK KRKA

The Krka National Park was established with a purpose of protecting natural and historical values of the river Krka area. The park includes the most precious part of the Krka River course: from the beginning of its canyon on the west rim of the Kninsko Polje to the Skradin bridge and the lower course of the river Čikola. The Krka National Park is situated in the southern Croatia, in the mid part of the east Adriatic coast and includes the heart of the continental part of the Šibenik-Knin County. Within the Park, the nature is protected systematically and in an organised way, a
nd the traffic of visitors is limited.

GENERAL DATA

FOUNDED in 1985

INCLUDES upper and middle course of the river Krka and lower course of the river Čikola.

AREA 111 km²

LENGTH OF KRKA COURSE IN THE NP 46 km.

LENGTH OF ČIKOLA COURSE IN THE NP 3,5 km.

FALLS Skradinski Buk, Roški Slap, Miljacka,Rošnjak, Manojlovac, Brljan (Ćorića Buk), Bilušića Buk.

LAKES Veliki Vir, Veliki Golubinjak, Mali Golubinjak, Pile, Veliko Jezero, Šupukovo Jezero, Visovačko Jezero, Babić, Brljansko Jezero (Ćorića Jezero, Bjelobar).

BRIDGES Skradin bridge, pedestrian bridge under Skradinski Buk waterfall, bridge at Roški slap and bridge at Brljan waterfall.

Fig. 8: Position of the NP Krka.

MILLS Skradinski Buk , Roški slap, Miljacka fall, Manojlovački Slapovi, Brljan, Bilušića Buk.

PLANTS Inner area of the Krka National Park is home to 860 species and varieties of plants and 36 mosses and fresh-water plants.

ENDEMIC PLANTS North-Dalmatian rampion (*Campanula lepida*) rampion (*Campanula pyramidalis*), a species of seseli (*Seseli tomentosum*), Dalmatian scented fern (*Tanacetum cinenrari ifolium*), Adriatic iris (*Iris illyrica*), Meadow bluebottle (*Scilla litardeirei*).

FISH 18 species.

ENDEMIC FISH 10 species, the strictly endemic: a species of salmon (*Salmo marmoratus*), a species of trout - (*Salmothymus obtusirostris krkensis*), ilirian chub (*Leuciscus illirycus*), species of brown trout (*Salmo trutta m. fario*).

AMPHIBIANS European green frog, fire salamander, Euro pean pond terrapin, proteus (*Proteus anguinus*).

SNAKES AND VIPERS grass snake, dice snake, Dahl`s whip snake, Aesculapian snake, leopard snake; poisonous: nose horned viper; semi-poisonous: Montpellier snake.

LIZARDS Italian wall lizard, European legless lizard, Balkan green lizard.

ENDEMIC LIZARDS Dalmatian algyroides (*Algyroides nigropunctatus*) and sharp-snouted rock lizard (*Lacerta oxycephalia*).

BIRDS 222 species, of which 80 nest in the Park.

MAMMALS 46 species – rare species: wild cat (*Felis silvestris*), Bechstein's bat (*Mythos bechsteini*), Daubenton's bat (*Mythos daubemtoni*), oter (*Lutra lutra*).

HISTORIC MONUMENTS mills on Skradinski Buk, Uzdah tower, fort Ključica, Rogovo (Babin grad), fort Kamičak, Franciscan monastery and church on Visovac, fort Bogočin-grad, Krka monastery, fort Nečven-grad, fort Trošen-grad, Roman camp Burnum.

WHAT IS TRAVERTINE?

The Krka waterfalls are not simply stone steps over which the water flows, they are, in a way, living beings! Their beauty is created and constantly changed by travertine - calcium carbonate deposited on the underwater objects and plants around stems and leaves of the certain mosses and algae called travertine-makers. In this way, Krka constantly builds travertine barriers, covers, beards, curtains and other geomorphic formations that constantly grow and in time change the river landscape. Travertine is the most important phenomenon and the basis of present hydrology and landscape of the Krka River. To put it simple: Krka, as we see and admire today is created by travertine. The experts distinguish between "living travertine" and "dead travertine". "Living travertine" forms the cascades of the Skradinski Buk, Roški slap and other features of the river. The majority of it has been created within the past 10.000 years and is the youngest part of the Krka landscape. The "dead travertine" testifies about position of the former Krka waterbed. It is ca. 125.000 years old. It can be seen 152 m above present-day waterbed of the river Krčić, i.e. some 50 m above the present-day Kninsko Polje.

The process of travertine formation is typical of the karst rivers, and Skradinski Buk is one of its most spectacular creations. It can be considered a living being as it is born, grows, develops, and grows old, and if the water runs out - dies. Travertine is extremely sensitive to every, even the tiniest ecological disturbance.

The folk stories follow this process from long time ago. A folk legend says "*This water changes wood into stone*" and the Šibenik poet Juraj Baraković "*A strange sign does nature give here/water turns water by water into the hard stone*".

RIVER KRKA

There is no river like Krka. It is one of the most beautiful, most unusual and most mysterious rivers in Europe. The location of its source is, to this day, uncertain. The location of its mouth - unknown, but it is known that its lakes are not real lakes. Its prettiest features - its waterfalls, are not just barriers, they are living beings that are born, grow and die.

Krka has 2 confluences, 5 tributaries, 7 waterfalls, 11 lakes, and on its banks 10 forts, 3 towns, 2 former and one present bishoprics, in its waters, lakes, swamps and canyons and on its banks live 222 species of birds, 8 species of amphibians, 19 species of reptiles, 18 species of bats, 10 species of snakes, 9 species of beasts, 3 species of turtles, 6 species of lizards, 8 species of frogs, 101 species of coleoptera, 860 species of plants and 18 species of fresh water fish, 10 of which are endemic.

Krka is ichthyologically the richest river of the Adriatic basin. Although three additional fish species were introduced, its original ichthyo-fauna is preserved, and it is appreciated as an ichthyological monument of the highest order. Apart from the number of fish species, Krka is one of the most valuable ornithological sites, due to the number and diversity of birds. Its basin and source are at the same time basins and mouths of other rivers, and its history is the history of many nations, states and rulers.

Krka is an unexplored phenomenon of interest for the world research, treasury of beauty, an open book of history of several European nations, the main column of the Croatian national and cultural history, open museum of art, building and creativity.

For centuries Krka has been a border dividing people and nations, and has now become a precious site uniting them. It is today a natural, cultural and spiritual line flowing across Šibenik-Knin County and Šibenik bishopric, which contain the site of the early medieval Croatian state and the names of Croatian rulers.

GENERAL DATA

LENGTH 72,5 km.

LENGTH FROM SOURCE TO SKRADINSKI BUK 49 km.

KRKA FLOWS THROUGH Podinarje, Kninsko Polje, Promina, Bukovica, continental Šibenik area(Šibenska Zagora), coastal Šibenik area.

LENGTH OF ESTUARY 23,5 km.

BASIN AREA between 2.083 km^2 and 2.610 km^2

LENTGH OF WATERWAYS in the summer: 187 km; in the winter: 270 km.

TOTAL FALL 242 m.

FORMER LAKE Bobodolsko Jezero.

RAPIDS Čavlinov Brzac.

CANYONS, GORGES, STRAIT Kanal Sveti Ante, Kanal Sveta Josipa, Skradinski Kanal and gorge Među Gredama.

KARST POLJES Kninsko Polje, Kosovo Polje and Petrovo Polje.

TRIBUTARIES Krčić, left tributaries: Kosovčica and Čikola; right tributaries: Orašnica, Butišnica and Gudača.

ISLANDS Visovac, Dračevica, Kalički Busen, Macelinuša, Veliki Busen, Mali Busen, Bara Svetog Jere.

TOWNS Knin, Skradin, Šibenik.

HYDROELECTRIC POWER PLANTS Miljacka, Roški Slap, Jaruka 2, Krčić.

FIRST MENTION IN WRITTEN DOCUMENTS 4 ct. BC.

FORMER NAMES Katarates, Tyrus, Titius, Kerka.

HOW WAS KRKA CANYON FORMED?

Krka canyon is one of the world miracles of nature. It is the youngest part of the Krka relief and basin, only travertine barriers being younger. It cuts across the stone plateau, ignores the main lines of relief, and has sides that are virtually vertical, with very little sign of erosion. The researchers feel that it was formed as the result of tectonic movement of African continental mass toward Euro-Asian, and subduction of the Adriatic micro-mass under south-European part of the Euro-Asian continent. Near the end of Pliocene and the beginning of Pleistocene, a wide karst plateau was formed by erosion in which Krka carved a canyon after the Ice Age.

There are several theories about the formation of plateau. One presumes the existence of a large, wide and slow river eroding the relief, while the other explains the formation of the plateau by abrasion created by the slow withdrawal of the sea. The third explains it by the simultaneous action of a huge pra-river and the sea-abrasion. The sea withdrew about three mil years ago. The canyon itself, it seems, was not formed little by little, but rather at once and the waterbed was tectonically determined. Krka canyon was longer than it is visible today. 18.000 years ago, the sea level was 120-125 m lower. Krka Canyon can be followed by the south side of the island of Zlarin, and it is supposed that Krka estuary was a delta near island of Žirje. As the ice slowly melted, 8.500 years ago, the sea level rose for 90-95 m and the climatic conditions became

favorable for travertine formation. Further rising of sea level caused sea to penetrate the waterbed of Krka up to Skradinski Buk, therefore forming present-day Krka estuary.

MOUNTAIN PROMINA

Promina is located in the north of Drniš, almost at the centre of the continental part of the Šibenik-Knin County, 35 km from the sea. It is the only mountain in Dalmatia in which, due to minerals and coal deposits mines were exploited. Promina has an important role in history.

Its name comes from pre- Roman name Promona, the name of the town and fortress of the Ilirian Liburna tribe. The Roman emperor Octavian conquered Promone in 33 BC. On the remains of Promona, the remains of a large medieval town Petrovac can be seen. According to the legend, Croatian king Zvonimir had once given feast to the 6000 guests here. At the foot of the mountain, there is a number of archeological sites; dating from antiquity to medieval times Among these, special place belongs to the remains of the one of the greatest early-churches churches m Trbounje.

GENERAL DATA

HEIGHT	1.148 m
HEIGEST SUMMIT	Čavnovka
TREKKING	Promina is easily accessible. A road leads to the very top. There are sev eral marked paths.
PROMINA BEDS	have been named after Mt.Promina!

Stop 1: SKRADINSKI BUK

Skradinski Buk is the longest and the most beautiful waterfall on the river Krka and one of the most famous nature sites in Croatia. It is the key feature of the Krka National Park. It is formed by travertine cascades, islands and lakes, which can be observed from the network of paths and bridges enabling an enjoyable and secure walk. Platforms are constructed on the most attractive sites. Visitors to Skradinski Buk can see the etnographic collection and water mills in which millstones and waterforce were used to produce flour; as well as koševi and stupe, traditional devices for washing rugs, covers and clothes.

Fig. 15: The lowest waterfall (and probably the most beatufull) in the waterfall series of Skrad. Buk.

GENERAL DATA

HEIGHT	45,7 m
WIDTH	200 - 400 m
NUMBER OF STEPS (FALLS)	17 m
PATHS	the entire cascade can be seen firsthand from the network of paths and wooden bridges.

Watermills are simple devices in which the force of the stream is exploited by means of wooden wheels. Watermills on the Skradinski Buk are mentioned from the earliest history of the town of Šibenik and date from the Roman times. The present appearance dates from the 19th century, when they were reconstructed on the remnants of much older ones. They are an important memento of the economic history of Šibenik area. The mills were the most important source of Šibenik wealth and a base for development of its cultural identity.

Fig. 16: Position of Stop 1. Skradinski Buk is placed between Prokljan and Visovac Lakes.

They are mentioned first in a document dating from 1251, in which the king Bela III defines a border between Šibenik and Trogir areas. During 14th and 15th century, water mills on Krka have an important role for the entire east Adriatic coast. Flour is produced here for all towns from Istria to Dubrovnik. According to the existing data, the rent for a mill on the Skradinski Buk went as high as two thousand gold coins per year! It is due to them and to the production of salt that Šibenik becomes the largest Dalmatian town and a centre of culture, science, art, and economy.

Stop 1 is outside the Promina Beds area. The Krka river is here incised into the Upper Cretaceous and Eocene limestones which are the remains of the disintegrated Adriatic carbonate platform.

In 1522, however Skradin was conquered by Turks, who built their own mills on the right bank of the Krka River, and the ones on the left were taken over by Venice. From 1537 to 1540, Turks were attempting to conquer Šibenik, and all the mills were pulled down completely for strategical reasons. In 1683, the Turks were thrown back from Krka and the mills rebuilt to become the main source of wealth for the town of Šibenik, until the invention of the steam engine and electrical energy. The end of 19th century sees the rise of an important Šibenik family - the Šupuks, who rented the Skradinski Buk mills. Šupuk, who is considered a father of modern

Fig. 17: The old watermills - an important source of wealth in the past.

Šibenik, rents in 1902 the six mills on the Skradinski Buk. Apart from cereal, he mills a plant called buhač (Chrisanthemum cinerariaefolium) - a natural pesticide. The mills brought him so much wealth that he could start building the first hydroelectric power plant in Croatia and a first alternating current electroenergetic system in the world. He used the electric power to build the first electric mill in Šibenik, so the mills on Krka stopped working. They are now conserved and protected as monuments of economic history. Stupe or stupare are the early devices in which water power moves wooden hammers used to soften rough woollen fabrics, while koševi are simple, but efficient "washing machines" in which clothes and fabrics are washed by running water.

Fig. 18: One of many wooden bridges.

The first modern electro-energetic system in the world!

Ante Šupuk, father of modern Šibenik has, in 1895, built, in co-operation with the engineer Vjekoslav Meischner, the first system of production, transportation and distribution of alternate current electric energy in the world!

Šupuk and Meischner have for one year overtaken even Nikola Tesla. Although Tesla's power plant on the Niagara Falls started working two days before Šupuk's on the Krka waterfalls, it has taken Tesla a whole year to build the transportation system for the electricity produced by the Niagara power plant. Šupuk has brought to Šibenik modern multiphase electric energy to homes and public lights to the town before electric light existed in many European metropoles, like Frankfurt, Rome, Wienna, London, even before Budapest, where the generators for his first plant on Skradinski Buk were produced. Ten years later, Ante Šupuk has built another plant some hundred metres downstream from the first, which, with additional turbines added in 1936, works to this day.

Fig. 19: The remains of the first electro-energetic system in the world.

Stop 2: ROŠKI SLAP

The wide cascade called Roški Slap consists of 22,5 m high main waterfall and numerous branches, cascades and travertine islets. Although a bridge across its middle part is wide enough for smaller cars and there is a hydroelectric power plant on its right bank, the majority of the waterfall area is the untouched, impassable wilderness inaccessible to man. Near its left bank, there is a line of attractive watermills, some of which are in very poor condition, but some are still working. The owners start them occasionally and bake bread from the wheat and corn flower milled in them.

Fig. 21: "Pearl neclaces" at the upper part of Roški Slap.

The Roški Slap power plant built in 1899 still works. River branches divide the left side of Roški Slap into and particles that were used as fields. Their owners grew crops, gardens and orchards, and one of them, Ovanin Skelin built a hotel in 1909. It was one of the first touristic buildings in Dalmatia and one of the first hotels to have electric lights. The majority of the mills on Roški Slap are here. All of them were named after familly names of their respective owners, and one of them belonged to Franciscan monastery on Visovac. The complex of mills on Roški Slap is one of especially interesting and precious etnographic monuments of Datmatia and Croatia, and as some of them are still working, they truly are the living history.

GENERAL DATA

HEIGHT OF WATERFALLS	22,5 m
HEIGHT OF CASCADES	27 m
WIDTH	450 m
LENGTH	650 m
NUMBER OF STEPS	17 m + cascades.
MAIN WATERFALLS	Bilo, Zanoga, Rošnjak, Ključić, Veliki Đilas, Mali Đilas.
LAKE	Babić.

The participants can see here the top part of Middle to Upper Eocene Ostrovica Unit (log RS 1) and the lowest part of conformably overlying Upper Eocene Roški Slap Unit (log RS 2).

The litofacies characteristics in Log RS 1 suggest deposition from the offshore to the lower and even upper shoreface with general shallowing upwards trend. The lower part of the Roški Slap Unit contains here thin sandy and sheet-like channels and relatively thick and extensive flood plain deposits erosively overlain by thick succession of lens- and extensive sheet-like gravel bodies.

Fig. 22: Position of Stop 2. Roški slap is placed in the canyon nortward of Visovac Lake.

Fig. 24: The main waterfalls at the lower part of Roški Slap.

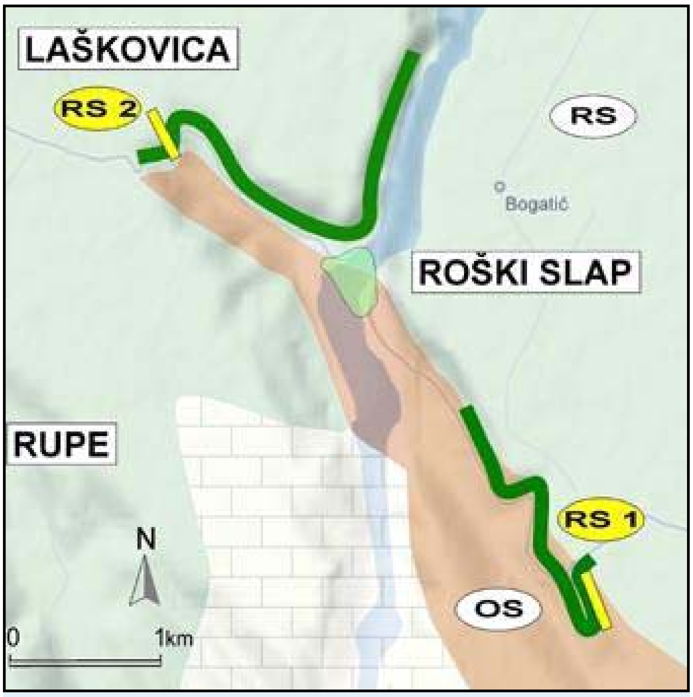


Fig. 25: Position of logs, lateral profiles and litostratigraphic units at Stop 3. The profiles and logs are placed nearby road Laškovica - Drniš which traverses Roški Slap waterfalls.

Fig. 23: Roški Slap - panoramic view

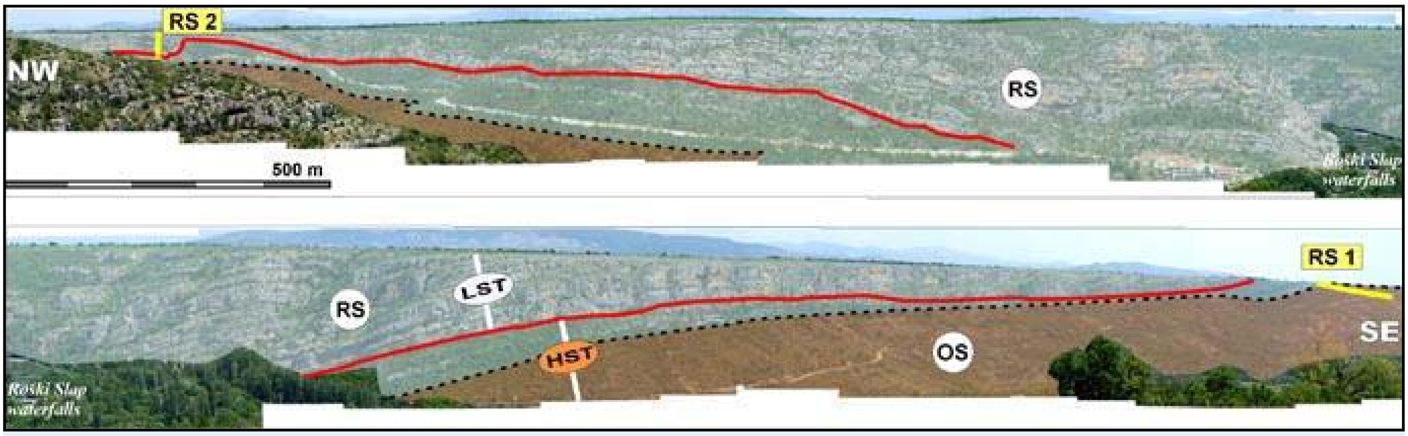


Fig. 26: The lower part of the Roški Slap Unit and the underlying top part of the Ostrovica Unit near the road that traverses the Krka Canyon at the Roški Slap waterfalls. A sequence boundary is in the lowest part of the Roški Slap Unit.

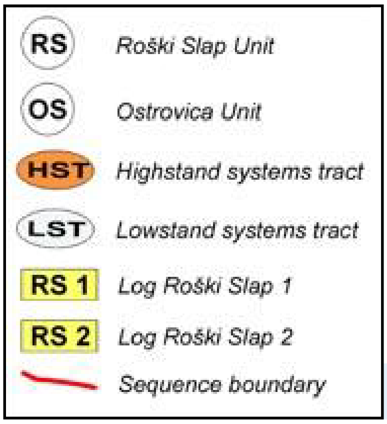


Fig. 26 Key

Fig. 27: The gravel lens-like channel deeply incised into the underlying thin sandy channels and floodplain mudstones. The lower part of the Roški Slap Unit above the road cutting the west side of the Roški Slap waterfalls.

Log Roški Slap 1 (RS 1)

Description

The Log RS 1 is located on the left side of the Krka Canyon near the road Laškovica-Drniš. The Log displays 65 m thick succession that consists of carbonate sandstones interbedded with finer-grained calcareous depostis. Its Middle to Upper Eocene age was established on the basis of large bentihic foraminefera (nummulitids, discocyclinids). The sandstones are very fine- to fine-grained calcarenites, sporadically medium- to very coarse-grained with granules, and consist mainly of various sparitic and micritic grains. Quartz grains are subordinate (less than 10 vol. %). The granules and the coarsest grains are frequently fragments of various shallow marine fossils like gastropods, bryozoas, bivalves etc. The sand grains and granules are subrounded to rounded and generally well to very well sorted, forming a grain-supported framework with mostly point or planar grain contacts. Interstitial spaces are filled with a microcrystalline carbonate cement and/or fine-grained calcareous sediment.

The finer-grained interbeds are carbonate siltstones and mudstones, moderately to strongly burrowed. The siltstones are calcisiltites composed mainly of medium to coarse silt-sized carbonate grains and up to 15 vol. % quartz grains. The calcareous mudstones are slightly clayey micrites with scattered silt-sized carbonate and quartz grains.

Fig. 28: The alternation of thin sandy sheet-like channels and sheet-like floodplain mudstones. The lowest part of the Roški Slap Unit above the road cutting the west side of the Roški Slap waterfalls.

The carbonate sandstone beds are predominantly tabular and separated by siltstone and mudstone layers. The sandstone beds vary considerably in thickness but their average thicknesses is in the range of 5 to 25 cm. Two, enormously thick (3-4 m) "sandstone beds" are present in the succession. The subsequent pervasive weathering at outcrop and possible strong bioturbation can prevent recognition of mudstone and siltstone interbeds.

Their basal surfaces are sharp and erosional, with an irregular relief of 1 to 7 cm, whereas their tops are slightly uneven or undulatory, with a relief of 2 to 4 cm. The great part of the beds are normally graded, with the particle size ranging from very coarse to fine or very fine sand. Some of them have angular mud intraclasts close to their base. The mudstone are up to 5 cm long and flat-lying to the basal surface. The thickest beds consist of pebble gravel and granules to medium sand. The basal surfaces locally show load casts, which are bulbous or irregularly-shaped features lacking preferred orientation. Basal mudstone injections in the form of load-flame structures occur in places.

Although the most sandstone beds are massive without recognizable internal lamination probably as result of bioturbation and/or previously mentioned pervasive weathering a few of them display internal parallel lamination or hummocky-cross lamination.

One bed consists of amalgamated sandstone beds stacked directly upon one another. This composite bed is recognizable by its greater thickness (about 50 cm), multiple normal grading and eroded remnants of mudstone layers.

The mudstone and siltstone are very common and relatively very thick, ranging in thickness between a few cm to 6 m. The most of them contain fine sand and silt interlayers with signs of pinch-and swell lamination, small wave ripples and isolated ("starved") ripples. There average thickness is 1 to 5 cm. The vertical spacing of these interlayers varies from a few centimetres to 20 cm or more, and they are commonly disrupted and deformed by animal burrows.

The log is terminated by a conglomerate body consisting of poorly sorted and matrix-supported, subrounded pebbles and granules.

Fig. 29: About 1.5 m thick sandstone bed in the base of the Log RS 1. Its basal surface is sharp and slightly erosional whereas the tops are flat or only slightly undulatory. The beds are normally graded, ranging in grain size from granules and very coarse sand to medium sand. The sand grains and granules are subrounded and generally well sorted, forming a grain-supported framework. The great number of fossil fragments (foraminiferas, bivalves, gastropods etc.) can be seen at its base. The plant fragments are present in the upper, finer grained part. The bed is encased by finer grained deposts. Its bed characteristics suggest deposition from turbulent sediment gravity flow during waning flow conditions. The "structureless" (massive) appearance of this bed is thus probably a result of bioturbation and/or subsequent pervasive weathering of the outcrop. The measuring stick is 1 m long.

Fig. 30: The sharp basal surface of the thick sandstone bed with a local-scale relief of 1 to 5 cm. Here can be seen numerous granule- and pebble-sized fossils fragments, carbonate clasts and mud intraclasts. They are subrounded, generally well sorted with a grain-supported framework. Matrix is very coarse to medium grained sands. Trace fossils can be seen in the underlying mudstone bed. The coin is 2.6 cm in diam.

Fig. 31: The alternation of two normal graded, massive sandstone beds and "structureless" mudstone beds. The measuring stick is 22 cm.

Fig. 32: The normal graded sandstone bed with angular and sream orientated mudstone intraclasts 3 cm above erosional basal surface.

Fig. 33: Vigorous bioturbation of interbedded thin, rippled sandstones and mudstones. See gastropod fossil at the top of photo. The coin (scale) is 2.6 cm in diameter.

Fig. 34: The conglomerates on the top of succession. The upper part of conglomerates covered by soil and vegetation.

Fig. 35: Close up photo of conglomerates on the top of succession.

INTERPRETATION

The intimate association of the discrete, erosional sandstone sheets rhythmically alternating with mudstone layers indicates episodic deposition from storm events in an offshore transition zone, which means a shelf area extending between the average fair-weather wave base and the average storm wave base. The offshore transition zone thus occurs outside the shoreface zone (perennially affected by waves) and is subject to episodic incursions of sand during storm events. Accordingly, the sandstone facies are considered to be tempestites (storm deposits), embedded in a "background" mudstone facies (fair-weather deposits).

Conglomerates present in the top of succession are gravel supply from coeval coarse-grained delta front and beach and the announcement of following relative sea-level fall. The succession display progradation characteristics (conglomerate body) and probably is part of the late highstand systems tract.

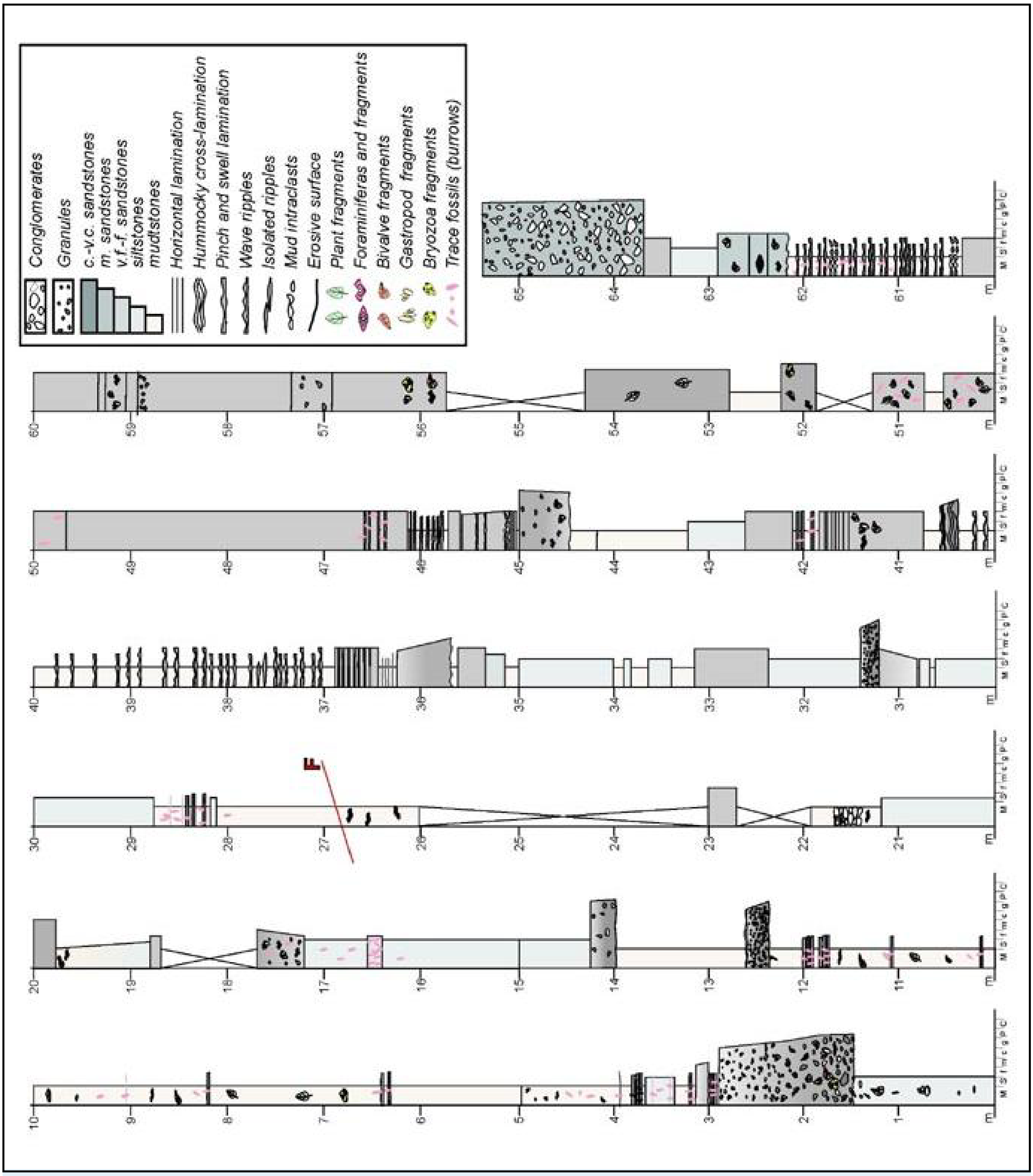


Fig. 36: Simplified log RS 1 (the top part of the Ostrovica Unit) at Stop 2.

Log Roški Slap 2 (RS 2)

Description

The log RS 1 is located on the right side of the Canyon Krka nearby the road Laškovica-Drniš. This is about 50 m thick two partite Upper Eocene succession contains. Its lower part (the first 12 m) consists of sandy, sheet-like channels and relatively thick and extensive flood plain deposits (for more details see Table 1 and 2 and Figs. 26, 27, 28, 38, 39, 40, 41, 42, 43, 44). The upper part is erosively incised into the lower part with an irregular relief locally up to 4 m. Narrow and relatively deep lens-like gravel channels are locally present in the base of the upper part. The gravel lens are succeeded by extensive, sheet-like multi-storey gravel channels (Table 1 and 2 and Figs. 26, 27, 28, 38, 39, 40, 41, 42, 43, 44). An average stream direction in the both type of chanels is roughly towards the south.

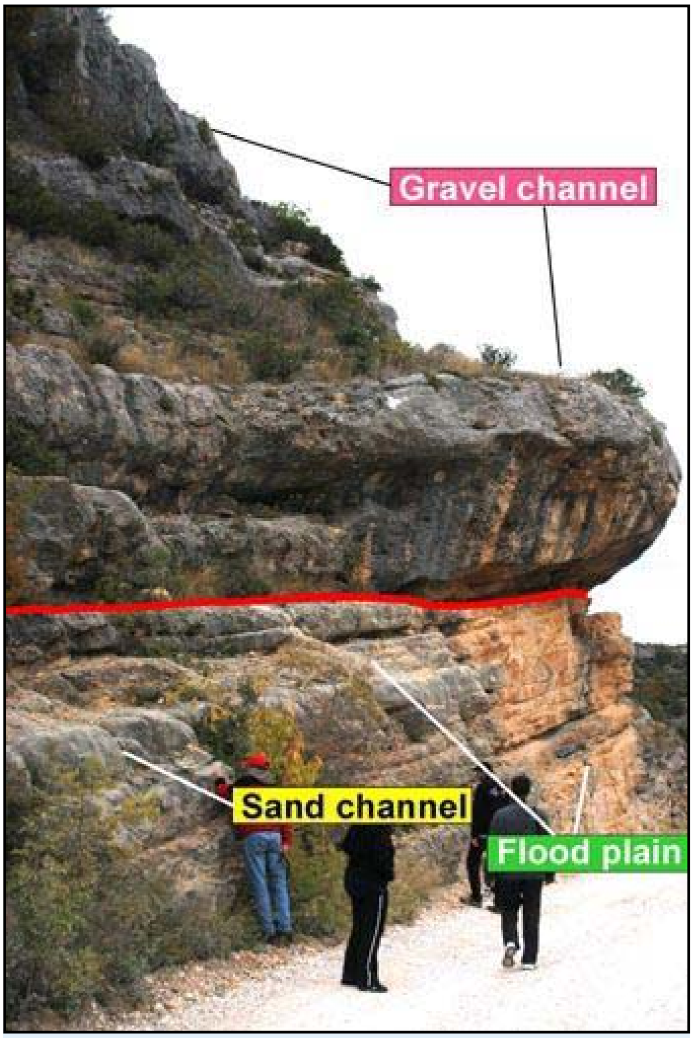


Fig. 37: The succession of the log RS 2. See clear and sharp contact between thin, sheet-like sandy channels and flood-plain deposits in the lower part and overlying thick and sheet-like gravel bodies.

The lower part of unit is probably deposited in sandy to gravely braided-plain (coastal plain) environments Conformably overlying shallow marine facies of Ostrovica Unit suggests prograding character and thus can be interpreted as the part of the highstand systems tract. The external geometry and internal characteristics of conglomerates in the upper part is typical for coarse-grained braided plain environments. Its erosional base with sporadically deep relief suggest a sequence boundary that is difficult to follow since erosive channel surfaces cross-cut each other. These erosively stacked and interconnected channels system suggest the early lowstand systems tract.

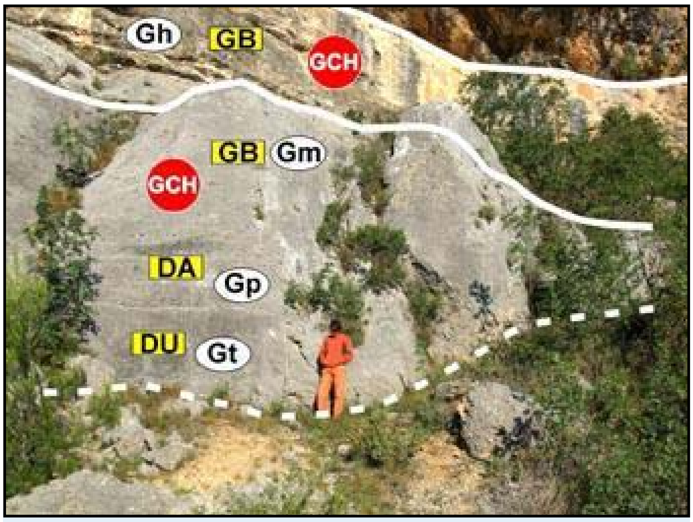


Fig. 38: The lens-like gravel channel overlain by sheet-like gravel bodies. In distinction from the clear external channel geometry its internal geometry is faint but some architectural elements and facies can be recognized. For more details see Table 1 and 2.

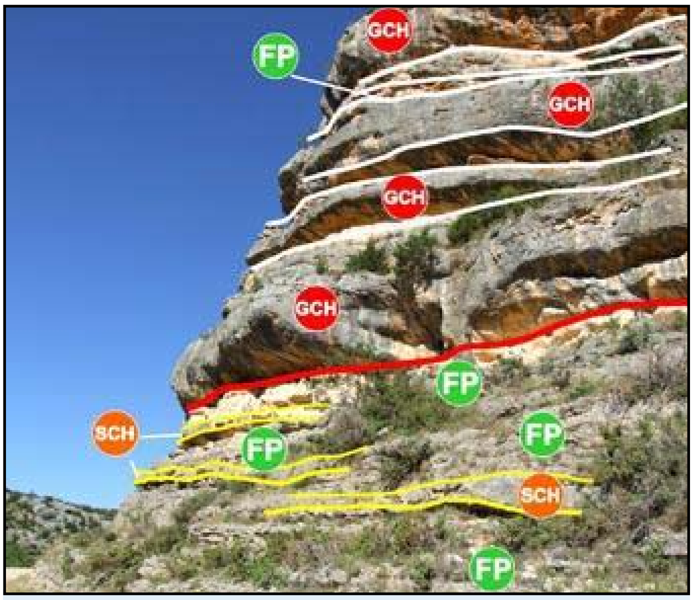


Fig. 39: The succession of the log RS 2. Its upper part consists of clearly stacked sheet-like gravel channels. See Table 1 and 2.

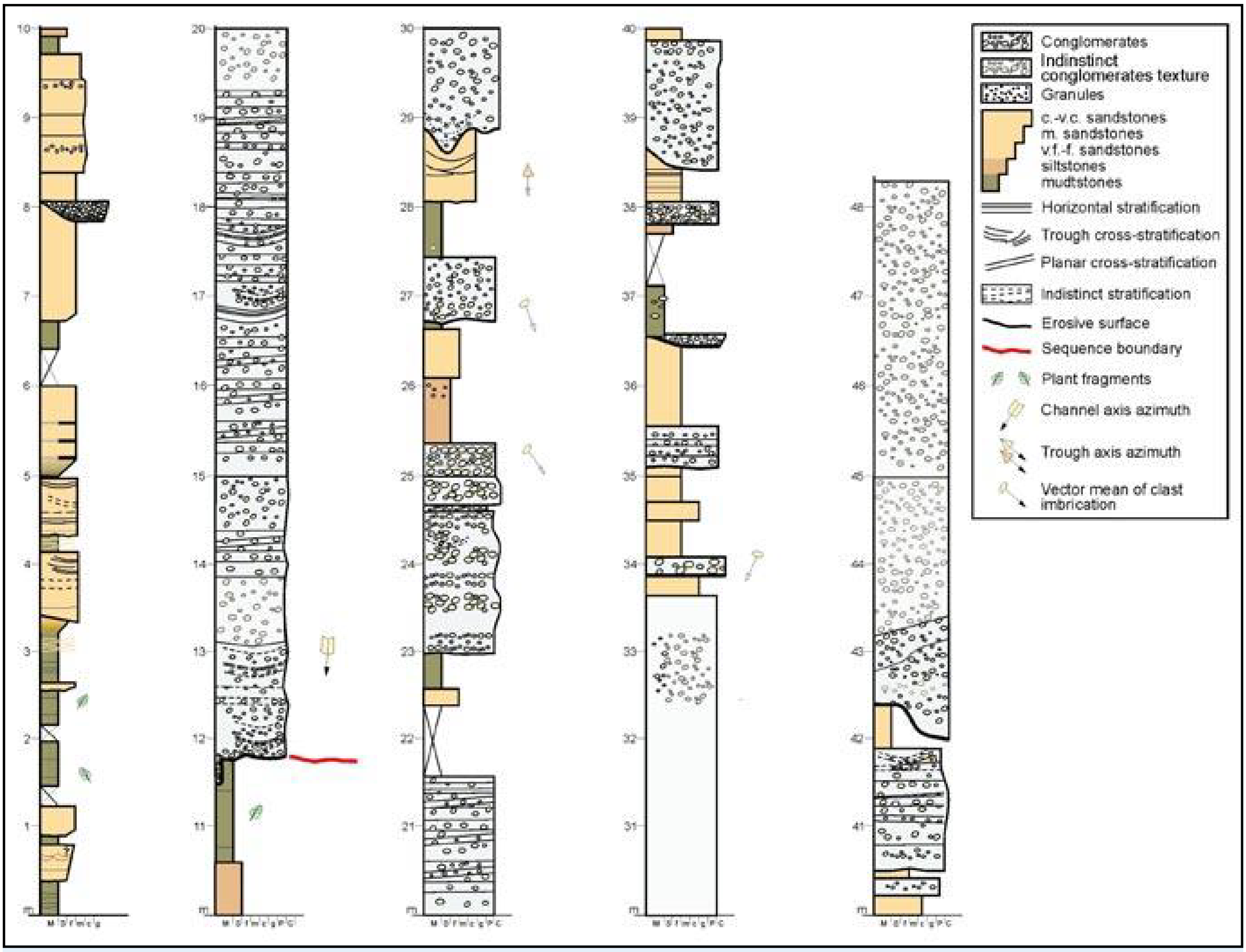


Fig. 40: Simplified log of the lower part of the Roški Slap Unit at Stop 2.

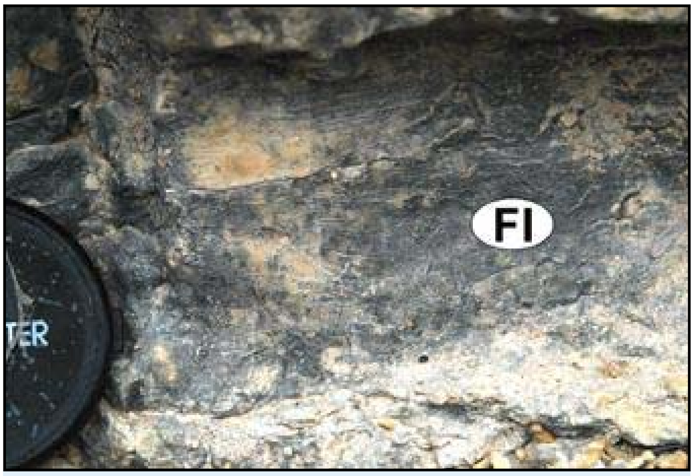


Fig. 41: Calcareous mudstone with very thin silty lamination (Facies Fl, see Table 1). The lower part of log RS 2. The cap lens is 6 cm in diametar.

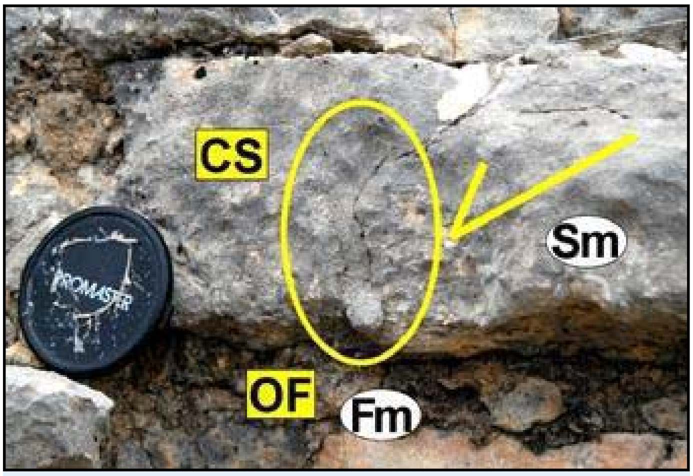


Fig. 42: Spider hole in very fine-grained carbonate sandstone. Sandstone bed is probably a crevasse splay (CS, see Table 1 and 2) encased mudstone flood plain deposits. The lower part of log RS 2. The cap lens is 6 cm in diametar.

Fig. 43: The lowest part of the Roški slap Unit above the road cutting the west side of Roški Slap waterfalls. The main palae-current directions are roughly towards the viewer.

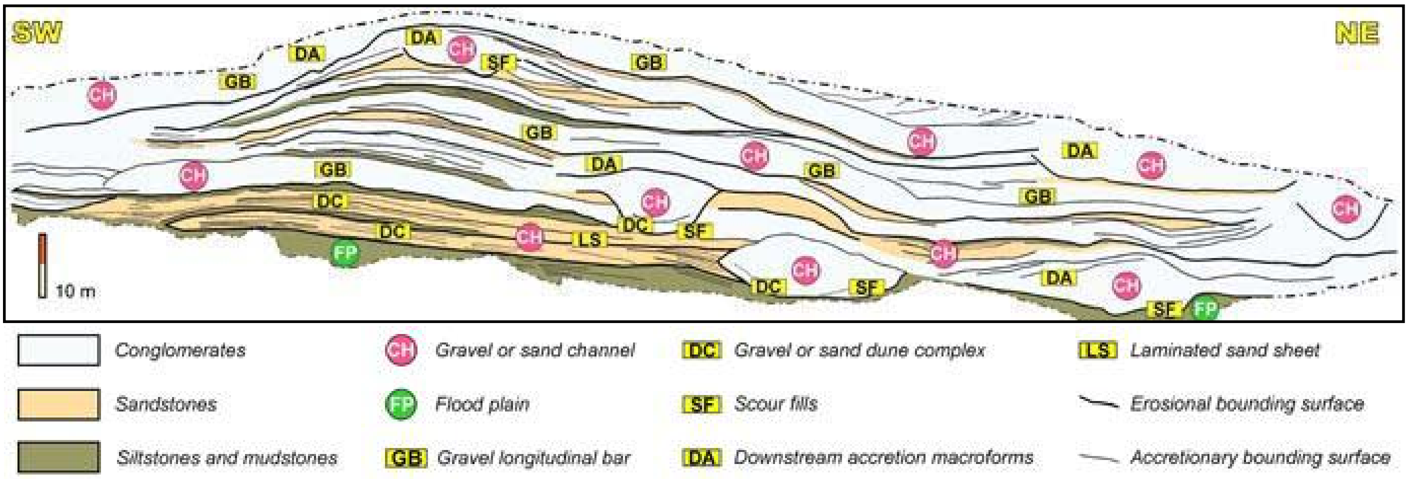


Fig. 44: The sketch of Photomosaics with the main architectural elements.

Table 1. Summary of facies determinated in log RS 2.

Facies code	Description	Sedimentary structures	Interpretation
Gm	Clast-supported, poorly to moderately sorted, granule-cobble gravels with sand matrix.	Massive to crude flat bedding, rare imbrication.	Longitudinal gravel bars, hyperconcentrated channel or sheet flows.
Gh	Clast-supported, moderately to well sorted, granule-cobble gravels with sand matrix or no matrix.	Clear flat bedding with imbrication.	Longitudinal gravel bars, hyperconcentrated channel or sheet flows.
Gt	Clast-supported, moderately to well sorted, granule-pebble gravels with sand matrix or no matrix.	Large-scale trough cross-bedding	3-D megariples, channel fills.
Gp	Clast-supported, well sorted, granule-pebble gravels.	Large-scale planar cross-beding.	2-D megariples, late stage transverse bars, late stage modification of longitudinal bars.
Ge	Clast-supported, poorly to moderately sorted, pebble-cobble gravels.	Massive with rare imbrication.	Scour fills.
St	Well sorted, fine to coarse grained sands and gravel sands.	Large-scale trough cross stratification.	3-D mega ripples.
Sp	Well sorted, fine to coarse grained sands and gravel sands.	Large-scale planar cross stratification.	Late stage bar modification, 2-D megariples.
Sh	Well sorted, medium to coarse grained sands and gravel sands.	Horizontal stratification	Planar beds (upper and lower regime flows).
Sm	Well sorted, fine to medium grained sands and granule sands.	Massive	?
Se	Poorly sorted, medium to very coarse grained sands and granules.	Mostly massive	Scour fills
Fl	Matrix supported, silts and muds.	Horizontal lamination, plant fragments and trace fossils.	Overbank deposits.
Fm	Matrix supported, silts and muds.	Massive, plant fragments and trace fossils.	Overbank deposits.

Table 2. Summary of architectural elements determinated in log RS 2.

Architectural elements	Lithofacies assemblages	Description
GCH Gravel channels	*Gh, Gm, Gp, Gt (minor, Ge, Sp, St, Sh)*	Sheet- or lens-like bodies 2 m to > 10 m thick and extending from 10 m to > 100 m laterally. Basal surfaces typicaly erosional, irregular and concave to planar. Upper surfaces usually eroded and planar to concave. Composed of stacked Gm, Gt, Gp, and occasionally Sh, Sp. Embrace smaller-scale architectural elements such as GB, LA, DA, DU, minor CH. May contain several combinations of gravelly channel-fill elements.
GB Gravel longitudinal bar	*Gh, Gm, (minor, Gp, Ge, Sp, Sh)*	Sheet-like bodies 20cm to 2 m thick and extending up to 20 m laterally. Amalgamated bodies > 2 m thick and extending > 50 m laterally. Typically composed of Gm overlying concave to planar basal surfaces. Top surfaces usually eroded. Amalgamated bodies distinguished by scour or slightly erosive surfaces or by thin sandstone sheets and lenses.
DA Down-stream accretion macroforms	*Gp (minor Sp)*	Sheet-like or wedge-like bodies 0.2 m to 2 m thick extending 1 m to > 10 m in downstream direction or down-dip direction. Reactivation surfaces within bodies. Erosively irregular to planar bases and upper surfaces.
LA Lateral accretion macroforms	*Gp (minor Sp)*	Sheet-like or wedge-like bodies 0.1 m to 1 m thick, 1 m to > 10 long m in downstream direction and extending 1m to > 10 m laterally down-dip direction. Reactivation surfaces within bodies. Erosively irregular to planar bases and upper surfaces.
DU Gravel dune complex	*Gt, Gp (minor St, Sp, Ge)*	Sheet-like bodies 0.3 m to 1.5 m thick, extending > 50 m laterally. Form laterally extensive cinglomerate bodies, commonly concave or irregular bases. upper surfaces generally eroded, irregular or concave.
SF Scour fill	*Ge (minor Se)*	Lenses 30 cm to 60 cm thick and up to 3 m wide. Bases always erosively irregular to concave. Upper surfaces gradational or sharply planar to concave.
SCH Sand channel	*Sm, St (minor Ge, and Se)*	Sheet-like bodies 0.1 m to 1 m thick and extending > 30 m laterally. Erosively irregular lower surfaces. Upper surfaces erosively planar to concave, where not eroded planar to slightly convex.
FPC *Flood-plain complex*		
OF Overbank fines	*Fm, Fl*	Sheet-like bodies 0.1 m to 2 m thick and extending > 100 m laterally. Basal surfaces planar or transitional. Erosional or irregular upper surfaces. Composed of silts and muds with leaf prints and terrestrial trace fossils.
CS Crevasse splays	*Sm (minor Sh, Sl)*	Sheet- or wedge-like bodies 0.2 m to 1 m thick and extending > 20 m laterally. Erosively planar to concave lower surfaces and planar to transitional upper surfaces.

Stop 3: MILJACKA

Stop 3 is very good opportunity to meet Lower Oligocene Modrino Selo and Miljacka Units. Deeply incising Krka River made fabulous outcrops on her vertical banks. Stop 3 is about 270 long profile (log MI) that embrace complete Modrino Selo Unit (about 240 m) and first 30 metres of overlying Miljacka Unit.

At first sight is possible to see that embraced units are very different type of fluvial deposits. These different "styles" can have explanation in the cyclicity of thrusting and offloading stages in the adjacent fold-thrust belts during overfilled phase of basin.

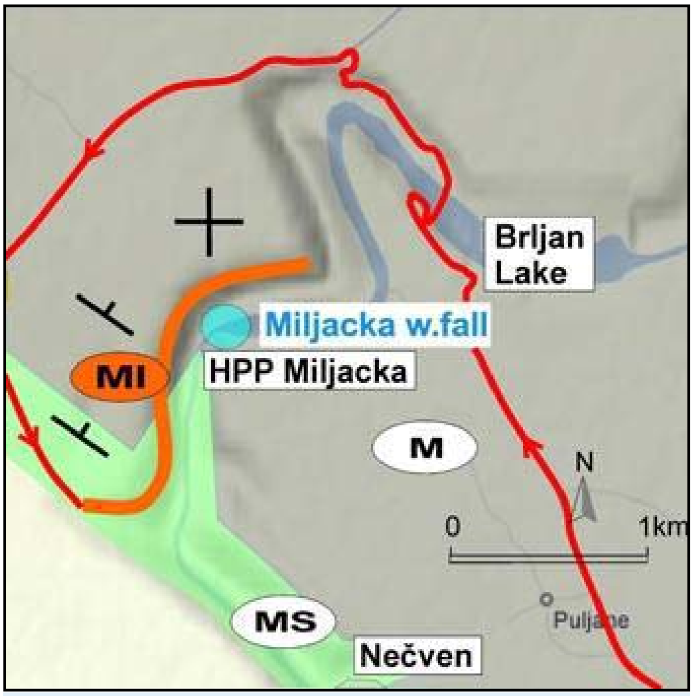


Fig. 48: Position of Stop 3. Profile is placed on the right side of the Canyon Krka in the vicinity of Miljacka waterfall and HPP.

MILJACKA UNIT - Description & interpretation

The unit is characterised by isolated, lens-like singlestoray fluvial channels of various dimensions, filled by sands and finer gravels. The channels are embraced by relatively thick flood-plain deposits that are very dominate in the lower part of unit. The flood-plain deposits consists of laterally extensive fine-grained (mudstone and siltstone) overbank deposits and fine-grained sandstone crevasse splay deposits. The crevasse splays vary from thin sheet-like to lens-like geometry. The faint lamination of overbank deposits is sporadically disturbed by numerous root traces. Various conifera species, immature paleosols sporadically present and 1-1.5 thick coal bed and few minor coal seams found in the vicinity of village Modrina Selo suggest a lowland area with relatively high water table and humid clime. The isolated channels embraced by thick flood plain deposits, higher water table and aggradational style of deposition is characteristic of the high-accommodation systems tract. For more details see Table 3 and 4 and Figs. 49, 50, 53, 54, 56, 57.

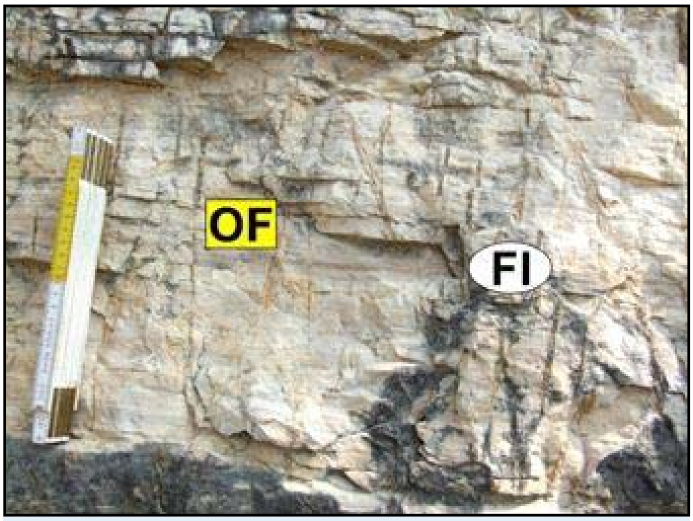


Fig. 49: Overbank mudstone with the faint horizontal silty lamination disturbed by root traces.

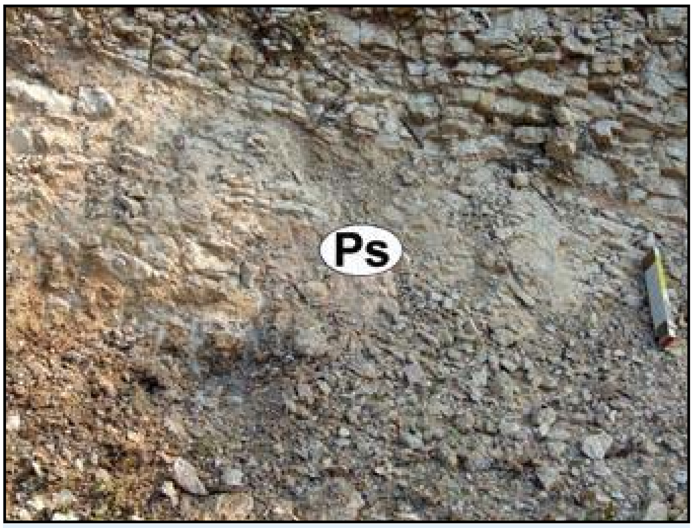


Fig. 50: Immature paleosols are sporadically present in the flood plain deposits.

Transition from Modrino Selo Unit to Miljacka Unit is more transitional than abrubt. It seems that the lens-like channel, dominate characteristic of Modrino Selo Unit gradually became more wider assuming multi-storey characteristics. For more details see Table 3 and 4 and Figs. 55, 56, 57, 58, 59.

Relatively thick and laterally very extensive sheetlike and amalgamated conglomerate bodies and general lack of fine-grained sediments is general characteristic of Miljacka Unit. Their external geometry and internal architecture is typical for coarse-grained braided plain with high-energy braided and unconfined streams.

The coarsest clasts measured in this part of log MI and high interconnection of channels speak for progradational

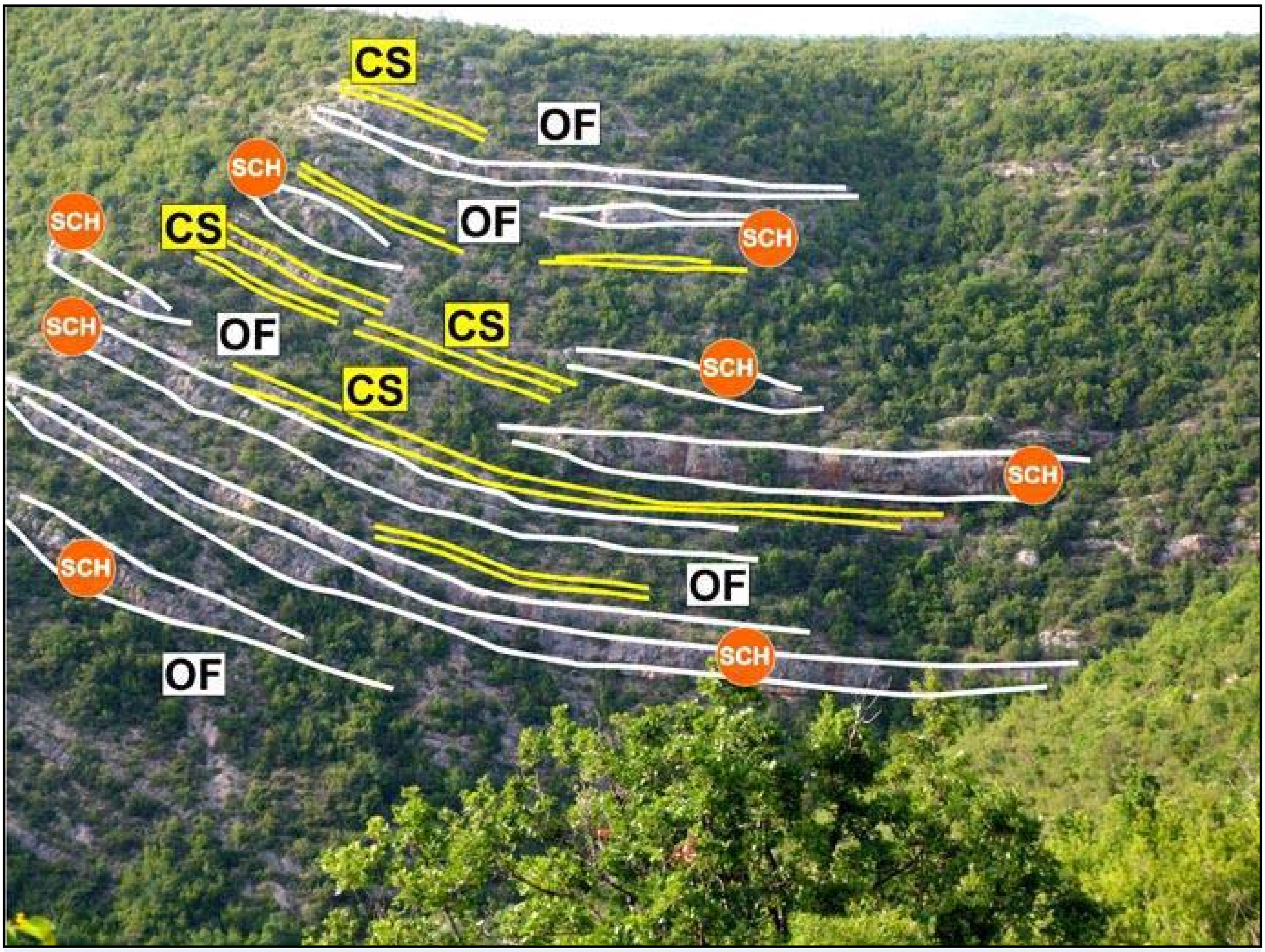
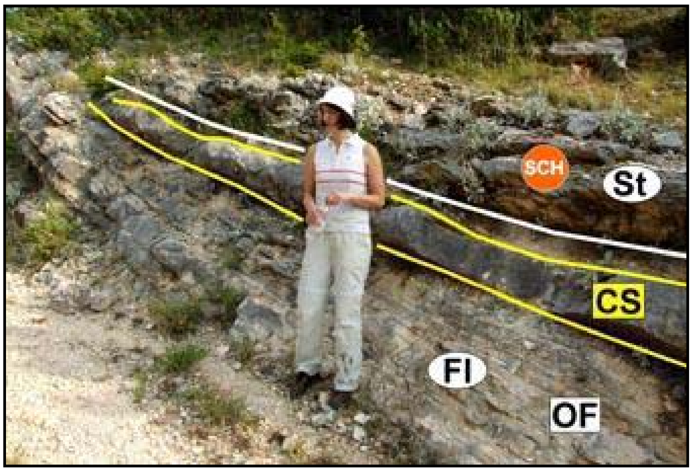


Fig. 51: The lower part of Modrino selo Unit. Stacked isolated and lens-like channels and thinner sheet-like crevasse splays are clearly seen. The photo is taken from old Nečven town. The height from bottom of the photo to the top of the bank is about 80 m.

style of deposition, accompanied by very low rates of aggradation (lack of fine-grained sediments). These features reflect early and slow base-level rise and in absence any marine distal equivalent it is more appropriate to talk about the low-accomodation systems tract than the lowstand systemes tract although coarse-grained sediments of both tracts have very similar characteristrics.



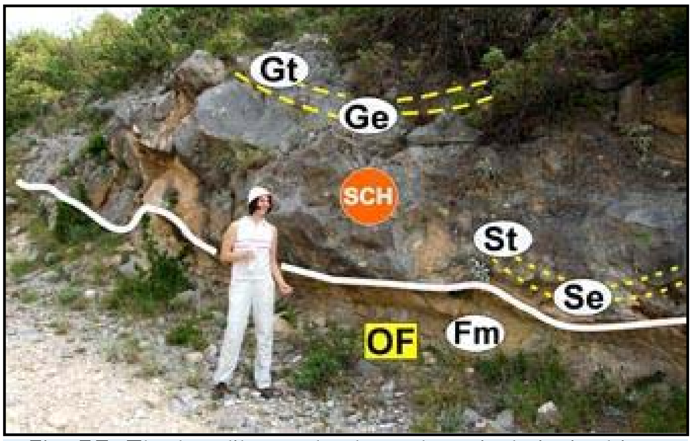


Fig. 53: The lens-like sandy channel erosively incised into overbank massive mudstone. The channel is mostly filled by sand facies except the its upper part which contains fine pebbles and granules.

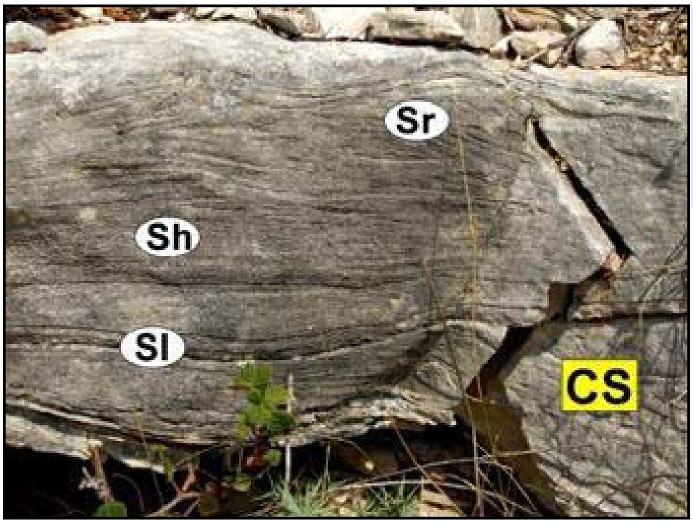


Fig. 54: The sandy crevasse splay with irregular erosive base and irregular upper surface. The lower and middle part display low angle cross- and horizontal lamination while the upper part has ripple cross-lamination. Sandstone is well sorted, medium- to fine-grained size. The crevasse splay is about 20 cm thick.

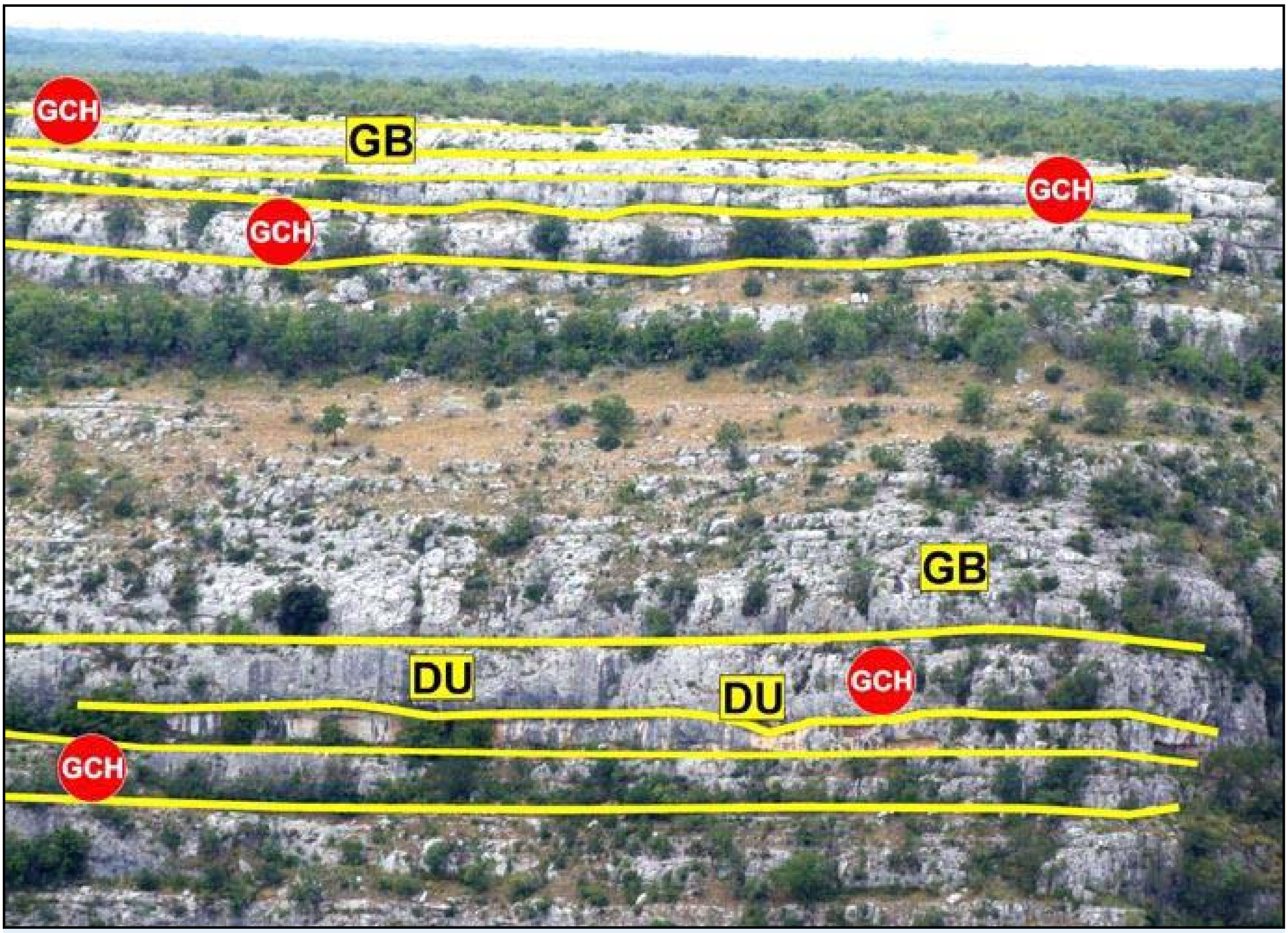


Fig. 55: Relatively thick and laterally very extensive sheet-like multy-storey conglomerate channels of Miljacka Unit. The photo is taken from the left bank of Canyon, above HPP Miljacka. The height from the bottom of the photo to the top of the bank is about 40 m.

Fig. 56: Photomosaic of the upper part of profile Miljacka (Miljacka Unit and the top of underlying Modrino Selo Unit). The profile is orienteted roughly paralle with the main palaeocurrent directions. The height from thebottom of photo to the top of bank is about 100 m.

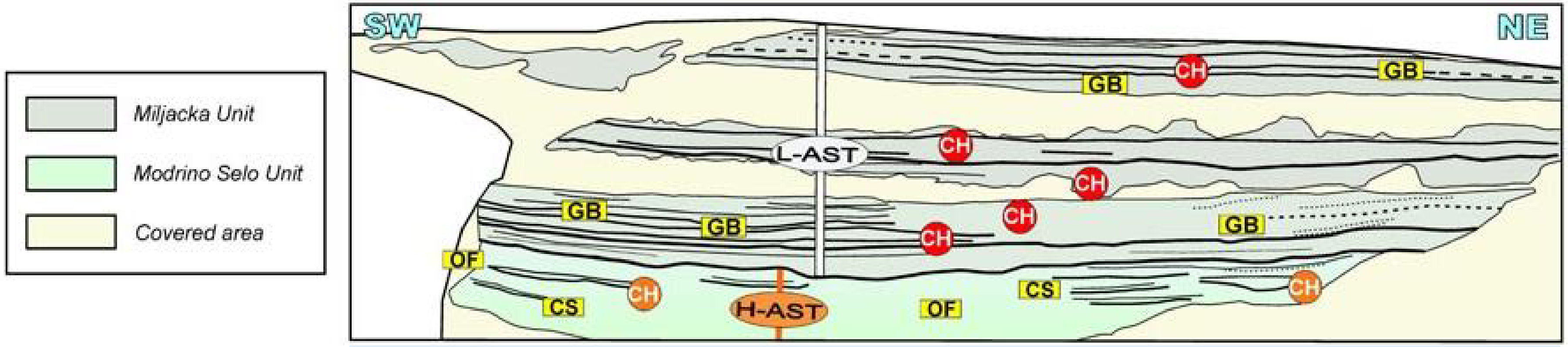
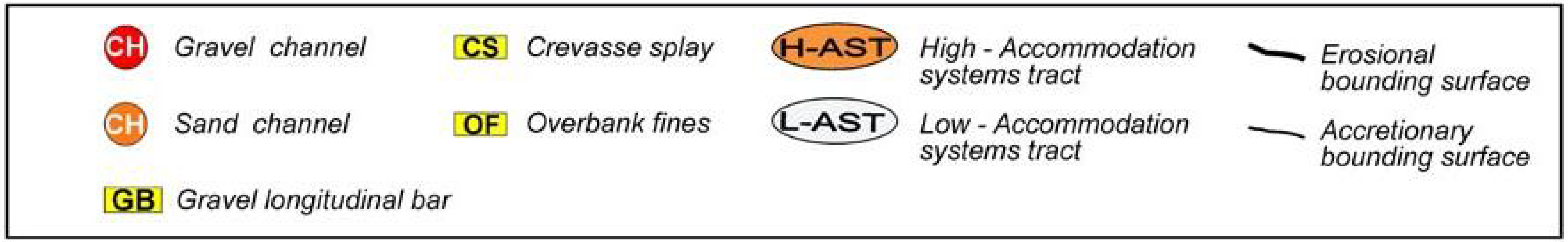


Fig. 57: Sketch of Photomosaics with the main architectural elements.



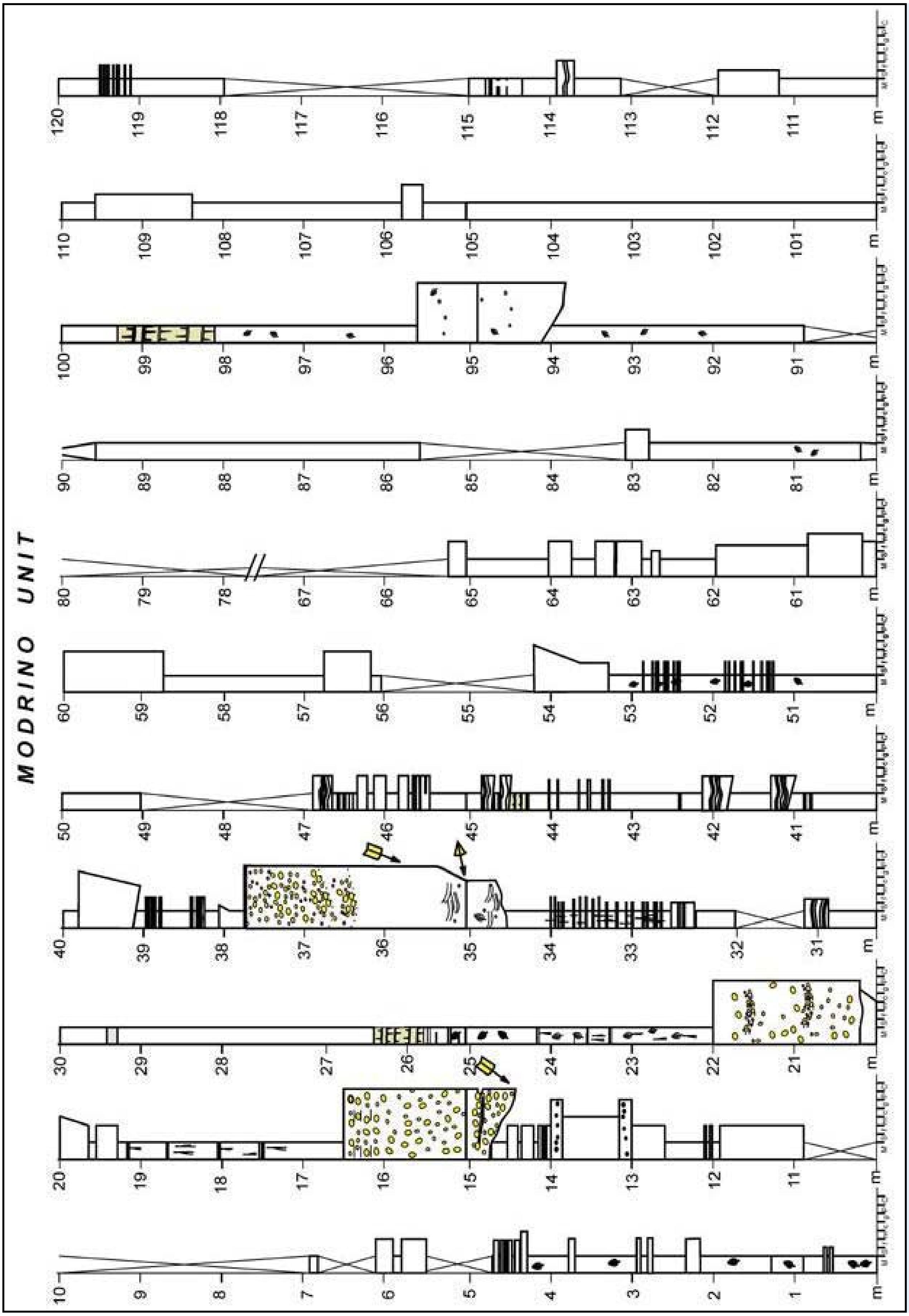


Fig. 58: Simplified log of Modrino Selo Unit and the lower part of Miljevac Unit at Stop 3.

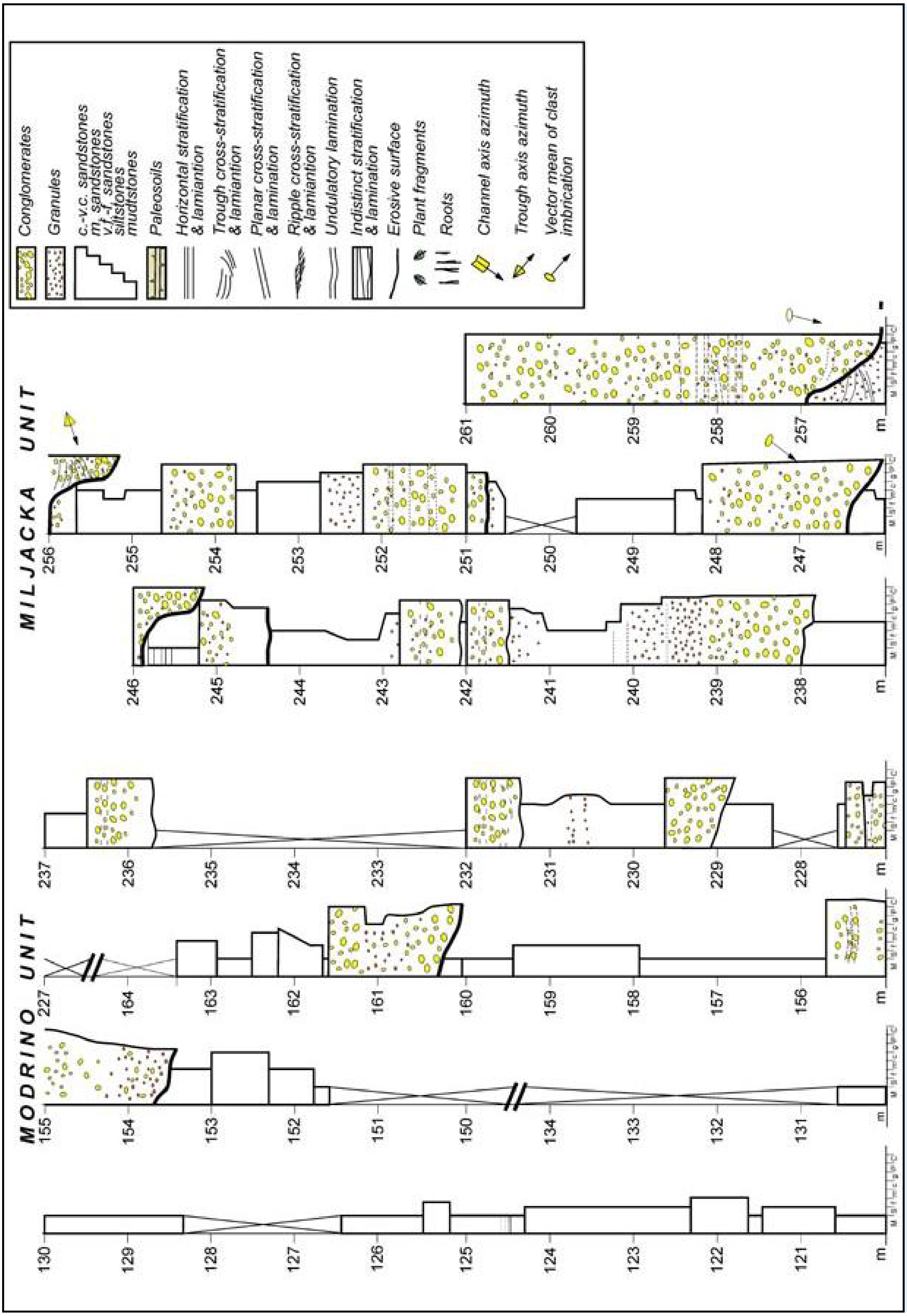


Fig. 59: Continued from the previous page.

Table 3. Summary of facies determinated in log MI.

Facies code	Description	Sedimentary structures	Interpretation
Gm	Clast-supported, poorly to moderately sorted, granule-cobble gravels with sand matrix.	Massive to crude flat bedding, rare imbrication.	Longitudinal gravel bars, hyperconcentrated channel or sheet flows.
Gh	Clast-supported, moderately to well sorted, granule-cobble gravels with sand matrix or no matrix.	Clear flat bedding with imbrication.	Longitudinal gravel bars, hyperconcentrated channel or sheet flows.
Gt	Clast-supported, moderately to well sorted, granule-pebble gravels with sand matrix or no matrix.	Large-scale trough cross-bedding	Three-dimensional megaripples, channel fills.
Gp	Clast-supported, well sorted, granule-pebble gravels.	Large-scale planar cross-bedding.	Two-dimensional megaripples, late stage trans verse bars, late stage modification of long. bars
Ge	Clast-supported, poorly to moderately sorted, pebble-cobble gravels.	Massive with rare imbrication.	Scour fills.
St	Well sorted, fine to coarse grained sands and gravel sands.	Large-scale trough cross-stratification.	Three-dimensional megaripples.
Sp	Well sorted, fine to coarse grained sands and gravel sands.	Large-scale planar cross-stratification.	Late stage bar modification, two-dimensional megariples.
Sh	Well sorted, fine to coarse grained sands and gravel sands.	Horizontal stratification.	Planar beds (upper and lower regime flows).
Sl	Well sorted, fine to coarse grained sands and granule sands.	Low angle cross-stratification.	Dune complex, scour fills and crevasse splay.
Sm	Well sorted, fine to medium grained sands and granule sands.	Massive.	?
Se	Pororly sorted, medium to very coarse grained sands and granules.	Mostly massive.	Scour fills.
Sr	Well sorted, fine to medium grained sands.	Ripple cross-lamination.	Two-dimensional small ripples.
Fl	Matrix supported, silts and muds.	Horizontal lamination, plant fragments and trace fossils.	Overbank deposits.
Fm	Matrix supported, silts and muds.	Massive, plant fragments and trace fossils.	Overbank deposits.
Ps	Immature soil.	Massive, plant fragments root and animal traces.	Overbank deposits.

Table 4. Summary of architectural elements determinated in log MI.

Architectural elements	Lithofacies assemblages	Description
GCH Gravel channels	Gh, Gm, Gp, Gt (minor, Ge, Sp, St, Sh)	Sheet-like bodies 2 m to > 10 m thick and extending from 10 m to > 200 m laterally. Basal surfaces typicaly erosional, irregular and concave to planar. Upper surfaces usually eroded and planar to concave. Composed of stacked Gm, Gt, Gp, and occasionally Sh, Sp. Embrace smaller-scale architectural elements such as GB, LA, DA, DU, minor CH. May contain several combinations of gravelly channel-fill elements.
GB Gravel longitudinal bar	Gh, Gm, (minor, Gp, Ge, Sp, Sh)	Sheet-like bodies 20cm to 2 m thick and extending up to 30 m laterally. Amalgamated bodies >10 m thick and extending 200 m laterally. Typically composed of Gm overlying concave to planar basal surfaces. Top surfaces usually eroded. Amalgamated bodies distinguished by scour or slightly erosive surfaces or by thin sandstone sheets and lenses.
DA Down-stream accretion macroforms	Gp (minor Sp)	Sheet-like or wedge-like bodies 0.2 m to 2 m thick extending 1 m to >20 m in downstream direction or down-dip direction. Reactivation surfaces within bodies. Erosively irregular to planar bases and upper surfaces.
LA Lateral accretion macroforms	Gp (minor Sp)	Sheet-like or wedge-like bodies 0.1 m to 1.5 m thick, 1 m to >20 m long in downstream direction and extending 1m to >10 m laterally down-dip direction. Reactivation surfaces within bodies. Erosively irregular to planar bases and upper surfaces.
DU Gravel dune complex	Gt, Gp (minor St, Sp, Ge)	Sheet-like bodies 0.3 m to 2.5 m thick, extending >50 m laterally. Form laterally extensive cinglomerate bodies, commonly concave or irregular bases, upper surfaces generally eroded, irregular or concave.
SF Scour fill	Ge (minor Se)	Lenses 30 cm to 60 cm thick and up to 4 m wide. Bases always erosively irregular to concave. Upper surfaces gradational or sharply planar to concave.
SCH Sand channel	Sm, St (minor Ge, Gt and Se)	Lens-like bodies 0.3 m to 5 m thick and extending >50 m laterally. Erosively irregular lower surfaces. Upper surfaces erosively planar to concave, where not eroded planar to slightly convex.
FPC Flood-plain complex		
OF Overbank fines	Fm, Fl	Sheet-like bodies 0.1 m to >5 m thick and extending >200 m laterally. Basal surfaces planar or transitional. Erosional or irregular upper surfaces. Composed of silts and muds with leaf prints and terrestrial trace fossils. Sporad immature paleosols.
CS Crevasse splays	Sm (minor Sh, Sl)	Sheet- or wedge-like bodies 0.2 m to 1 m thick, extending >50 m laterally. Erosively irregular to concave lower surfaces and irregular to planar and transitional upper surfaces.

Stop 4: BURNUM

Burnum (Burnistarum) is a Roman military camp, built on the foundations of earlier Ilirian fort. Later, it developed into a trade centre, which had a renessanse near the end of 5th and beginning of 6th century. The IX and IV legion of the Roman army were housed here, and the camp could house 4.000 to 6.000 soldiers. Burnum controlled the passage over Krka near the Brljan waterfall, and all Roman forces in the campaigns in these parts. The army of emperor Claudius left Burnum in 86 A.C., and emperor Hadrian gave it a status of a municipium. Burnum become a town of Roman veterans and develops into an urban settlement. It was one of the most important towns on the east coast of Adriatic. It had a large sanctuary, amphitheatre, 15 km long aquaduct, paved roads and streets and other characteristics of an urban settlement. Under its walls, many battles took place, and the most fierce were between the Goths and Bizant army. Burnum is mentioned for the last time in 537, when a battle of Romans against Goths was lead by Ugitil. Burnum was pulled down in 639, during Avaro-Slavic wars.

Fig. 60: Position of Burnum amphitheatre (near Brljan Lake, satelite image).

Fig. 61: Burnum amphitheatre, a satelite photo.

Fig. 62: The remains of Roman camp Burnum.

Fig. 63: The remains of Burnum amphitheatre.

Fig. 64: The remains of Burnum amphitheatre.

Stop 5 - BRIBIRSKE MOSTINE

The stop area is a narrow NW-SE trending cliff belt southeastern margin of Promina Beds basin that extends from the Goluguz trough Divič to Bribirska Glavica hill. The old historical town Bribir is placed on the top of Bribriska Glavica.

The cliff has opened about 300 m thick succession with three litostratigraphic units: Ostrovica (about 180 m), Bribir (about 100 m) and Roški Slap (>100 m). The clif succession is logged at six localities: logs GO (Gologuz), OS

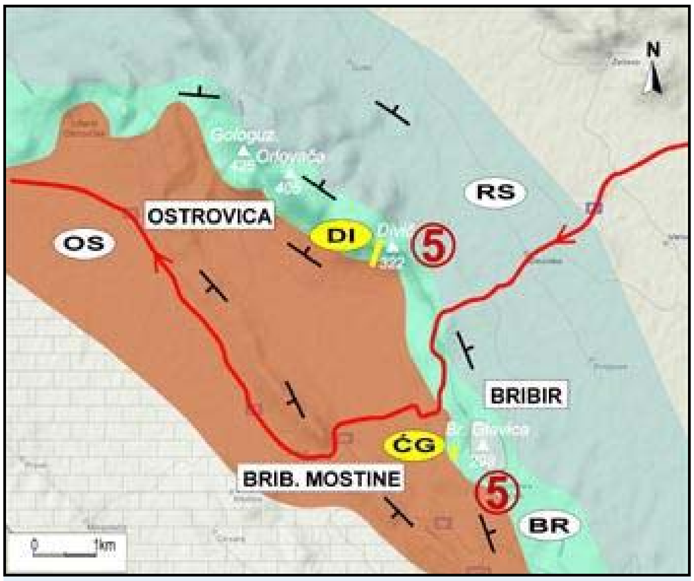


Fig. 65: Litostratigraphic map of the Bribirske Mostine area with position of stops with their logs.

(Ostrovica), ČE (Čelinka), Di (Divič), BR (Bribir) and ĆG (Ćoroška Glavica). The participants are going to see localites with logs DI and ĆG.

OSTROVICA UNIT - Description & interpretation

The Ostrovica Unit is the Middle to Upper Eocene heterolithic unit which is here characterised by monotonic beds alternation of sandy and marly siltstones or sandy siltstones and mudstones. The beds are 50 cm to 3 m thick and mostly consist of calcareous (sparitic and micritic) silt-sized grains. Quartz and clay grains are present up to 25 vol. % except in the top part of unit where their presence is negligible. The sandy siltstones contain rare very fine- and fine sand-sized quartz and calcitic grains.

The bed contacts are gradual or indistinct. The beds are massive - it is almost impossible to see any bed structures. The hummocky-like and horizontal-planar stratification or lamination can be seen spopradically. The beds underwent the highest degree of bioturbation. The lower part of succession is deformed and mutually mixed by slumping processes.

The macrofossils (bivalves, gastropods, corals, bryozoans, echinoids, plant fragments) and microfossils (*Miliolidae*

Fig. 66: Position of logs

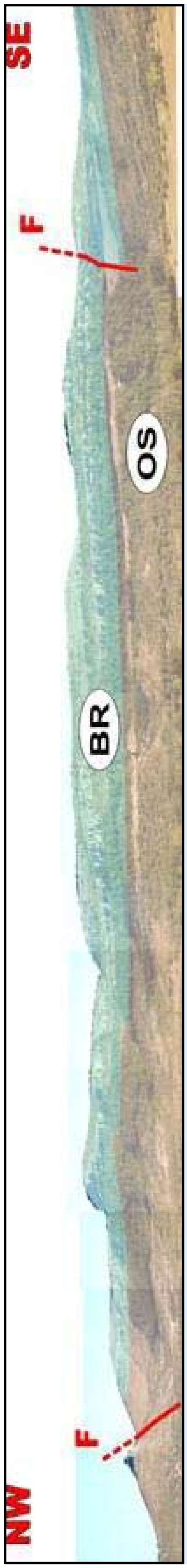


Fig. 67: Position of Ostrovica Unit and continuously overlying Bribir unit.

sp., *Discocyclina* sp., *Dendrophyllia* sp., *Nummulites* sp., *Neorotalia* sp., *Coskinolina* sp., *Asterocyclina* sp., *Textularia* sp., *Subbotina* sp.) are very common. The rate of planctonic foraminiferas slowly decreases going from the lower to the upper part of unit. The lateral persistant and 10 to 30 cm thick intervals of the stream orientated nummulites, bryozoans, gastropods and corals can be frequently seen within marly siltstones and mudstones.

The rarely seen lithofacies characteristics suggest deposition in the lower shoreface and offshore, discrete storm events, relativelly high sediment suply and accommodationn and probably frequent minor changes in relative sea-level (parasequences). The general shallowing upwards trend (progradation) is suggested by decreasing rate of planctonic foraminiferas.

The Ostrovica Unit can be seen in the base of logs DI i ĆG.

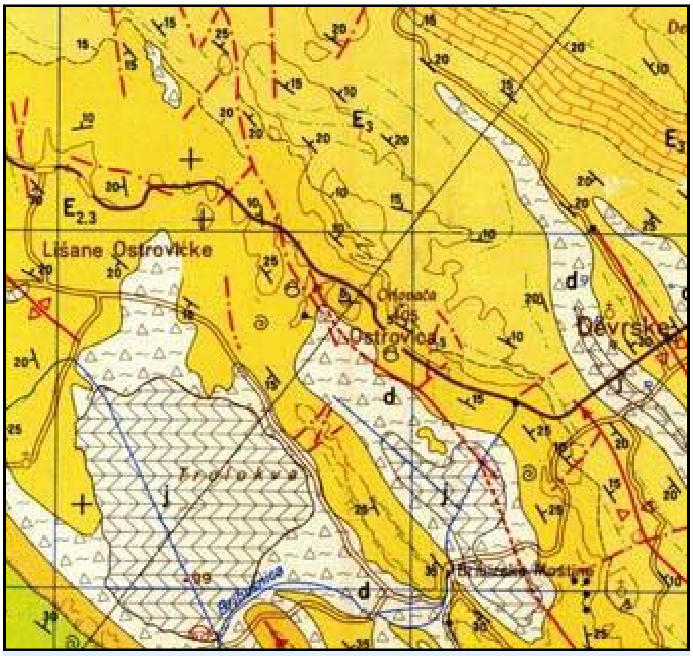


Fig. 68: A General Geological Map of Bribirske Mostine area, Sheet Šibenik (Mamužić 1975).

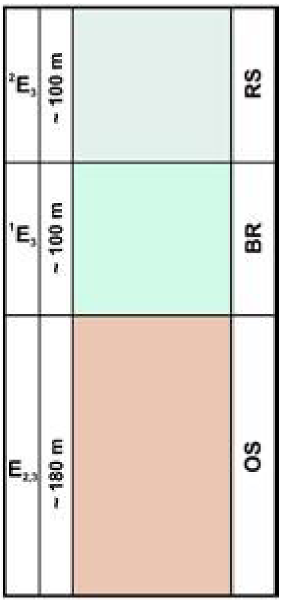


Fig. 69: Litostratigraphic units.

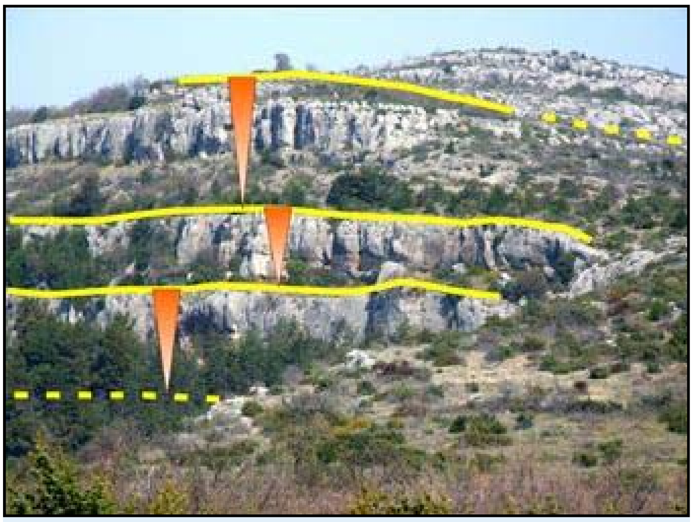


Fig. 70: Parasequences in the lower part of delta complex, log DI, Bribir Unit. The height from the bottom of the photo to the top of the third parasequences is about 60 m.

Fig. 71: The sandy siltstone bed and underlying at the bottom of the photo.

Fig. 72: Mixed and totally deformed sand siltstone and mudstone beds.

Fig. 73: The trace fossil burrow in silty mudstone filled by foramineras. The height of photo is 4 cm.

Fig. 74 & 75: The highest degree of bioturbation. The mottled structure of silty mudstones. The burrows are filled by sandy siltstones, foramineferas, various fragments of plants and gastropods.

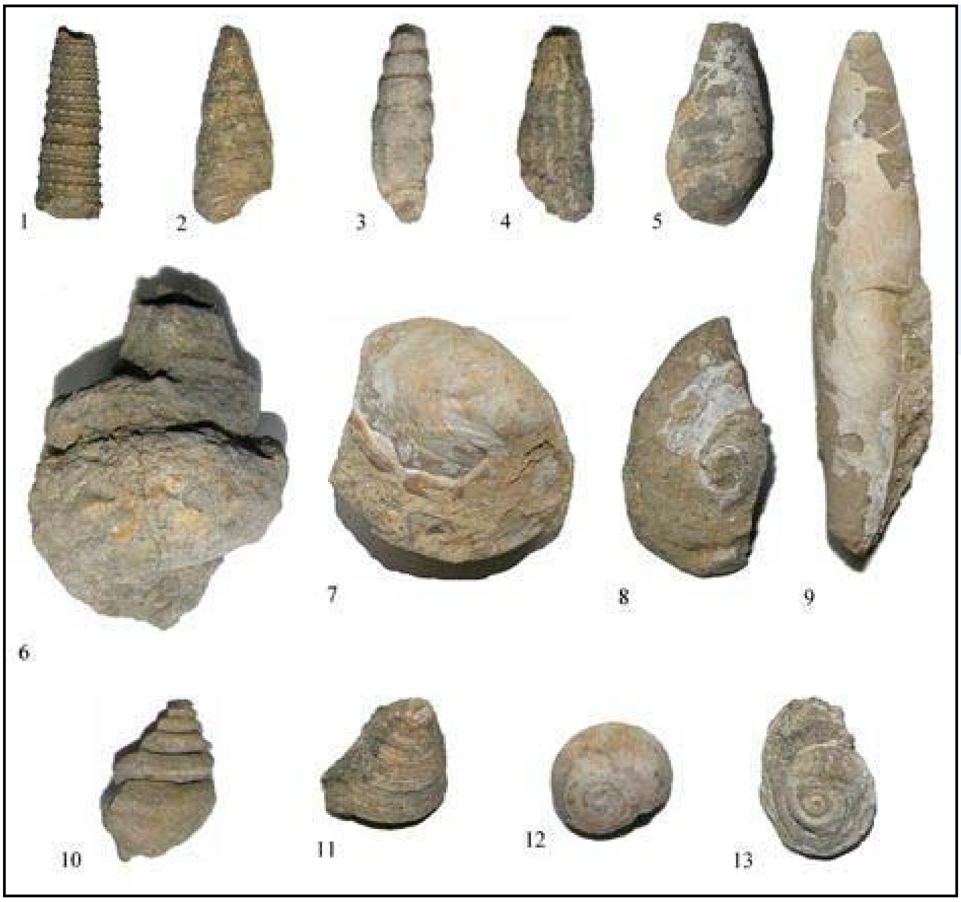


Fig. 76: Gastropoda from Ostrovica Unit at Stop 5: 1. *Tympanotonos* sp., 2. *Rimella* cf. *fissurella*, 3, 4. *Rimella* sp., 5. Undetermined gastropod mold with partly preserved shell, 5. *Campanile* sp., 6. *Campanile* sp., 7. *Velates perversus*, 8. *Xenophora* sp., 9. *Seraphs sopitus*, 10. *Globularia* sp., 11. *Potamides croaticum*, 12. *Ampullina* sp., 13. *Postalia destefanii*. Determined by G. Mikša.

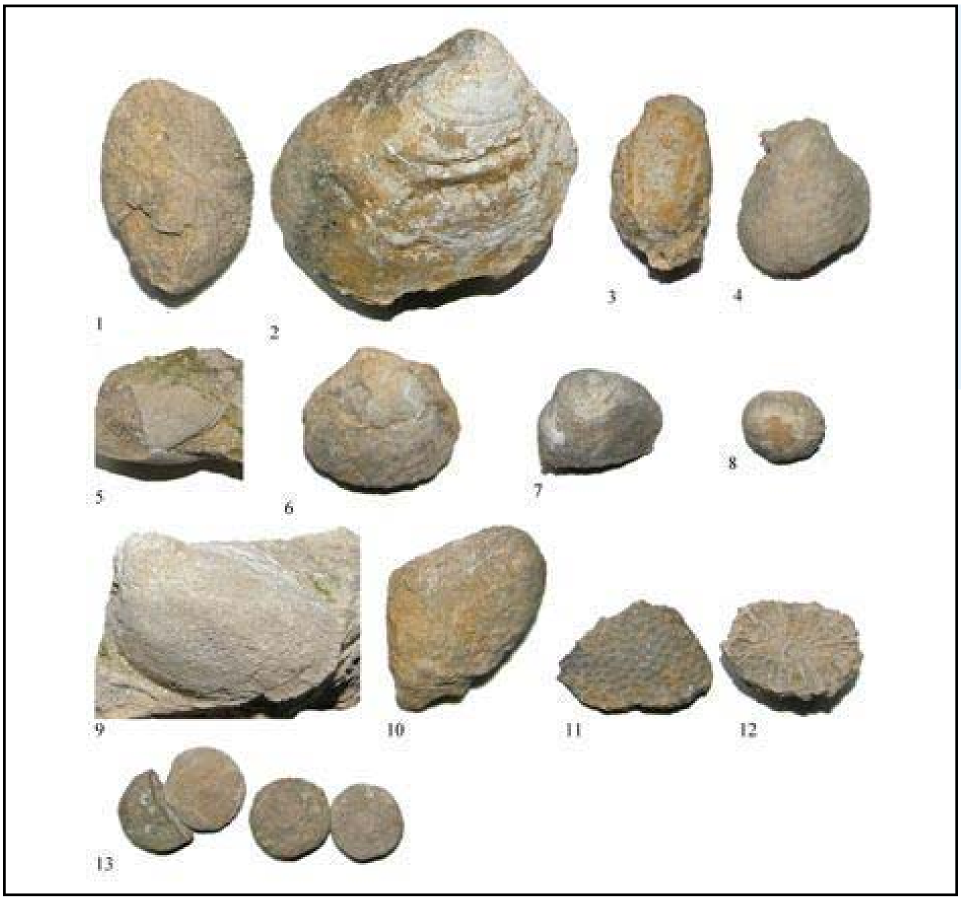


Fig. 77: Fauna from Ostrovica Unit at Stop 5. Echinoidea: 1. *Eupatagus formosus*; Bivalvia: 2. *Pseudomiltha prominensis*, 3. *Cucullaea* sp., 4. *Spondylus* sp., 5. *Tellina* sp. 6. *Miltha pullensis*, 7. *Corbicula* sp., 8. *Cucullaea* sp., 9. *Trachycardium* sp.?; Anthozoa: 10. *Chevalieriphyllia costata*, 11. *Goniopora* cf. *ramosa*, 12. *Streptocyathus* sp.; Foraminiferids: 13. Large benthic foraminifers, probably *Nummulites*. Determined by G. Mikša.

BRIBIR UNIT - Description & interpretation

The succession represents a Deltas complex that consists of isolated sheet-like carbonate conglomerate bodies both underlain and overlain by calcareous mudstone and sandstone beds (Mrinjek et al. 2007). Conglomerate sheets are laterally very extensive (500-1.000 m in strike direction) and 8-10 m thick. The sandstone beds and conglomerate sheets stacked upon one another form 6 recognizable coarsening-upward cyclothems composed of delta-front, prodelta and shelf deposits.

The shoreface sandstones at the base of the lowest cyclothems are in the gradational and conformable contact with the top part of Ostrovica Unit - siltstones and mudstones deposits with the typical features of offshore transitional zone and outer shelf. Separating highstand normal regressive deposits below from forced regressive deposit above this relatively gradational contact can be interpreted as a regressive surface of marine erosion (regressive wave ravinemnet) in forced regression sensu Hunt & Tucker (1992).

The basal surface of conglomerate sheet (delta front) in the lowest cyclothems is sharp and slightly erosive but conformable with underlying sandstone beds (prodelta) and is interpreted as a within-trend forced regressive surface of forced regressive delta (sensu Catuneanu 2006). The remaining 5 cyclothems can be attributed to a series of minor relative sea-level rises followed by normal regressions (parasequences) or even to autocyclic shifting of mouth bar lobes - the both possibilities can be realized during lowstand normal regression.

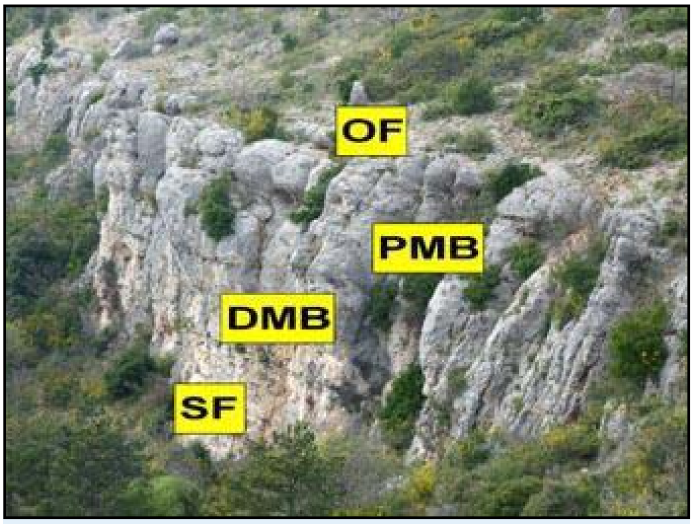


Fig. 78: The mouth-bar conglomerates and shoreface sandstone complex overlain by offshore mudstone of a subsequent parasequence. The height of outcrop is about 15 m.


Fig. 79: Proximal mouth-bar complex mostly composed of PMB1 facies. The outcrop is in the vicinity of log DI. The height of the outcrop is 10 m.

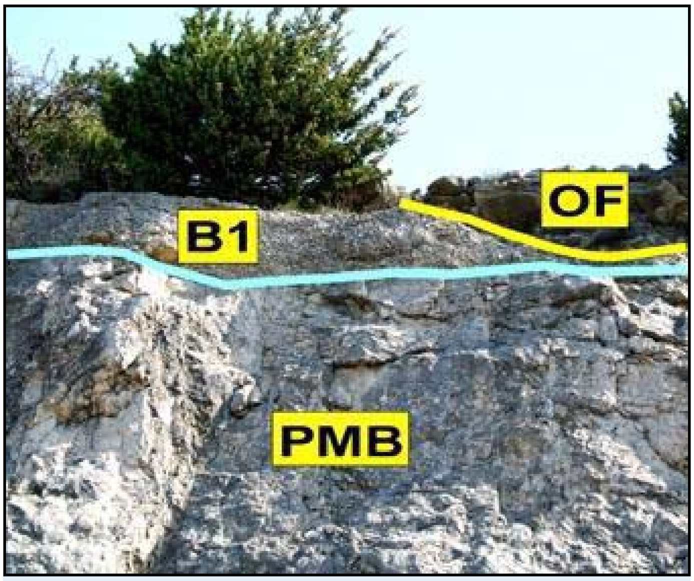


Fig. 80: Proximal mouth-bar conglomerates (PMB) capped by beachface conglomerates (B1). The outcrop is close to the railway-track in the vicinity of log DI. The height of the conglomerates is 5 m.


Fig. 81: The very well-stratified beachface conglomerates: very well sorted and rounded showing distinct vertical variations in the shape and size. Suthwestward dipping a(t)b(i) imbrication. Facies B1. The measuring stick is 22 cm long. The outcrop is located in the vicinity of log DI and the railway track.

Fig. 82: The gently seaward dipping, planar laminated fine- to medium sized sandstones with rare very well rounded, pebble- to granule sized clasts. Facies B2. The outcrop is located in the vicinity of log ĆG.

Fig. 85: Braided-plain pebble- to cobble-sized conglomerates on the top of the third parasequences (log DI). Suthwestward dipping a(t)b(i) imbrication of the cobble-sized clasts. The measuring stick is 1 m long.

Fig. 83: The upper shoreface sandstone beds with symmetrical wave ripples. Log DI. The coin is 2,6 cm in diameter.

Fig. 86: Braided-plain pebble- to cobble-sized conglomerates on the top of the third parasequences (log DI). Horizontal and planar-cross stratified conglomerates are clearly visible.

Fig. 84: The upper shoreface sandstone beds with wave ripples disturbed by intense bioturbation. Log DI. The coin is 2,6 cm in diameter.

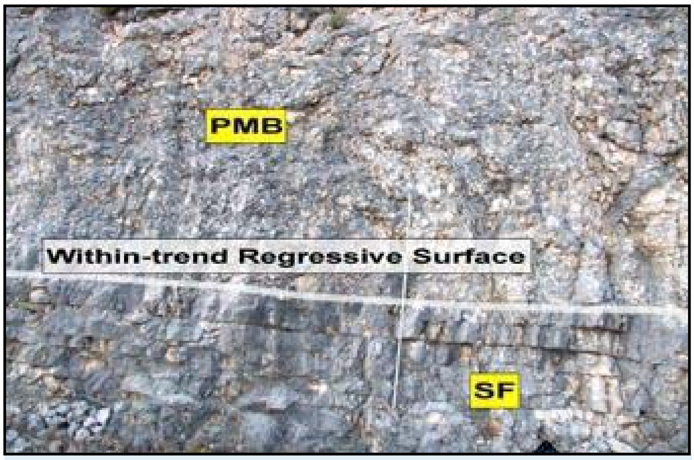


Fig. 87: The within-trend regressive surface between the shoreface sandstones and overlying proximal mouth-bar conglomerates. The outcrop is in a railway cut near the log DI. The measuring stick is 1 m long.

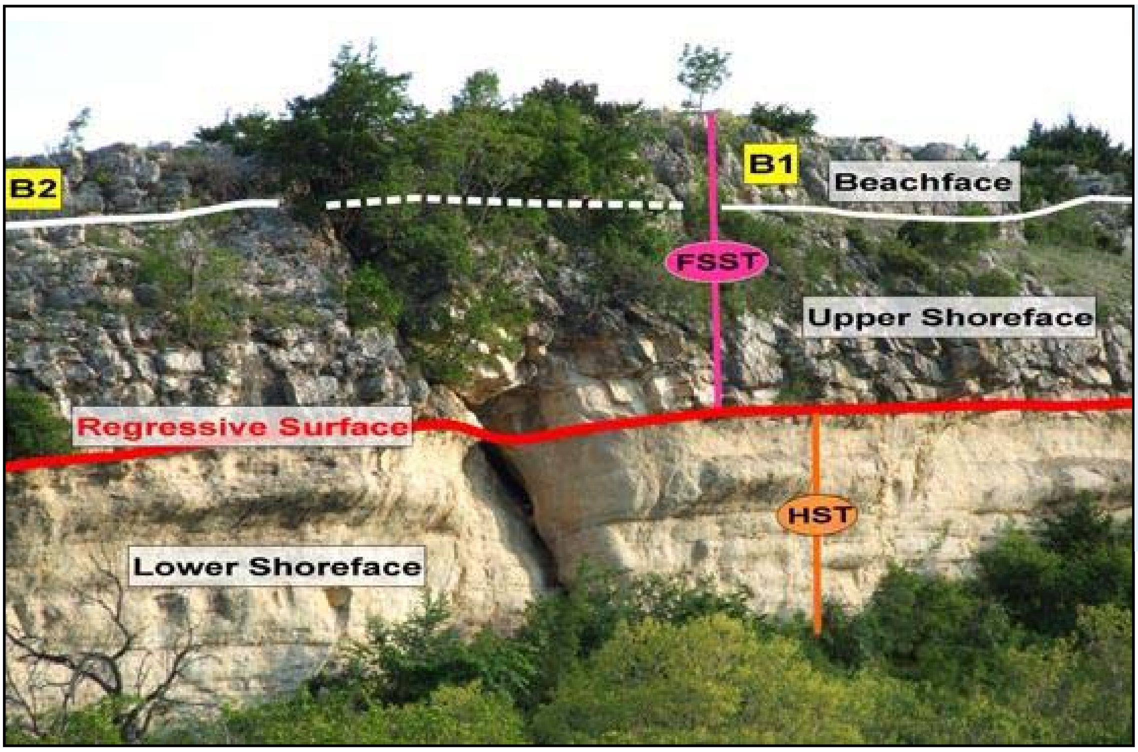


Fig. 88: The regressive surface of marine erosion separates the lower shoreface facies from upper shoreface facies and beachface facies. The upper shoreface sandstone are sharp-based due to wave scouring into the lower shoreface deposits during relative base-level fall. The log ĆG. The height of the bottom of the photo to the top of outcrops is about 10 m.

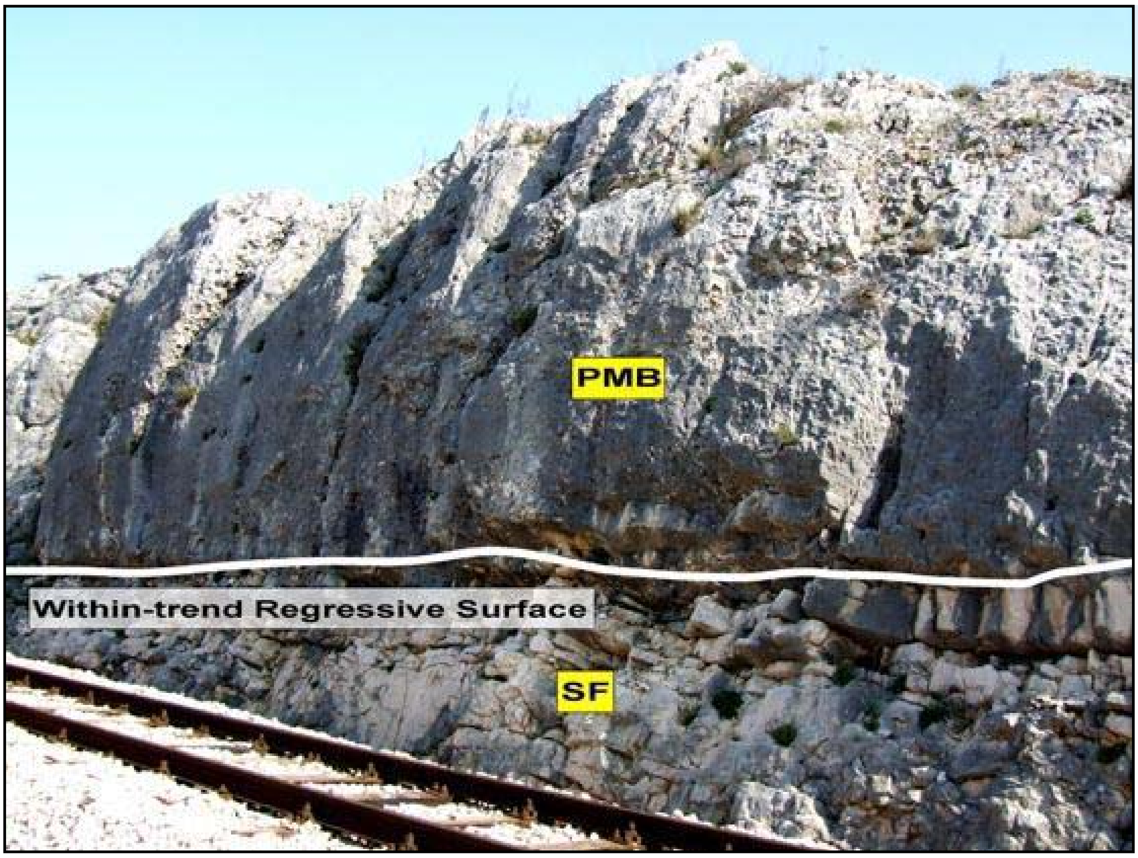


Fig. 89: The within-trend regressive surface between the shoreface sandstones and overlying proximal mouth-bar conglomerates. The outcrop is nearby a railway track in the vicinity of log DI. The height of the outcrop is about 10 m.

Fig. 90: The regressive surface of marine erosion separates the lower shoreface facies from upper shoreface facies The upper shoreface sandstone are sharp-based due to wave scouring into the lower shoreface deposits during relative base-level fall. The log DI. The outcrop is ca.15 m high.

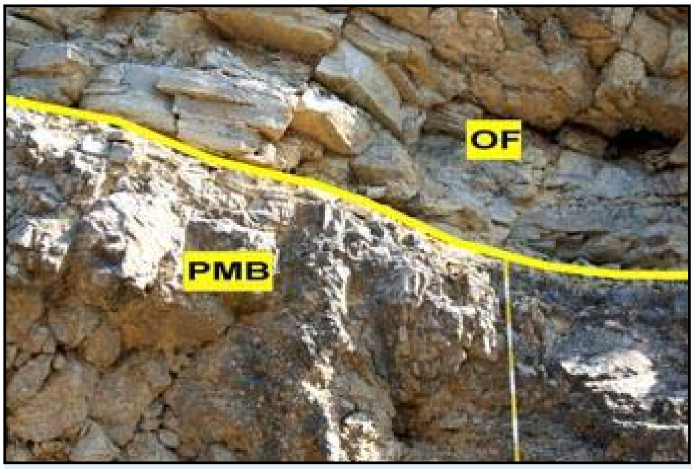


Fig. 91: The flooding surface separates the mouth-bar conglomerates from younger offshore sediments. The outcrop is nearby a railway track in the vicinity of log DI. The measuring stick is 1 m long.

Description of facies recognised in the Bribir Unit

PMB1 facies - *Plane-parallel stratified conglomerates*: clast-supported, moderately- to well-sorted pebbles and granules. Beds 10-50 cm thick, ungraded or normally graded, distinct horizontal stratification. Planar or slightly erosive basses. North and northwest-dipping a(T)b(i) imbrication. Associated sandstones beds and lenses are 5-20 cm thick, composed moderate-to well-sorted, medium-to coarse-grained sandstones with flat-lamination or low-angle cross lamination. Stream processes (traction currents and bedload sediment transport) in the uppermst levels of mouth bars. Fluctuationin the flow strength and period of low flow-stage conditions.

PMB2 facies - *Disorganised clast-supported conglomerates:* 20-100 cn thick conglomerate beds composed of pebble- and cobble-sized clasts with variable degree of sorting. The bases of the beds are flat or slightly undulating with minor basal erosion. Debris flows (Lowe 1979, 1982), rapid depositon from high concentration flows.

PMB3 facies - *Disorganised matrix-supported conglomerates:* poorly- to moderately-sorted pebbles. Indistinct bed boundaries. Clast-supporting mechanism is buoyant lift of dense sands and water matrix. Debris flow origin.

PMB4 facies - *Inversely graded, matrix-supported conglomerates:* poorly- to moderately-sorted pebbles. Planar and non-erosive bases. Cohesionless debris flows.

B1 facies - *Well-stratified conglomerates:* well-sorted and well segregated into horizontal beds (5-20 cm thick) showing distinct vertical variations in the shape and size sorting of the clasts. Southward and southwestward-dipping a(T)b(i) imbrication. Tractive transport, reworking and winnowing by waves and storms in the upper beach face.

B2 facies - *Conglomerates and laminated sandstones:* gently inclined, seaward dipping layers of sandstones and conglomerates. Conglomerates are one- clast layers (spherical and rod shaped pebbles) with sand and granule matrix. Sandstones are moderatelly- to well-sorted, medium- to very coarse-grained, showing horizontal or low-angle parallel lamination and Skolithos type of trace fossils. Reworking of mouth bars gravels by waves in the upper shoreface and lower beachface zone.

DMB1 facies - *Massive, pebbly sandstones:* clast randomly sccatered throughout the beds composed of medium- to coarse-grained sands The beds (10 - 40 cm thick) have flat or slightly erosive bases.Low-concentration sandy debris flows.

DMB2 facies - *Normally graded sandstones:* grade upwards from coarse sand to fine sand. The beds are 10 t0 40 cm thick with irregular, scoured bases and upper flat, sometimes ripple-capped bed surfaces.Massive or with indistinct parallel lamination in upper part. Deposition from high-density turbidity currents.

DMB3 facies - *Massive sandstones:* grade upwards from coarse sand to fine sand. The beds are 10 t0 30 cm thick with sharp bases that may be either erosive or non-erosive.Deposition from high-density turbidity currents.

DMB4 facies - *Horizontally laminated sandstones*: very fine- to medium-grained sandstone (10 to 30 cm thick) with sharp and flat bases. Produced by tractional deposition from unidirectional upper flow regime currents Variations in grain size and current velocities. Deposition from high-velocity turbidity currents.

DMB5 facies - *Trough cross-stratified sandstones:* fine- to coarse-grained sandstone (15 to 50 cm thick) with the width trough of 30 to 100 cm. Cross-stratification indicates large ripples or dunes.

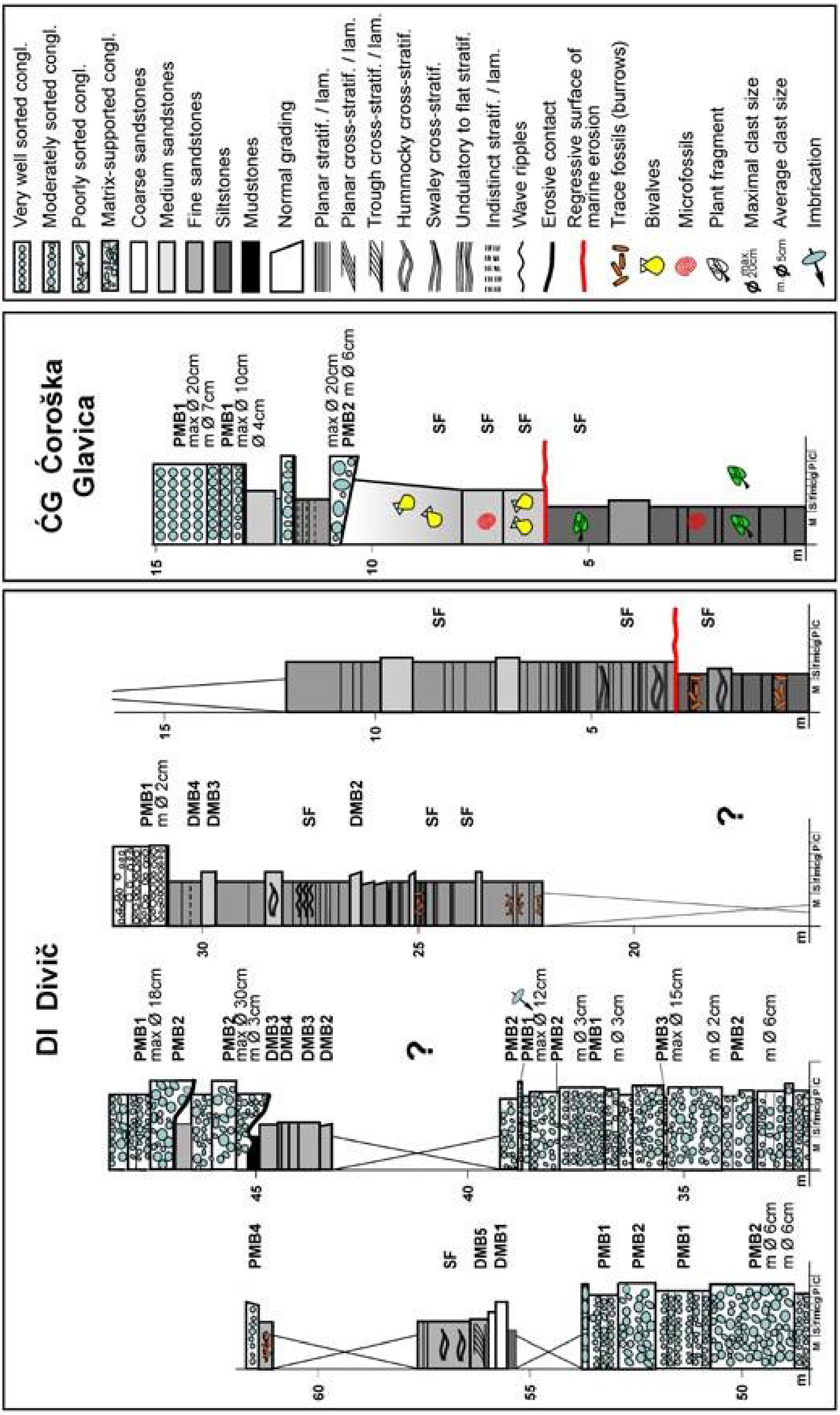
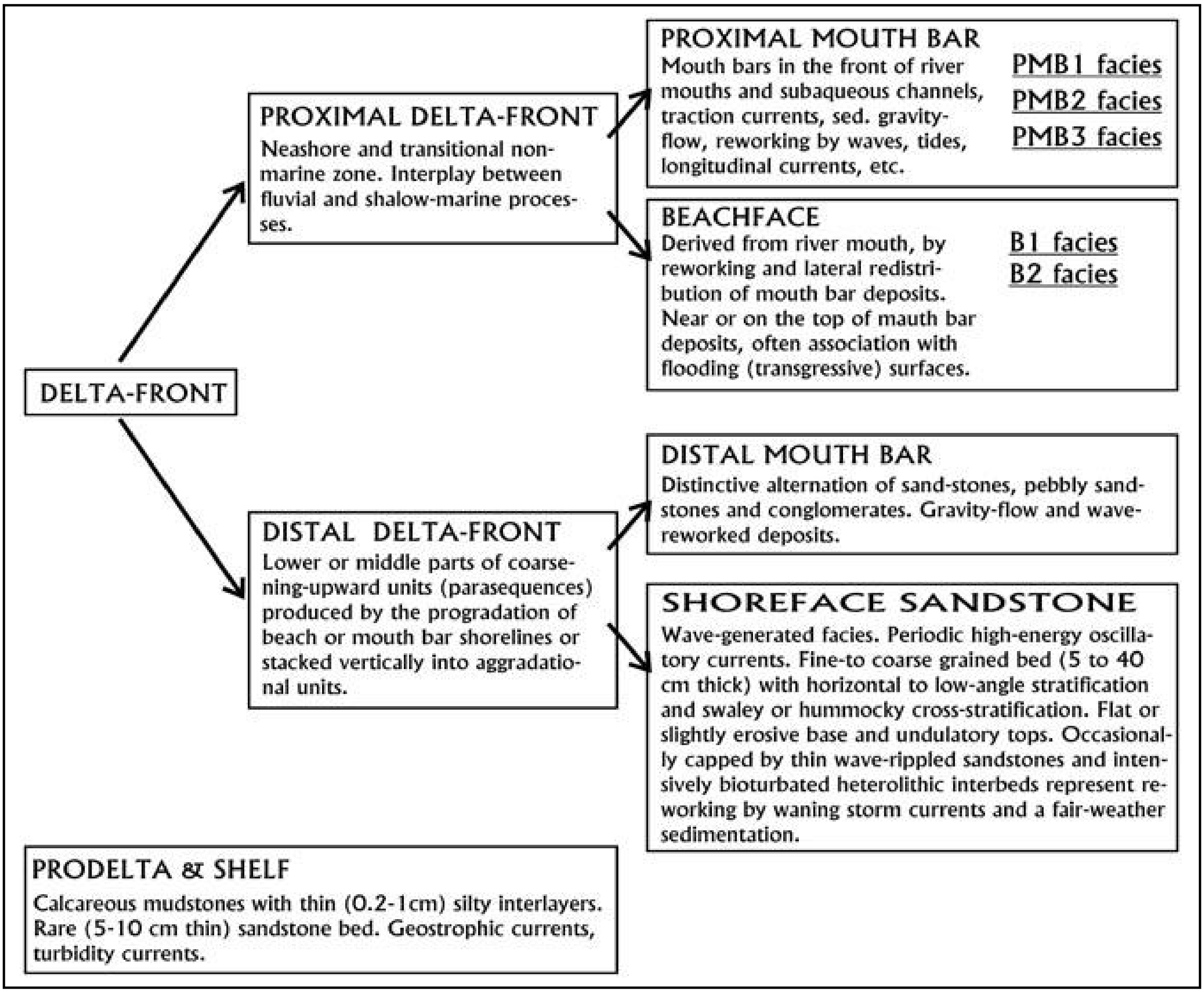


Fig. 92: Simplified logs Divič-DI and Ćoroška Glavica-ĆG. Bribir Unit.

Facies and facies associations recognised in the Bribir Unit.



Stop 6: BRIBIR

Bribir is the most important archeological site in the Šibenik-Knin County. It is still not completely explored. The first settlement dates from the Copper Age, some 1.500 years B.C. During etnogenesis of the Ilirian tribes, Liburnis settled in the coastal area, and one of their important centres is Varvaria (Bribir). It was a center of a wider Liburnian community, and at the time of Ceasar obtained municipal status. The eastern walls of Bribir probably date from that time. Croatian settlers arrived at the beginning of 7th century. It is known as Bribir (Breber) in the 10th century. The town-fort of Bribir is acquired by Šubić family, which is from that time known as Šubić of Bribir. In the 13th century, Šubić of Bribir ruled Split, Trogir, Šibenik and Omiš. The duke Pavao Šubić of Bribir was "ban of Croatia and a ruler of Bosnia". Šubić family ruled Bribir until the 16th century, when the town was taken by Turks. The Venetian Republic has, between 1686 and 1689 colonised Bribirska Glavica by orthodox Vlachs from Bosnia, who have later founded a new settlement beneath it and called it Bribir after all county name Breber.

Bribir is located on hill Bribirska Glavica which is approximately 300 m above sea level, and has a relative altitude of approximately 150 meters. Its flat peak resembles a large oval plateau, tipped toward the southeast, and the surface area is approximately 72.000 m^2. Owing to favorable conditions, such as inexhaustible sources of potable water, the fertility of Bribirsko Polje and open pastures suitable for stock grazing. Below the steep slopes, Bribirčica Brook emerges from the west, marking the beginning of the fertile field known as Bribirsko-Ostrvičko Polje. Bribirska Glavica dominates the entire region. From here, you can see the islands of the Šibenik Archipelago.

In good weather, you can even see the island of Vis, and from the other side parts of Ravni Kotari, Bukovica as far as the Dinaric massif, and across the Krka River all the way to Mt. Promina, Mt. Moseć and the hill of Trtar before Šibenik.

Fig. 94: Position of Bribir town-fort.

Fig. 95: The remains of Bribir.

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VISOVAC

The first reliable mention of the island of Visovac was in a deed dated 1345, issued by King Louis of Anjou, granting the city of Rog and the island of Visovac to Budislav Ugrinić, the son of Ugrin of Bribir. Under the protection of the Croatian nobility, the island was settled by the Hermits of St. Augustine, who in the 14th century built a small monastery and church dedicated to St. Paul. The Franciscans came to Visovac in the year 1445. The island was given to them by the ruler of the Kamička fortress, Grgur Utješinović. The Augustinian monastery was enlarged and adapted by the Franciscans. They built a new church on the north side of the monastery and transformed the Augustinian church into a sacristy. The Franciscan church was built near the end of the 15th century or the beginning of the 16th century, but certainly before Visovac fell under Turkish authority in 1522. During the Candian War, the monastery was burned and demolished, and the church was severely damaged. After the war, in 1672 the Franciscans returned to the island of Visovac and began to rebuild the church and monastery. By 1694, the church was extended and expanded, and another apse (Holy Cross) was added next to the old apse.

The Island of Visovac

The remains of the cloister with the well and chapel of these buildings are preserved today. hroughout the turbulent history of this region, the island of Visovac has always been an oasis of peace and prayer, where the Franciscan monastery and church served as fortresses of spirituality, morality, faith, Croatian culture and national identity.

http://www.npkrka.hr/

ZADAR

In the early days of Croatian history (11th century) Zadar was closely related to Croatian kings (Benedictine Abbess Èika was a half-sister of King Petar Krešimir IV). In the twelfth century (1102) a Croat Hungarian King Coleman was crowned in Biograd. The period from 1102–1409 was marked by the rule of Croat Hungarian soveringns and many rebellions against the Venetians. Venetian domination lasted from 1409–1797, when it was replaced by Austrian (until 1806), and French government (1814–1818). The city was handed over to Italy by the Papal Agreement of 1920. After a severe bombing of the city in the Second World War Zadar was annexed to Croatia, at that time ah republic of former Yugoslavia. Proof of the vitality of this region are recent evil events, when this region underwent yet another siege: in 1991 Serbian paramilitary units, with the aid of the Yugoslav army, brutally attacked the city - the city and the surrounding towns were attacked and demolished right up to the successful counterattack by the Croatian Army in 1995.

Zadar was popular as a settlement for more than three millennia. The first written evidence is found in the 4th century, and material evidence in the 9th century B.C. The first inhabitants were the tribesmen of the Liburnia, but the city became important during the Roman conquest. At the beginning of the seventh century it became the capital city of Dalmatia and remained as such until 1918. In the eleventh century it was the seat of the Byzantine theme.

Apart from Zadar, as the seat of the County and the most important historical destination, it is worthwhile to visit Nin, the oldest royal Croatian town and at the same time a Bishop's seat, where the Croatian state was born. Biograd, once a coronation town and Pag (at the island of Pag) were built according to plans of Juraj Dalmatinac (a famous architect and artist), thus making them monuments of early urban planning.

For centuries the metropolis of Dalmatia, and today the centre of the region, Zadar has been a city of rich monumental heritage of world importance visible at every step: the Roman forum dated to the 1st century AD, the church of St. Donatus dated to the 9th century AD – the most famous Medieval basilica and the symbol of the city, renovated Romanesque churches of St. Krsevan and the belfry of St. Mary dated to the year 1105, the cathedral of St. Anastasia dated to the 13th century AD, the People’s square with buildings of the Municipal loggia and the Town guard loggia from the 16th century AD, the mighty city walls with representative Port and Land gates from the 16th century AD, as well as the Square of Three Wells (Trg Tri bunara) and the Square of Five Wells (Trg Pet bunara) and numerous palaces, villas and other monumental heritage. Antique Zadar is founded on the typical regular rectangular layout conditioned by cardo and decumanus (main streets of all Antique time cities directed north – south and east – west) derived from the Roman military camp – castrum.

In addition, numerous islands of the zadar archipelago possess valuable historical heritage. On the islands of the Zadar Archipelago a number of old fortifications are to be found: Kastelina on the island of Vir and St. Mihovil on the island of Ugljan, towers like Toreta on the island of Silba, and in Veli rat on the island of Dugi otok one of the most beautiful Croatian lighthouses is situated. However, the most important cultural heritage of the Zadar Archipelago relates to the largest island – Pag. It is the island of salt, cheese and lace, connected with the mainland by bridge, with another old tower nearby. The city centre of Pag dated to the 15th century AD is known by its regular streets, designed by the famous Croatian architect Juraj Dalmatinac. The church of the Assumption of the Blessed Virgin Mary from the same period is located in its centre.

On the island of Pašman two valuable monasteries are situated: The Franciscan monastery from the 14th–18th century AD and the Benedictine monastery from the 12th–15th century AD. The latter one is important as the only active Benedictine monastery in Croatia with a valuable collection of old paintings and an attractive location. Nearby the island of Ugljan, on the islet Galevac, a Franciscan 15th century's monastery has found its place.

The hinterland of Zadar with regions of Ravni Kotari and Bukovica abounds with valuable cultural – historical monuments. Among them a special place hold monuments connected with the Knights Templar and the Knights of the Order of the Hospital of St. John (Hospitallers) in Croatia. Their seat of power in Croatia was the city called Vrana, and the famous priors of Vrana held the main role in the administration of the Croatian Mediaeval state until the fall of Vrana into Turkish hands in the 16th century AD. Today, nothing is left of Vrana, except a few fortifications near the same-named village by the shores of Vrana Lake. The contemporary centre of Ravni kotari, Benkovac, is proud of its mighty fortress that exists in a somewhat better shape, with an old church standing beside it. Benkovac was in ancient times an important seat of power, which is confirmed by the presence of the nearby ruins of the city of Asseria dated to the Antique period, with its beginnings in the Iron Age period. Old forts Klicevica and Karin are to be found in the neighborhood of Benkovac. Beneath the Fort Karin, by the shores of the deepest Adriatic gulf - the Karin Sea, a Franciscan monastery from the 15th–18th century is situated.

Even deeper inland, in the karst wasteland of Bukovica, in the valley of the river Krupa, an Eastern Orthodox monastery from the 16th century is located. The church belonging to the monastery is well known by its interior decorated with frescoes. In the Ravni kotari and Bukovica there are a lot of other old churches and towers harmoniously incorporated in the landscape between the slopes of the Mount Velebit and the sea coast.

SPECIAL ATTRACTIONS

The Sea organ was constructed following the project of Nikola Bašić, an architect; it is positioned near the new cruiser port as a part of Zadar's Riva and is easily recognized as a specifically shaped part of the coast that consists of several stairs descending into the sea. The stairs extend for about 70 meters along the coast, and under them, at the lowest sea-tide level, 35 pipes of different length, diameter and tilts were put up vertically to the coast, rising aslant to the paved part of the shore and ending in a canal (a service corridor). On the pipes there are LABIUMS (whistles), which play 7 chords of 5 tones. Above the canal there are perforated stone stairs through which the sound comes out as the air is pushed by the sea.

Greeting to the Sun At the very top of Zadar Peninsula, next to the globally known Sea Organ, now shines the Greeting to the Sun designed by the same architect, Nikola Bašić. The Greeting to the Sun consists of three hundred multi-layer glass panels set on the same level as the quay paving, in form of a circle having a diameter of 22 meters. The Greeting to the Sun is conceived as a spatial installation in form of an amphitheater surrounded by a stylized display of all Solar System planets and their orbits. When the "most beautiful sunset in the world" comes, the lighting elements built into the circle are activated, producing a wonderful, exceptionally impressive game of lights to the rhythm of the waves and the sound of the Sea Organ according to a specifically programed scenario.

http://www.zadar.hr/English/Zupanija/Povijest.aspx
http://www.zadar.hr/English/Zupanija/Kulturne.aspx
http://www.zadar.hr/English/Atrakcije/Zanimljivosti.aspx

STARIGRAD – PAKLENICA

The Paklenica Riviera has a special charm of unique meeting point of the sea and mountains. The Riviera runs along the coast of the Adriatic Sea, beneath the massive Velebit mountain range and the most beautiful part, Paklenica National Park, is found right here.

Velebit is the largest Croatian mountain range (2274 km^2), deeply interwoven into the space, lives and consciousness of the locals. Due to the impressive beauty of the landscape, the variety of relief shapes, flora and fauna as well as the untouched nature, it was declared a Nature Park.

Numerous hiking trails, historical buildings, old regal trails, fortresses and sacred monuments are evidence of man's centuries long relationship with this mythical mountain range. Paklenica National Park, with its monumental Velika and Mala Paklenica canyons, is the most beautiful part of this mountain range; and has been included in the World Biosphere Reserve by UNESCO.

Here Velebit opens up to the sea, and allows for the mixing of sea and mountain air, creating ideal climatic conditions. Paklenica will satisfy everyone – from the visitor checking out the caves, viewing points, old windmills or forest huts; hikers setting out to tackle the highest peaks, scientists studying the valuable natural heritage, to alpinists conquering the vertical slopes.

Starigrad-Paklenica emerged from the foundations of the ancient town Argyruntum and is now the centre of the Paklenica Riviera.

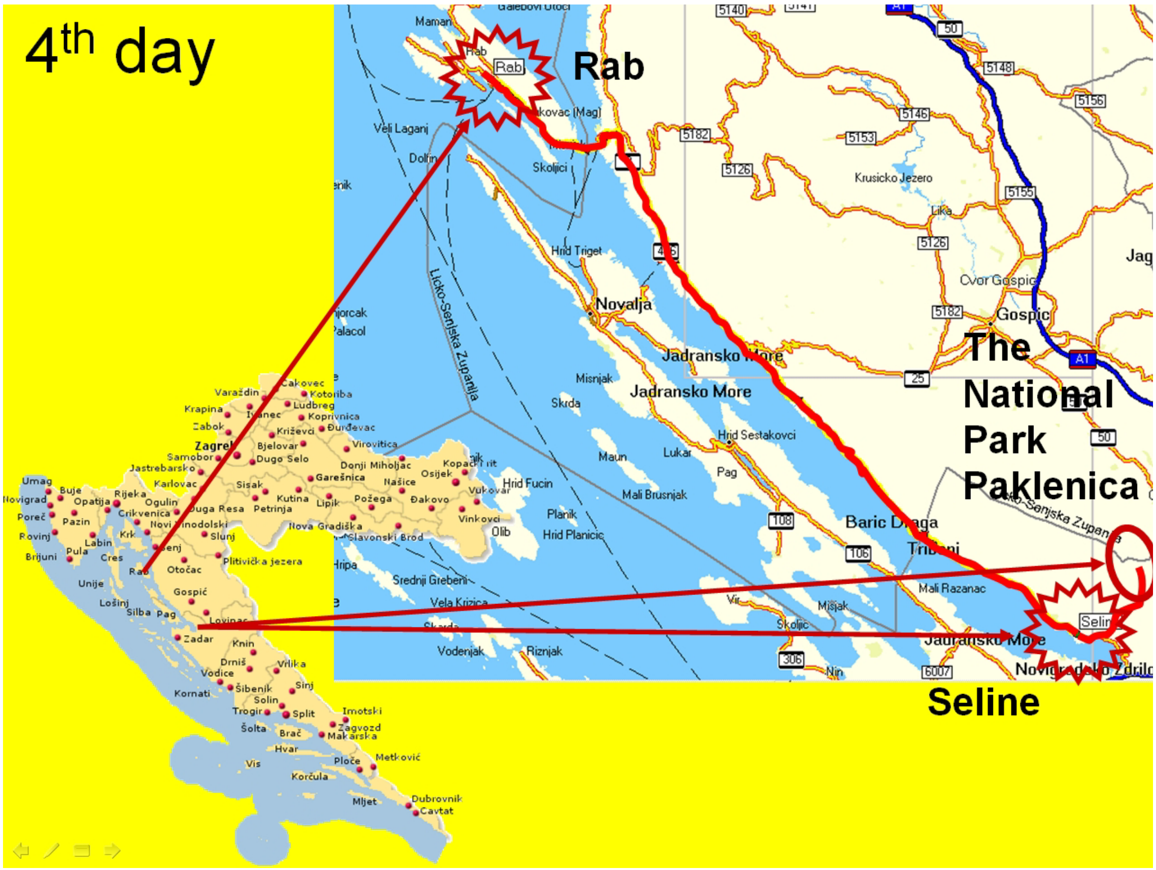
It will offer you its coastline and lead you into the impressive Velika Paklenica canyon, which reveals its beauty to visitors only several minutes away from the centre of town.

The Paklenica Riviera is open from early spring to late fall and offers: sun and sea, mountain climbing, alpinism, rafting, canoeing, bird watching, wellness, off-roading, education on natural and cultural heritage, an abundance of entertainment and sport and recreation ...

http://www.rivijera-paklenica.hr/en/index.php

7. DAY 4

National Park Paklenica



Source:
Marjanac, T., Sremac, J. & Marjanac, Lj. (2008): Velika Paklenica Canyon, outline of geomorphology and geology. 5th International ProGEO Symposium on Conservation of the Geological Heritage and ProGEO Working Group I Annual Meeting GUIDEBOOK, 1st – 5th October 2008, Rab Island, Croatia, 26–35. Zagreb, September 2008.

DAY 3

NB. This part of the excursion is also shared with the excursion 3A

Visit to the Paklenica National Park. Drive from Starigrad Paklenica to Rab, where the excursion ends. Crossing the Velebit Channel from Jablanac by ferry, 15 minutes of journey.

LEADERS:
Tihomir Marjanac & Ljerka Marjanac

VELIKA PAKLENICA CANYON, OUTLINE OF GEOMORPHOLOGY AND GEOLOGY

Tihomir Marjanac, Jasenka Sremac & Ljerka Marjanac

LEGAL STATUS

Velika Paklenica Canyon is a part of the Paklenica National Park which covers the area of 9506 ha and was proclaimed a protected area in 1949. It comprises two canyons; Velika and Mala Paklenica, Bojinac karst area and the high mountain plateau and dolines of the Velebit Mt. range, which is protected Nature Park in its own right, and UNESCO biosphere reserve. The Park basic phenomena are preserved woods (in otherwise unforested part of the Velebit Mt.) and canyon geomorphology.

The Paklenica National Park is administrated by the Paklenica National Park public institution which is located in the city of Starigrad.

The park is a popular destination of many visitors, and their number is around 130.000 per year. The Paklenica National Park homepage is: http://www.paklenica.hr/

GEOMORPHOLOGY

The Velika Paklenica Canyon is central geomorphological feature of the National Park, and shares basic characteristics also with the Mala Paklenica Canyon, which is located 3 km to the southeast. The basic difference between the canyons is their width and anthropogenic influence. The Velika Paklenica Canyon is much wider compared with the Mala Paklenica Canyon, which is in some places as narrow as several metres.

The Velika Paklenica was inhabited in the past ages, and there is an asphalt road which runs through the lower part of the canyon, and continues up canyon as a wide trail which reaches the Paklenica Mountain hut and partly abandoned Ramići village.

The Velika Paklenica Canyon strikes approximately normally through the Velebit Mt. foothills, exposing up to 400 m high steep rock walls which attract many climbers every day. At Anića Luka, 340 m a.s.l. and 2,7 km from the entrance, the Canyon widens into a mountain valley which stretches for another 4 km. Finally, 500 m a.s.l. the Velika Paklenica valley sharply meets a longitudinal valley which strikes along the mountain front, forming "T"-shaped valley head.

The Velika Paklenica Canyon is partly filled with large amount of glacial and glaciofluvial sediments which are preserved in erosional remnants at its flanks.

Modern geomorphological processes comprise rockfalls, formation of colluvial cones, and karstification. Fluvial processes are periodically intensive and redistribute gravel on the canyon floor, distally forming outwash fans. The Starigrad outwash fan is significantly anthropogenically altered, so the only active modern fan can be seen near Seline, at the outlet of the Mala Paklenica Canyon.

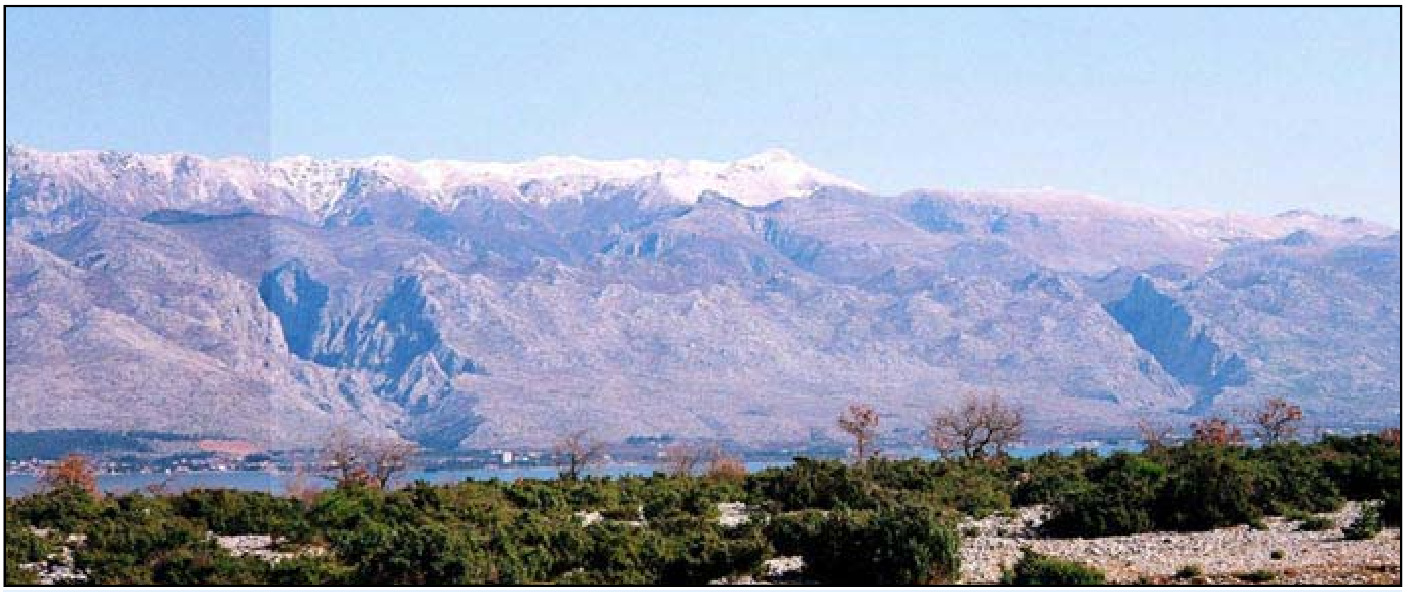


Fig. 13: Velika Paklenica (left) and Mala Paklenica Canyon (right), view from the sea.

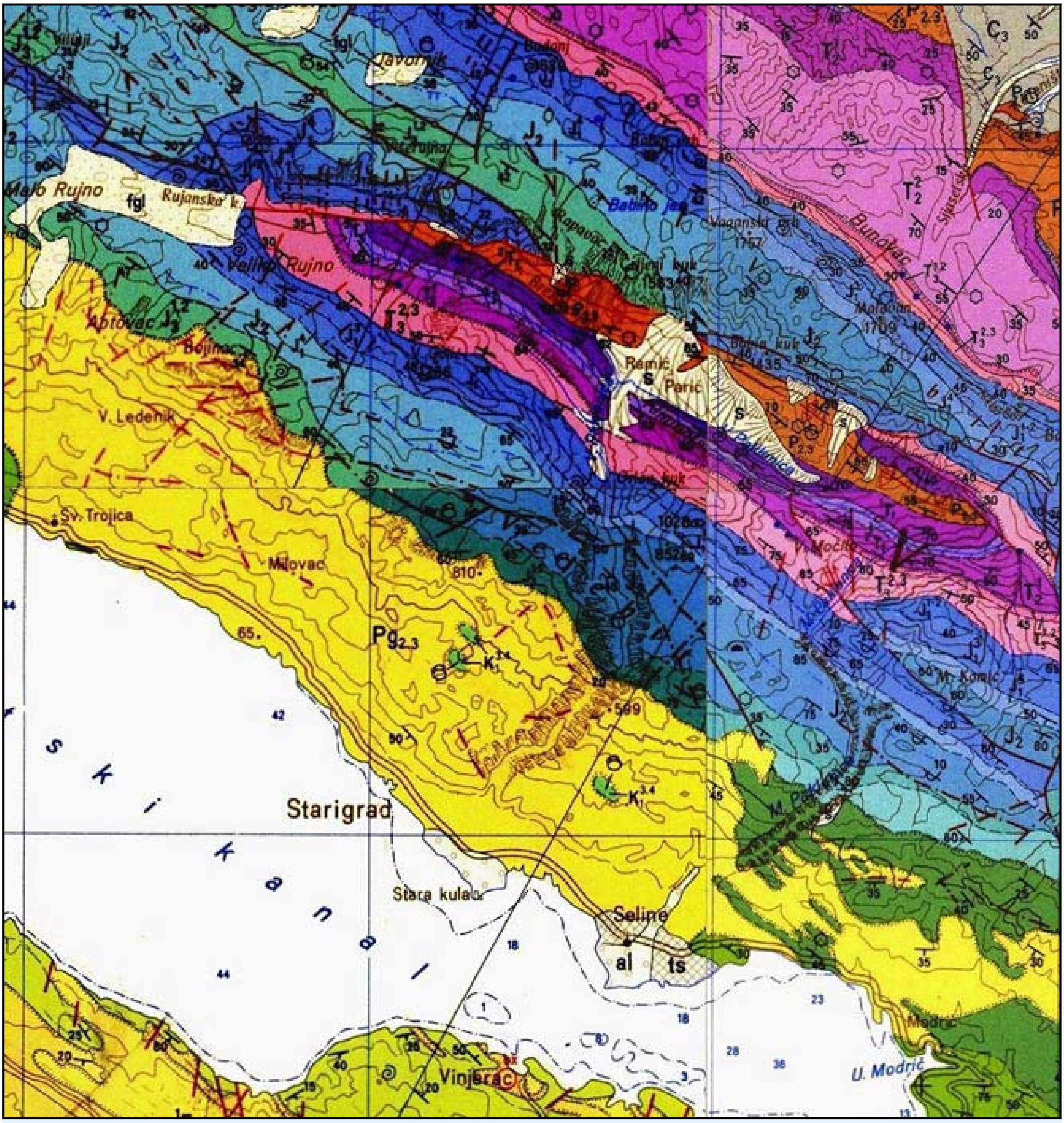


Fig. 14: Geological map of the wider area of Paklenica 1:100.000 (from the General Geological Map sheets Gospić and Zadar (Majcen et al. 1973, Sokač et al. 1976).

Karst features in the Velika Paklenica Canyon comprise large corosional features like flutes, kamenitzas, and caves - Manita Peć being one of them. The intensity of modern corrosion can be estimated on weathering of some recent rock engravings. Detailed description of the Paklenica National Park karst features is provided by Perica et al. (2001) and Perica & Marjanac (in print).

GEOLOGY

The Velika Paklenica Canyon transects the foothills of the Velebit Mt., and exposes the suite of sediments ranging from Late Permian to Quaternary in age (Figs. 14 and 15).

The oldest, Upper Permian fine-grained clastics are normally overlain by Lower Triassic (Werfenian/Scythian) clastics. The contact between the two is currently being studied by the University of Zagreb and University of Lausanne team.

PALEOZOIC
(J. S.)

Permian

The wider area of Paklenica is an anticline structure composed of Middle-Late Permian rocks in its core. These are the oldest rocks in the National Park. Permian dolomites were deposited on the shallow bottom of the former tropical sea in palaeoenvironmental conditions similar to the recent Bahama Bank. They cover the area 9,5 km long and 1 km wide (Fig. 14). Minimum thickness of these rocks is 500 m, but the underlying horizon is not exposed on the surface (Salopek, 1952; Sremac, 2005). Within the Permian dolomites, intercalations of black limestones and shales occur sporadically, containing excellently preserved marine fossils. Rich and diverse shallow marine communities are dominantly composed of calcareous algae, benthic foraminifera, sponges, bryozoans and brachiopods, with sporadic occurrence of fossil mollusks, sea lilies and echinoids. Particularly common Permian microfossil in the Permian of Paklenica is dasyclad alga *Mizzia velebitana*. It is a cosmopolite species described for the first time from this area, as well as a small fusulinid foraminifera *Eoverbeekina paklenicensis*. Among brachiopods there are several endemic species (e.g. *Martinia velebitica*). In the uppermost Permian horizons clastic intercalations are more common. These yellowish rocks were named „Transitional dolomite" by Salopek (1952). „Transitional dolomite" is overlain with „Sandy dolomite" (Salopek 1952) and the boundary between these two units was traditionally considered as the Permian-Triassic Boundary (PTB). Negative Cerium anomaly and the enrichment in siliciclastic material and major, trace and rare earth elements have shown that this lithological change is actually marking an Upper Permian regression. The depositional environment was shallow and unfriendly, and very few opportunistic taxa were able to survive. Therefore, biostratigraphy was unable to reveal the exact position of the PTB. Stable isotope analyses have shown a typical negative shift in carbon isotopes of carbonates within the „Sandy dolomite", which was interpreted as the most probable position of the Permian-Triassic boundary (Fio et al. 2007, 2008) (Fig. 15). The analyses of stable isotopes of carbon and nitrogen from kerogen have confirmed the reduction of productivity at the PTB, showing that the only survivers shortly after the catastrophe were cyanobacteria.

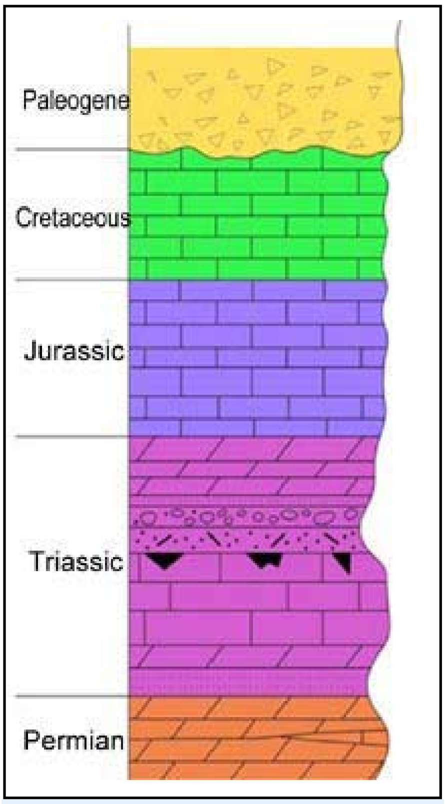


Fig. 15: Schematic geological column of the area of the National Park Paklenica.

MESOZOIC

Triassic

The Early Triassic mixed clastic and carbonate rocks continuously overly the Permian Transitional dolomite. In clastic intercalations typical Scythian fauna was found, including the bivalves *Anodontophora fassaensis*, *Pseudomonotis* (*Claraia*) cf. *tridentata* and *P.*(*C.*) cf. *kittlii*. Source of the clasts is combined – terrestrial and marine. Silicate grains are often cemented with dolomite. Ferrous oolites occur sporadically. Ripple marks and cross-lamination in these rocks are typical for a very shallow and turbulent marine environment. Sea-level rise lead to the change in the mode of deposition. Campilian dolomites contain amonites, but the amount of the terrestrial component in these rocks is still high.

During the Middle Triassic (Anisian) terrestric influence abruptly decreases. Almost pure marine carbonate rocks occur, among which late-diagenetic sacharoidal dolomites and laminated fine-grained dolomites prevail. Calcareous algae are common, with dominant genera *Diplopora*, *Macroporella*, *Oligoporella* and *Physoporella*.

Ladinian rocks have not been found in this area, and Late Triassic (Norian-Rhaetian) dolomites overly the Anisisan rocks. These rocks are well stratified, purely marine in origin and contain the index species *Gyroporella vesiculifera*. Three lithotypes can be distinguished in the Park: microbialites, dolomitized oolitic calcarenites and pure crystalline dolomites.

Jurassic

The highest parts of the Velebit Mt. are built of the Jurassic rocks, continuously overlying the Triassic rocks. Marine calcarenites and biolitites can be observed, with no clastic input from the land.

Lower Jurassic calcarenites contain calcareous algae *Palaeodasycladus barrabei*, *P. mediterraneus*, *Petrascula heraki*, *P. illyrica*, *Thaumatoporella parvovesiculifera*, and small gastropods. Bioaccumulated lithiotid limestones contain numerous lithiotid bivalves, foraminifer *Orbitopsella*, calcareous algae, gastropods and brachiopods. These are the typical deposits of a carbonate shelf. Overlying deposits exhibit the visible environmental change. Fossil communities are less diverse, and dolomites can be well recognized in the field by their spotty outlook. Index taxa of microfossils were found in these rocks, such as *Selliporella donzelii*, *Teutloporella gallaeformis*, *Pfenderina salernitana* and *Meyendorffina bathonica*.

Upper Jurrasic limestones were continuously deposited on spotty dolomites. They contain a typical microfauna: *Kurnubia palastiniensis*, *Pseudocyclammina lituus*, *Griphoporella minima*, *Cylindroporella anici*, *Macroporella sellii*, *M. pygmaea* i druge. Limestones are dark-coloured, calcarenites to calcilutites in structure. Rather high amount of magnesium ions in calcite crystals indicate the warming in this period.

Cretaceous

Cretaceous rocks transgressively overly the Jurassic limestones. They are in most cases covered with Palaeogene Jelar beds, and outcrop sporadically in the southernmost part of the National Park Paklenica. Calcareous breccias prevail, with scarce bioclasts of molluscs, foraminifera (e.g. *Orbitolina* cf. *discoidea*) and calcareous algae.

CENOZOIC

Tertiary
(T.M.)

Northern Adriatic Dinarides are characterized by well-known carbonate development of Mesozoic units (e.g. Grubić 1980), but also with extensive breccia which crops out in a large part of Dinarides, known as Jelar-beds (herein referred to as Jelar-breccia, because breccia is by far predominant lithology of these "beds"), first described by Bahun (1974). The Jelar-breccia is massive, of calcareous composition, with predominantly angular, weakly sorted debris. It is commonly grain-supported, although matrix-supported varieties locally occur. The breccia matrix is of carbonate composition, gray-to reddish-coloured. Debris stratigraphic composition is varied, most common are clasts of Cretaceous limestones and dolomites, but other lithologies are also represented, although subordinately. The debris grain sizes are very variable, and clasts range from a few mm to several decimetres in size, but also up to several metres or more across. Vlahović et al. (1999) stated that in some areas, like on the Velebit Mt. flanks, occurs stratigraphic inversion of debris.

The area covered by this breccia reaches ca. 688 km^2, but its thickness is poorly known. The only available direct account on its thickness was acquired by geotechnical drill-hole during construction of the St. Rok road trunnel (Matičec et al. 1999) on the southern part of the Velebit Mt., which penetrated 300 m of Jelar-breccia before entering into the underlying Mesozoic carbonates.

Not only the thickness of Jelar-breccia is poorly known, but also its age remains a controversy. It was treated as an Eocene, Oligocene unit by authors of the General Geological Maps of Croatia (Ivanović et al. 1973, Mamužić et al. 1969, Šušnjar et al. 1970), what means that is represents a post-flysch sedimentary unit. However, some other authors interpreted the breccia as post-Cretaceous, but pre-flysch sedimentary unit (Tari & Mrinjek 1994) of the Early Eocene age. The youngest debris found in Jelar-breccia are clasts of Early Eocene Alveolina Limestones, what constraints its age to Upper Lutetian - Bartonian span (Sakač et al. 1993, Vlahović et al. 1999). Some researchers argued that Jelar-breccia represents time-equivalent of Promina-beds (Herak & Bahun 1979, Vlahović et al. 1999) which are Eocene-Oligocene (Šikić 1965, Komatina 1967, Ivanović et al. 1976), primarily alluvial to paralic (Zupanič 1969, Kruk et al. 1995, Babić & Zupanič 1983), sequence widely exposed in Central Dalmatia and Herzegovina.

The Jelar-breccia genesis was discussed by Bahun (1974) who related its genesis to reverse faulting and thrusting of Velebit Mt. Herak & Bahun (1979) extended the interpretation to thrusting over eroded terrains with gravitational transport of debris. Vlahović et al. (1999) interpreted the breccia as a syntectonic unit formed during tectogenesis of Dinaric range when tectonic fracturing provided abundant debris which was gravitationally transported down steep slopes forming rockfall breccia fans which filled marginal lakes, and subordinately, shallow sea.

Quaternary

Deposits of Pleistocene age were considered a secondary subject during previous geological studies and were given little attention. Thus, the only determination given on the General geological maps published during 1960-es referred to fluvioglacial conglomerates and colluvial debris apron, in spite of fact that Pleistocene deposits occur in the whole length of the Velika Paklenica Canyon.

For historical reasons it is important to note that the earliest idea about Mediterranean being affected by glaciations, and so the Adriatic as the northeast epicontinental sea, was brought just as a hypothesis by Luis Agassiz (1840) in his discussion about glaciations. Recently studied deposits along the Adriatic coast, interpreted as of glacial origin, yielded evidence in favour of his hypothesis (Marjanac et al. 1990, Marjanac & Marjanac 2004).

Acording to evidence from the other regions of Mediterranean, it is assumed that the most extensive phases of glaciation have occurred during the Middle Pleistocene (Hughes et al. 1996).

Pleistocene age deposits can be found within broader surroundings of Velika Paklenica Canyon - generally on Southern Velebit peaks and slopes, particularly on Veliko Rujno and Bojinac, but also along the coast, e.g. near Seline, Žegar and in Novigrad and Karin Seas.

Veliko Rujno moraine is an elongated sedimentary ridge (Fig. 16) composed of glacially derived material. It consists of three smaller gravel bodies, each representing a different phase of glacial advance. The sediment is unconsolidated, matrix-supported conglomerate. Majority of unsorted rounded debris with an average maximum diameter of 25 cm is represented by predominantly dark grey Jurassic limestone and small red-coloured Lower Triassic sandstone clasts. The large boulders - eratics - with sizes in range from 60 cm to 2,5 m across occur scattered on the surface of this moraine ridge, as well as along the mountain slopes and even on top of some mountain ridges.

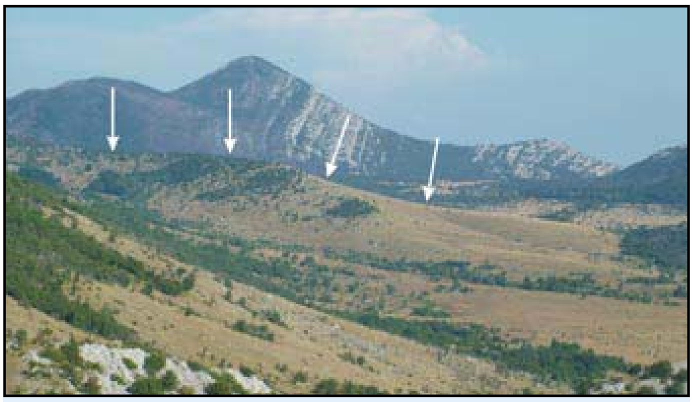


Fig. 16: Medial moraine of Veliko Rujno, view towards SE.

The Veliko Rujno moraine is located between 830 and 950 m a.s.l. and was interpreted as a terminal moraine ridge by Nikler (1973), Belij (1985) and Perica (1993). However, it shows all characteristics of a medial moraine, and was obviously formed by junction of two large valley glaciers; the one interpreted by Nikler and Belij as deriving from the north, and the one which came from the Velika Paklenica Canyon direction. Thus formed composite glacial tongue proceeded further downslope towards lower altitudes leaving behind an extensive lag of coarse debris which was later resedimented and sorted by meltwaters.

The Rujno moraine was attributed to the Würm glacial by Nikler (1973), and that attribution was adopted also by subsequent researchers (e.g. Belij 1985).

Velika Paklenica moraines occur almost in the whole length of the canyon. They change by composition from proximal to distal part of the canyon depending on the source area where the ice was coming from. This regards the various lithologies of Permian, Triassic or Jurassic age which were eroded by advancing ice and meltwaters during the ice retreat. Thus, the moraine in the proximal canyon is a typical diamictite, matrix-supported with high clay content derived from Lower Triassic clastics. Towards the canyon mouth diamictites become predominantly carbonate in composition with little matrix, or become openwork conglomerates due to washing of fine-grained matrix. Clasts of Lower Triassic rocks become very rare because they are softer and easily weathered during transport. The limestones and dolomites of Jurassic age predominate and their clasts are much larger, commonly rounded boulders over 1 m in diameter. Sediments are more-or-less cemented. Distally downstream moraine is commonly reworked, redeposited and sorted so it becomes clearly bedded. In several places an alternation of diamictites with boulders and intervals of reworked moraine are visible, which probably represents several phases of ice advance and retreat. An excellent section of the road cut shows such two intervals, glaciofluvial conglomerate beneath unsorted diamictite with large rounded boulders interpreted as basal moraine. A sediment wedge in the glaciofluvial conglomerate was recognized and interpreted as a possible ice wedge filled with coarse debris during ice advance.

The most impressive remnant of a terminal moraine in the Velika Paklenica Canyon is located in Anića Luka (Fig. 17). It probably represents a remnant of last major glaciation which affected the Velebit area. This one is composed of cobbles and boulders 1 to over 20 m in diameter which are incased in well-cemented gravel- to arenite-size matrix. The boulders and cobbles are subrounded to rounded, commonly spherical to oval, extremely poorly sorted. The moraine itself has been partly destroyed, probably by catastrophic failure of this natural dam. Water percolating through the dam washed out the fine-grained matrix and weakened the dam, which probably failed under pressure of increasing inflow of meltwater, and its enhanced percolation through increasingly more permeable barrier. Washed-out fines and gravels were transported by streams and accumulated in alluvial fans in front of the Paklenica canyon, today the area of Starigrad, whereas catastrophic dam failure caused almost instantaneous erosion of canyon-fill sediments by the released flash-flood. This erosional event was in many respects similar to jökulhlaup known form Island and other glaciated areas.

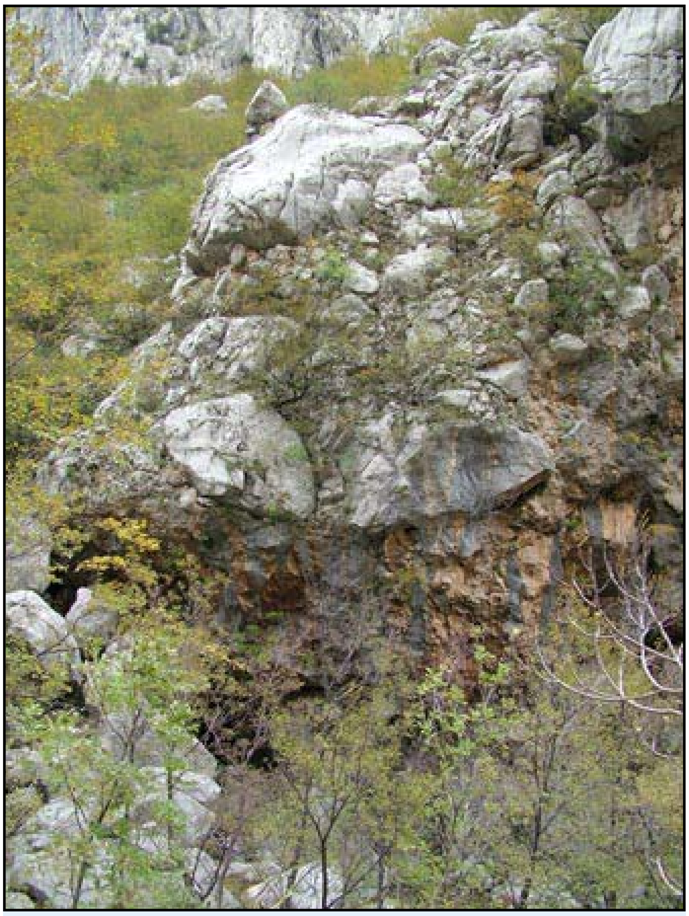


Fig. 17: Anića Luka moraine. Large blocks are ca. 10-20 m across.

Velika Paklenica glacio-fluvial conglomerates occur in Anića Luka and close to the end of canyon. They are reworked moraines and therefore sorting is much better. Horizontal bedding is clear and even planar cross bedding is visible in some places. They represent the ice-melting phase, probably during an interstadial.

In the scope of world initiative to recognize and protect the Earths' glacial heritage, the area of the National Park Velika Paklenica represents one of the key zones in Croatia for understanding the glacial history of the Dinaric Alps, and therefore part of the glacial framework for geoconservation.

SELECTED EXAMPLES OF GEOHERITAGE

The Velika Paklenica Canyon hosts several important sections which have great importance for the study of geology of the Dinarides.

1) The Permian/Triassic contact section is currently being studied in search for clues on the associated faunal crisis. The section is located in upper part of the canyon, and out of normal trails, which provides good natural protection, but poor accessibility.

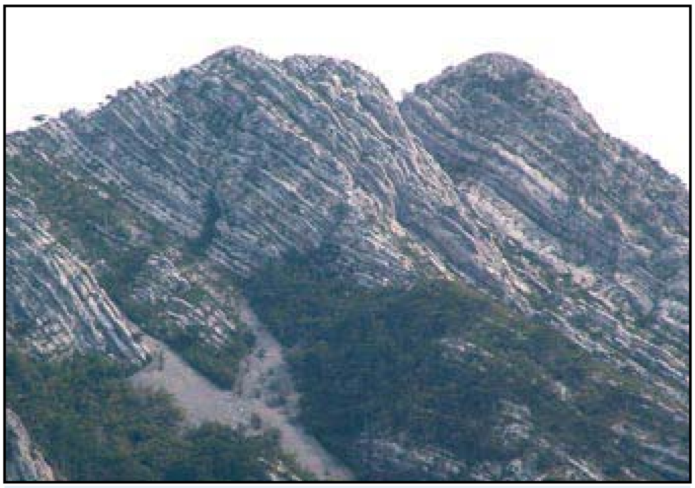


Fig. 18: Jurassic limestones form spectacular bedding, visible from far distance.

2) The Jurassic/Paleogene contact is geomorphologically well expressed. The Jelar Breccia of the presumed Paleogene age overlies rocks of older ages, and the differential weathering makes the contact well visible in the topography. The Jelar Breccia is extensively corroded and hosts some of nicest karst features (best exposed in the Bojinac area, Fig. 19).

3) Spectacular karst features in the Bojinac area, part of the Paklenica National Park; mogote, variety of flute karren, giant kamenitzas (Fig. 19). The area is in a relativelly remote part of the Park, and is visited by a small number of dedicated visitors. Few marked trails are challenging even to experienced mountaineers.

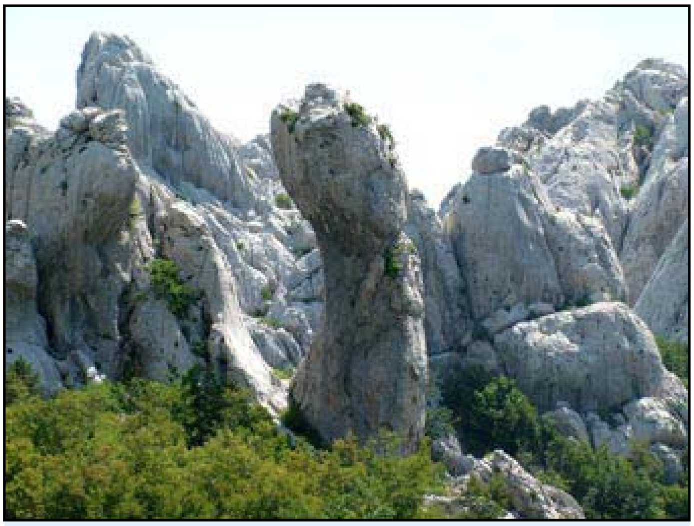


Fig. 19: Weathering of Jelar Breccia produces magnificant landscapes and exotic karst features.

4) Veliko Rujno glacial valley (Fig. 20) is located outside of the National Park, and hosts rebuilt and refurbished shepard houses, which are used by local population for recreational purposes. In 1950-es and before, the valley had about several hundred permanent inhabitants, but today there are no permanent residents. The newly built road makes access easy, and inspired plans to start mountain tourism. Unfortunately, the vegetation in the valley was partly devastated by several forest fires in the past few years.

Fig. 20: Veliko Rujno glacial valley, view towards NW.

5) Pleistocene glacial and glaciofluvial clastics form several spectacular outcrops in the Canyon. These are located along the canyon road and the mountain trails and document a complex geological history, which is important for understanding of Earth climate changes during the last one million years. Detailed study of Pleistocene deposits by the University of Zagreb team is still in progress, but already provided several significant discoveries. The outcrops are large and easily accessible. They are subjected to small or negligible threat, since the Park administration does not plan to undertake any construction works which would endanger them.

STOPS

1

LOCATION: Entrance to the Velika Paklenica Canyon, 25 m a.s.l.
STOP TYPE: Scenic stop
TOPICS: Geomorphology and culture of the area.

Note also traditional architecture in Marasović Village. Concrete rounded roofs, once prevailing in the area, are today preserved only on old buildings and water mills in Paklenica. The National Park administration supports restoration of old abandoned houses to preserve the traditional architecture (Fig. 21).

The Pleistocene-age sediments are cemented glaciofluvial coarse conglomerates. The debris was provided by glacial erosion at the head of the canyon, and transported by glacial melt-water which also provided matrix and cement. The provenance of debris is documented by clasts of Permian age siltstones and Lower Triassic micaceous sandstones.

Fig. 21: Refurbished old water mill.

2

LOCATION: Canyon road-cut, 50 m a.s.l., ca. 0,7 km from the entrance
STOP TYPE: Observation stop
TOPICS: Glacial and glaciofluvial sediments.

The section shows glaciofluvial conglomerates below, and basal-moraine diamictite with large boulders above (Fig. 22). However, the glaciofluvial conglomerates are also underlain by older basal moraine, visible below the road, in the brook. Thus the section documents two ice-advance episodes. separated by an ice-retreat episode. The ice-advance episodes climatically correspond to stadials, whereas ice-retreat episode corresponds to an interstadial. The exact age is at the present stage of knowledge unknown, and we suspect it belongs to Mindel or Riss glacial.

The glaciofluvial sediments were formed by meltwaters which washed the matrix of diamictes along with pebbles which suffered sorting and rounding during the transport. The end of glaciofluvial episode was characterized by significant temperature fall which froze the soil, creating a permafrost. The frozen soil locally cracked, and ice-wedges were formed, whose casts were later filled by coarse debris during the next ice-advance episode.

Fig. 23. Ice-wedge cast infill.

Fig. 22: Glaciofluvial (below) and glacial sediments (above) in a sharp contact. Glaciofluvial deposits are cut by small glatiotectonic faults, formed by stress of overriding glacier tongue.

Fig. 24: Mid-part of the Velika Paklenica Canyon, view downstream.

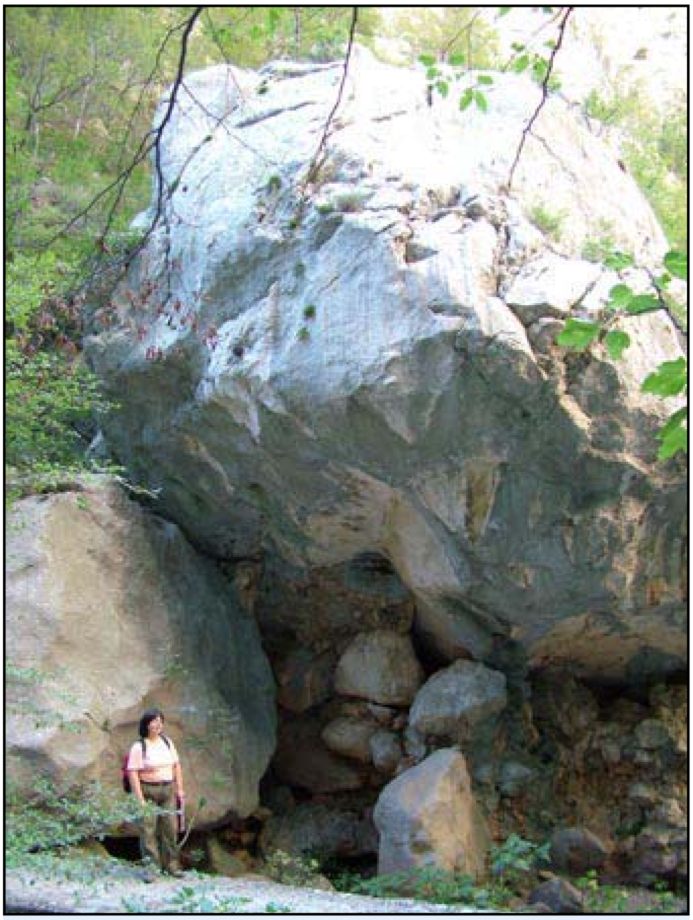


Fig. 25: Anića Luka moraine, extremely poor sorting of debirs.

3

LOCATION: Anića Luka, 340 m a.s.l., 2,7 km from the entrance
STOP TYPE: Observation stop
TOPICS: Glacial sediments, geomorphology.

The large outcrop shows a wide range of clasts in this moraine. The size of clasts ranges from several centimetres to more than 20 m across (Figs. 17 and 25). Some clasts were karstified prior to their mobilisation which is documented by remnants of strongly eroded and rounded flutes which are rotated from their primary position.

The moraine and ice probably completely clogged the canyon, forming a barrier which dammed the meltwater during one ice-retreat episode, forming a proglacial lake. Eventually, the dam was breached and the lake water catastrophically flushed down the sediment-filled canyon. This catastrophic outflow eroded a large part of the canyon-fill and formed the present shape of the canyon. The evidence of this catastrophic outflow are large boulders which lie scattered along the canyon floor, unrelated to nearby sediments.

STARIGRAD - RAB

The journey will follow Adriatic coastal road, very scenic, with a lot of curves! At the place Jablanac it will take a ferry to cross the Velebit Channel.

Crossing the channel takes only 15 minutes, but provides excellent view of the Velebit Mt. as well as the Rab Island northern coast, which is very steep. The sea in this part of the Velebit Channel reaches depth of 110 m, which is much deeper than the northern Adriatic offshore.

Fig. 26: Ferryboat route from Jablanac to Rab.

Fig. 27: Velebit Channel is connected with the mainland by ferryboat line which is operated by the local ferryboat company Rapska Plovidba.

Fig. 28: North side of the Rab Island is tectonically-controlled steep slope

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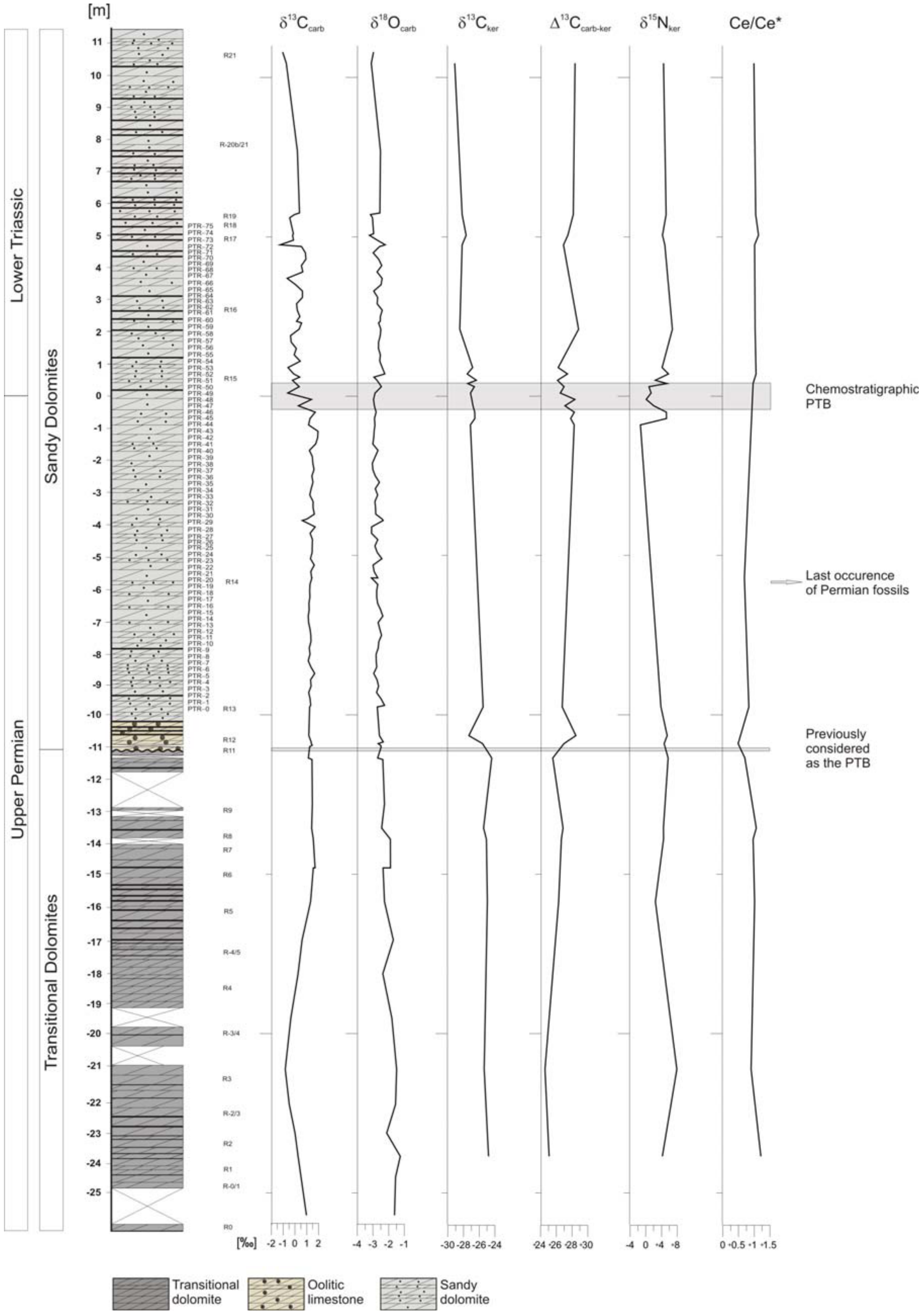
Redefinition of the Permian−Triassic Boundary in Velebit Mt., Croatia

Karmen Fio

The Permian–Triassic boundary (PTB), 251.4±0.3 Ma ago (Bowring et al., 1998), marked by the most extreme mass extinction in the Earth's history, is one of the most intriguing geological events. Many different hypotheses have been suggested to explain this environmental crisis, but synergistic combination of different events is still considered to be the most plausible cause (Erwin, 2006).

Two sections with continuous sedimentation across the Permian–Triassic transition have been located in the Velebit Mt. area, SW Croatia, Rizvanuša and Brezimenjača section. The uppermost Permian sediments are known as the Transitional dolomite. Overlying the Transitional dolomite is the Sandy dolomite rich in terrigenous material which was generally attributed to the Lower Triassic (Salopek, 1948), although they commonly lack any fossils in their lower part. The lithostratigraphic boundary between Transitional and Sandy dolomite characterized by depositional break caused by regional emergence used to be considered as the Permian–Triassic boundary (Sokač et al., 1974, 1976).

Geochemical approach used to set the chemostratigraphic P−Tr boundary includes stable isotope of carbonates ($\delta^{13}C_{carb}$, $\delta^{18}O_{carb}$) and associated organic matter ($\delta^{13}C_{ker}$, $\delta^{15}N_{ker}$), carbonate trace elements, and biomarker analyses, which were performed at the Institute of Mineralogy and Geochemistry of the University of Lausanne. Two stress events have been recognized in studied sections. Pronounced enrichment in REE concentrations, negative Ce anomaly, negative shift in $\delta^{13}C_{ker}$ values and disappearance of microfossils coincide with the occurrence of ooids, marking the first stress event, most probably the Late Permian regression. Regressive phases were common in the latest Permian (Sremac, 2005), causing the decrease in biodiversity and the appearance of opportunistic taxa. Findings of the Permian fauna 5 m above the lithologic boundary in the Rizvanuša section have indicated that the oldest part of the *Sandy dolomite* is definitely still Permian. A pronounced negative shift in $\delta^{13}C_{carb}$ 6 m above the last Permian fossils, i.e. 11 m above the lithological boundary, and a second fossil disappearance within a single *Sandy dolomite* bed, marks the second stress event and the position of the chemostratigraphic PTB in the Rizvanuša section. In the Brezimenjača section chemostratigraphic PTB lies 0.2 m above the lithological boundary. The $\delta^{15}N_{ker}$ values show a preferential marine influence during the Late Permian (~7‰) before the regression phase, and enhanced terrestrial influence towards the PTB with presence of cyanobacteria (−2 to +4‰), which seems to be the only surviving taxa (Fio et al., 2006 a, b).



Schematic geological column of the Rizvanuša section, Velebit Mt. showing sampling positions, results of stable isotope analysis and Ce-anomaly. Note difference between lithological boundary (previously considered to represent PTB) and chemostratigraphic PTB; also note position of the last Permian fossils.

Biomarker analyses of long chained *n*-alkanes (C_{17}–C_{31}, max. C_{26}), with even/odd predominance show presence of the freshwater green microalga *Botryococcus braunii*, and indicate lagoonal-type environment. Prystane and phytane, derived from chlorophyll, are present in most samples showing the presence of algae and cyanobacteria. The distribution of *n*-alkylcyclohexanes (C_{17}–C_{24}, max. C_{21}) with even/odd predominance indicate a bacterial biomass contribution. Hopanes, the prokaryota biomarkers, have been identified in almost all samples (C_{29} to C_{32}), while steranes, biomarkers of eukaryotic organisms, have been found mostly in small abundances, usually maximizing at ste-C_{27}, indicating marine input (Fio et al., 2007, 2008).

New biogeochemical data have redefined the position of the Permian–Triassic boundary in the Velebit Mt., Croatia, previously positioned at the lithological boundary between *Transitional* and *Sandy dolomite*. At studied sections lithological boundary represents a consequence of the Late Permian regression, and it does not coincide with the PTB. However, in other areas characterized by longer emergence, transgression might have happened later, in Early Triassic, and lithological boundary might represent a boundary between the Permian and the Triassic with a certain stratigraphic hiatus.

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JABLANAC

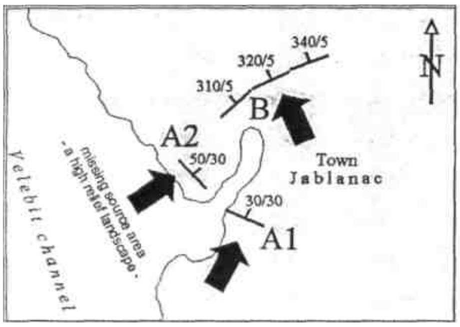
Ljerka Marjanac & Tihomir Marjanac

Source: Quaternary clastics of the Jablanac cove in the foothills of the Velebit Mt., reprint from Field-Trip Guide Book, IAS Lecture Tour 99.

The area of Jablanac cove and its hinterland are primarily built of limestones and carbonate breccias of the Palaeogene-Neogene age (Mamužić et al. 1969). Locally, thick-bedded Cretaceous limestones crop out in erosional windows. Quaternary deposits follow with an angular unconformity. Koch (1929) described them as "older diluvial deposits" (meaning older Pleistocene). Besides clasts of what he called Promina-conglomerates (today Jelar - Breccia), he has also found bone fragments of land mammals. These Quaternary deposits have not been further studied until recently. There were no fossils found in them later, so the stratigraphic age is still assumed to be older Pleistocene.

Quaternary clastics of Jablanac are represented by the colluvium - a slope talus deposits as the older, and alluvial fan deposits as the younger succession (sensu Nemec & Kazanci 1999, Blikra & Nemec 1998). They have been deposited in a closed circular valley which was

later opened to the sea by erosion and postdepositional tectonics. They are well exposed at three locations: older sections at the ferry dock (Al) and the hotel site (A2), and younger section below the church plateau (B).

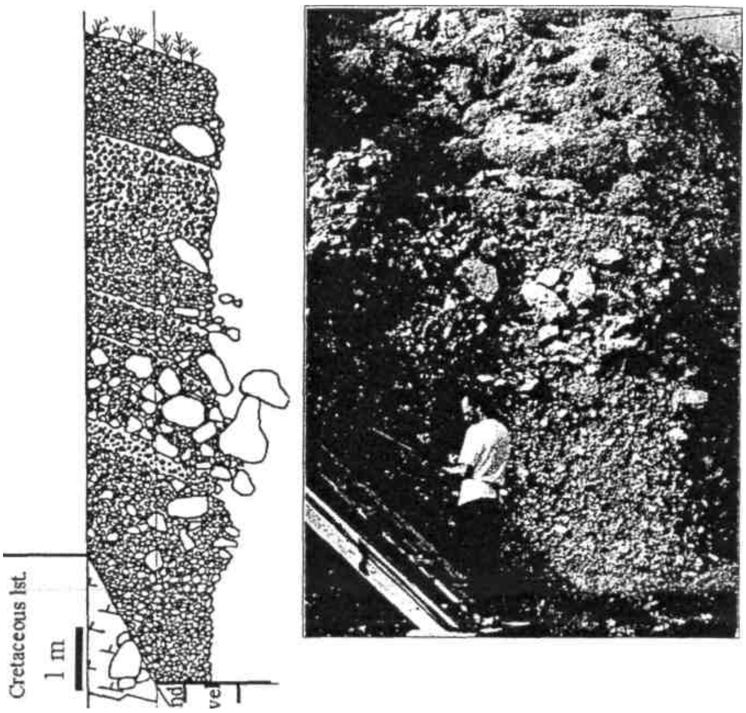


Location of outcrops. Black arrows show paleotransport.

These outcrops are the erosional remains of deposits which once filled the whole valley. Relation between the older and the younger sections is not clear although it seams they are in a succession. The total visible thickness is about 30 m. Quaternary elastics overlie paleo relief with steep slopes, 40-60°, developed in calcareous Jelar - Breccias and Cretaceous limestones.

Location AI. Colluvial debrisflow deposits.

The colluvium sediments are exposed in sections AI and A2 where bedding dip is around 30°. Deposits are over 10 m thick, composed of mainly clast-supported, open-work breccias, rarely matrix- supported. Beds are 30 cm to more than 1 m thick, and their lower bedding plane is locally erosive. The average grain size ranges from 2 to 4 cm, whereas the largest clasts are 30-100 cm in diameter. Clasts are angular to subrounded, but the most of them are subangular. Clast-supported breccias range from poorly sorted to well-sorted.



Location A2. Debrisflow deposits: matrix-supported breccia below and clast-supported breccia above. The sediment log on the left shows contact with the base rock.

They are normally graded, but exceptionally also inverse graded. The well-sorted breccias are commonly cemented. Matrix-supported breccias are medium-sorted and have less than 20% red soil as matrix. Red soil is also infiltrated in some open-work breccia beds.

Colluvium was deposited by high-viscosity debrisflows as indicated by presence of matrix in some beds, and low-viscosity debrisflows that produced open-work and normally graded beds. The inverse graded, open-work beds were deposited by grainflows. Large block observed in section A2 temporarily deposited by a rockfall.

The alluvial fan deposits are exposed in section B (Fig. 4) where bedding is almost horizontal. They are over 12 m thick, composed of clast-supported to matrix-supported gravel to pebble beds that reach thickness of 30-100 cm. Beds are normally graded, but exceptionally also inversely graded. Their lower bedding plane is commonly erosive, so each bed is at least partly eroded by the younger one. Planar cross stratification is locally recognizable and marked by sorting of coarser debris, documenting deposition by waterflows.

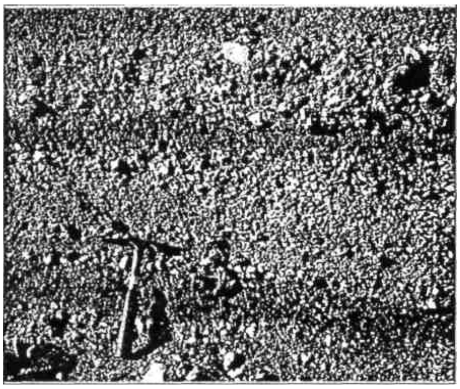
Location B. Younger alluvial gravel and pebble deposits.

Limestone clasts are subrounded to well rounded. The average clast size is between 6-8 cm in gravely beds, and between 9-11 cm in pebbly beds. The maximum clast size varies between 10 and 20 cm, although there are intervals with large blocks up to 60 cm in diameter. Imbrication, where developed, shows transport towards the centre of the valley. There are several matrix-supported gravel beds which are very similar to the described slope talus breccias with red soil matrix.

Alluvial gravel to pebble deposits accumulated by debrisflows, episodically grainflows shown by characteristic inverse grading in gravel beds, and waterflow - stratified sandy-gravel beds. Within alluvial deposits there are two red soil horizons about 10 cm thick, divided by inverse graded gravel beds. The soil horizons indicate periods of warm and arid climate.

In the soil rich interval there are thin layers of gravel or pebbles.

As indicated by imbrication of platy clasts the transport direction was from southwest and southeast towards the centre of the valley. Higher percentage of rounded clasts indicates longer transport from a further source area, while in the older colluvum angular debris is of local origin.



Red soil horizons in alluvial succession at location B. An inverse graded, open-work gravel bed in the middle is a grainflow deposit.

Similar Quaternary deposits are located on the Rab island in the Misnjak cove, but with opposite transport direction - that is from the northeast. Based on these transport directions we assume that the source area (the land with high relief) must have existed in the place of todays Velebit channel. The apex zone of colluvial or alluvial fan is not known due to erosionand possibly tectonical dislocation. We can not say if there was a single or several colluvial fans/aprons developing. At least one had its apex in the "missing zone". It is not easy to conclude on such strong tectonical movements which could destroy a mountain range and open the Velebit channel in its place, although this is indicated by the studied sediments. It is obvious that erosional processes opened the Jablanac cove and eroded the majority of Quaternary. This questionable relation of tectonics and sedimentation in the Jablanac area is still the subject of our exploration.

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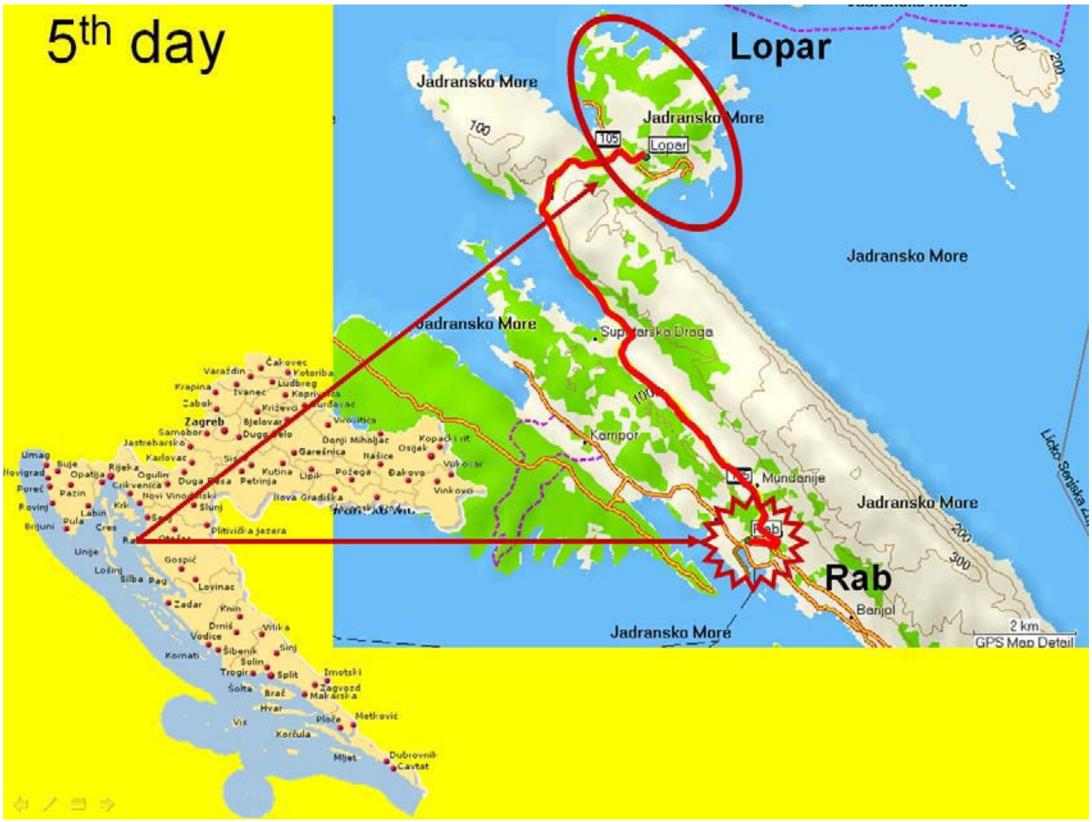
8. DAY 5

Island of Rab



Source:
Marjanac, T. & Marjanac, Lj. (2008): Geoheritage of Premužić-1 Trail, Island of Rab. 5th International ProGEO Symposium on Conservation of the Geological Heritage and ProGEO Working Group I Annual Meeting GUIDEBOOK, 1st – 5th October 2008, Rab Island, Croatia, 79–94. Zagreb, September 2008.

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EXCURSION 4A
Rab

Geoheritage of Premužić-1 Trail, Island of Rab

LEADERS:
Tihomir Marjanac & Ljerka Marjanac

EXCURSION ON THE RAB ISLAND, AN INTRODUCTION

Welcome to the Rab Island excursion! This guide will provide basic information about the island, its natural and cultural heritage, and it's up to you to discover its hidden pearls and enjoy them.

The island is rather small, and with 86 km^2, stands at the 9th place among the eastern Adriatic islands. It is one of Kvarner Bay islands, and is culturally and historically connected with the Republic of San Marino, since its founder St. Marin was a decedent from Rab.

The Rab Island has a permanent population of ca. 10.000 inhabitants, which more than doubles during the summer season. Tourism is, naturally, their main source of income. Virtually all activities on the island are in one way or another connected with tourism, being it construction business, trade, ship building, or transportation. Before the tourist boom in early 1970-es, food production was significant and could sustain the local community, though not in luxury. The food production today is minor, though expanding again, and encompasses fishing, sheep breeding, production of grapes, olives, cheese and honey. Vegetables are cultivated only for domestic consumption, as well as fruit. The Rab Island traditions and crafts are still preserved by local population who present them at the local summer festivities.

TRADITIONAL RURAL ARCHITECTURE

Traditional rural architecture is widely abandoned, and its remains can be seen on hill slopes overlooking Barbat, Banjol, and Supetarska Draga settlements. These are represented by cluster of houses attached to each other in a linear fashion, generally with storage room and kitchen on the ground floor, and sleeping rooms upstairs. The houses are usually narrow, and their cluster keeps together all members of a family, so the settlement bears the family name. This small settlements were built on steep hill slopes to save the precious agricultural land, but also to get protection from cold northerly bura wind. The water was traditionally provided from numerous springs or wells.

Fig. 1: Traditional family houses, "dvor".

During the Roman times, the island was inhabited by several rich families, as documented by remains of several villa rustica, monuments and historical data. We hope the Rab city will manage to build a museum so that the archaeological findings and heritage will be available to the public view. The Rab Island was apparently on a significant Roman trade route, and its coastal waters hide remains of several ship wrecks. The one at 40 m depth off the Sorinj Peninsula is today protected by a steel net and preserved for scuba-diving tourists as well as future research.

Fig. 2: Wreck of a Roman ship near the Sorinj Peninsula is still full of amphors and possibly the whole ship is buried under the sand.

WALKING TRAILS ON THE ISLAND

Today, there is about 100 km of marked walking trails on the island, in addition to a vast network of trails for cyclists. The walking trails are marked by standard red and white marks, and maintained by the Kamenjak mountaineering club of Rab. Several educational trails are designed to provide basic information about the flora, and cultural heritage.

The tradition in trail building on the island stems from the old ages when the population lived and worked all over the land and built a complex network of trails, commonly fenced by stone walls which were protecting the soil from denudation and secured pasture land for their live stock (usually sheep and goats). Most of these trails are today abandoned, being too narrow for cars and tractors.

In early 20th century the well-known Croatian forester Ante Premužić (1889-1979) built walking trail along the Velebit Mt., which was completed in 1933. In the same year he started construction of the walking trails on the Rab Island, which are unfortunately only partly completed in length of 15 km. These trails are in his honour called the "Premužić-trails", and two segments are preserved on Rab; the trail from the 13th century St. Peter church over the Kamenjak ridge to San Marino tourist complex in Lopar, and the trail from the heart of the Kalifront forest to the coast through the protected Dundo forest. These two Premužić-trails are also routes of the first two geotrails on the island.

Fig. 3: The Premužić Trail is well built and crosses very attractive parts of the island.

The geotrails are designed to follow the existing trails, preferentially those which are already marked and labelled on the tourist and mountaineering maps. These trails are already being visited by dozens of tourists every day, particularly those who prefer quiet atmosphere, exotic smells of Mediterranean vegetation, and deep shadows of century-old oak forest.

HISTORY

The earliest artifacts discovered on the Island of Rab date back to the Palaeolithic age. Hundreds of stone tools of Palaeolithic, Mesolithic and Neolithic age were found on the Lopar Peninsula, but also in wider Rab city area, in addition to Bronze and Iron age findings in vicinity of Lopar and Kampor settlements. However, most of the island still awaits thorough archaeological excavations.

Rab was first mentioned by a Greek geographer who wrote about Mertorides - the islands of Rab and Pag - in 360

Fig. 4: Artefacts from Rab, photo archive of Istitute of Quaternary Paleontology and Geology Croatian Academy of Sciences and Arts

BC, although in its old form "Arba". It is thought that Rab's old name "Arba" originated from the Illyrian word "arb", which means dark/green/wooded, but it may well be of Roman origin since "arbor" means "wood" in Latin. Whatever the origin of the name root, the name "Rab" (presumably derived from "Arba") was first mentioned in the 15th century.

From the 9th to the 1st century BC the island was inhabited by Illyrian tribe Liburnis, the Indo-European people who migrated to the region around 1.200 BC. With later expansion and, consequently, division of the Roman Empire, Rab fell under the Roman rule in the 2nd century BC., and became a part of the Western Roman Empire. Under the Emperor Augustus (Gaius Julius Caesar Octavianus, 63 BC-14 AD) the city of Arba prospered as a Roman municipium, with its own governmental and cultural institutions. It was honoured with the name Felix Arba; "Felix" indicating a special, high status in the Empire, shared in Dalmatia only with Salona.

Despite the fall of the Western Roman Empire in 476 AD, Rab remained under the Roman rule until 493, when the Eastern Goths took over, but it continued to prosper as it did before. In the first half of the 6th century the island fell under the jurisdiction of the Byzantine Empire, which left a strong imprint in Rab's architecture. At that time Rab became an autonomous district and was organized and functioned like former municipium.

Very little is known about subsequent Slavic or other colonizations of the Rab island. There seem to be no Slavic toponyms, and only some documents from the 11th century confirm that the Croats arrived on the island (probably already in 7th century), built settlements and reached high positions in the city government.

Over the time, after the proclamation of the Croatian Kingdom in 925, the autonomous towns in the region slowly became integrated into Croatia, falling under the domination of the Roman Pope, as opposed to the Byzantine patriarch. After several more political changes, Venice entered the scene in 1115 and remained the ruler of Rab until 1797, except for the short period in the 14th century. At the end of the 14th century the island had as many as 10.000 inhabitants, with half of that number in the city of Rab only. The plague of 1449 and 1456 caused severe depopulation of the island, so the population number stagnated until the beginning of the 20th century.

After being a part of Napoleon's Illyrian Province for less than a decade, in the early 1800-es, Rab became a part of the Austrian-Hungarian Empire. The island of Rab was occupied by Italy in 1919, and after the Treaty of Rapallo, signed in 1921, it became a part of the Croatian territory. During the WW II the island of Rab was under Italian occupation from 1941 until 1943. In that period, infamous Kampor concentration camp was established on the island, which claimed 4.641 lives. From September 1943 until March 1944 Rab was a free territory, to be occupied by German forces in 1944 which held it until 1945.

With the relative political stabilization in the 20th century, the island of Rab relied on tourism as the main economic resource based on its diverse natural, historical and cultural heritage, reaching impressive 120 years of tourist tradition, being one of the most popular tourist destinations in the Adriatic.

FLORA AND FAUNA

The island of Rab is located in the northern part of the eastern-Adriatic zone of evergreen vegetation, whereas the neighboring island of Krk, to the north of Rab, is already in the deciduous zone. The dominant forest species is the holm oak (Quercus ilex), and Rab has some of the most beautiful holm-oak forests in the Mediterranean, the Dundo forest, a special protected forest reserve in the central part of Kalifront peninsula, in particular. The other most frequent species in the evergreen holm-oak forests of Rab are the phillyria (*Phillyrea latifolia*), laurustinus (*Viburnum tinus*), strawberry tree (*Arbutus unedo*), myrtle (*Myrtus communis*), tree heath (*Erica arborea*), juniper (*Juniperus oxycedrus*), wild olive (*Olea europaes*) and many other rare species.

However, these forests also have some deciduous species, such as the flowering ash (*Fraxinus ornus*), downy oak (*Quercus pubescens*), service tree (*Sorbus domestica*) and in Dundo wood about one hundred cork trees, truly rare on the Adriatic. Of deciduous shrubs we find the *Coronilla emeroides*, blackberry, hawthorn, thorn-bushes, common privet, *Prunes spinosa* and *Prunes mahaleb*.

The most important climbing plants are the thorny smilax (*Smilax aspera*), ivy (*Hedera helix*), asparagus (*Asperagus acutifolius*), sweet honeysuckle (*Lonicera implexa*) and some others. Most of the evergreen forests grow on the island hills and cover the whole of the Kalifront Peninsula, the hills between Kamporska Draga and Supetarska Draga, a part of Lopar, Fruga valley and some small parts of the Kamenjak hill. The Rab Island hosts also communities of endemic species, like the Croatian birthwort (*Aristolochia croatica*), Croatian marguerite (*Leucanthemum croaticum*), Dalmatian knapweed (*Centaurea dalmatica*), Istrian bellflower (*Campanula istriatica*) and Kvarner hart's-tongee (*Phyllitis hybrids*).

The town park Komrčar is dominated by the Aleppo pine (Pinus halepensis), and other predominantly Mediterranean trees and shrubs. This park was designed by Rab's senior forester Pravdoje Belia (1853-1923) who turned a city pasture land into one of the most beautiful parks in the Adriatic, and initiated artificial forestation of Rab..

The largest indigenous mammal on Rab is the hare, whereas all larger animals like deer and muflons, and in recent times jackal, are imported. There are many more rabbits than hares on the island, and their number seems not to be affected by tourism. The stone marten is also an indigenous carnivore.

The most numerous reptiles are lizards, amongst of which stands out rare Balkan green lizard (*Lacerta viridis*). The island is also a home of the European grass snake and Aesculapian snake, but there are no poisonous snakes on the island.

Some 161 species of birds live permanently or seasonally on the Rab Island. About 40 bird species are nesting on the island, including shag (*Phalacrocorax aristotelis*), kestrel, pheasant, plover (*Charadrius dubius*), herring gull, common tern, rock pigeon, collared dove, turtle dove, European cuckoo, little owl, plain swift, small nightingale, jackdaw, crow, raven short-toad eagle, sparrowhawk, buzzard, owl, nightjar, and some others. The Rab Island seems to be a home of the

Fig. 5: Balkan green lizard, "zelembać".

Fig. 6: The lagrest bird on the island in graceous flight.

largest bird in the Adriatic, the griffon vulture (*Gyps fulvas*), which can be frequently observed to circle above the Kamenjak hill cliffs. Rab is also very important stopover for migratory birds, especially marsh birds.

BRIEF HISTORY OF RAB TOURISM

The first indication of some primitive sort of tourism on the island is recorded by Venician traveler Alberto Fortis already in 1774, who reported that the inhabitants of Rab preferred to sell their products to visitors than to export them to Venice. Most of the 19th century writers also mention well-arranged accommodation facilities like inns, coffee-houses, and lodgings.

The year 1889 is very important for tourism on the Rab Island. In that year, professor Schrotter, a doctor and balneologist from Vienna, and professor Frischauf of Graz arrived on Rab with the written proposal about how to intensify tourist development, and provided comprehensive arguments for all the advantages Rab had. They included many proposals for the arrangement and construction of hotels, roads and parks and establishing necessary better connections with Rijeka, Zadar, Lošinj and Pula. The Municipal Council discussed the proposal in May of 1889 and accepted the suggestions. We can assume that this was crucial for the further development of tourism on Rab, because soon new facilities began to be built, and in 1895 the Society for a More Beautiful Town and Surroundings was founded. The goal of this society was to make the town more beautiful, to build and arrange beaches, as well as accommodation and catering facilities with their own assets collected through membership fees, contributions and from other sources, or to stimulate others interested in investments.

The first hotel in the Rab city was opened soon afterwards, in 1895, and was followed by opening of other new hotels in 1908 and 1909. In 1912 the Association of Bank Clerks opened a sanatorium for its members, whose building today serves as a therapeutic facility of the Zagreb Clinic.

The oldest visitors' book dates from 1910, from which we can get impression of the number of guests on Rab. It is recorded that in 1914 6.000 tourists visited Rab, which number approached the whole population of the island. The cinema was open in 1913.

The wars always interrupted the tourism, so it ceased during the WW I and WW II, as well as 1991-1995 Croatian Independence War.

The island of Rab is generally considered the forerunner of naturism on the Adriatic. It officially started in August of 1936 and the visit of the King Edward VIII of England who was allowed by the Rab authorities to bathe nude on the Kalifront Peninsula beach. In practice, however, naturism on Rab begun already at the turn of the century, as mentioned in contemporary Czech and Austrian magazines.

The new tourist boom begun on the Island of Rab in the years following the WW II, and it quickly expanded to other communities on the island, incorporating the hotels built by the Imperial Rab-owned hotel company and many private apartment houses. Nautical tourism is in expansion since 1984 and it is met by construction of marinas and dry marinas.

As tourist capacities grew, so did the number of tourists. Today, most tourists visit Rab in the summer season, but when the tourism started, Rab was a winter tourist resort owing to its mild winter climate. The basic advantages of winter, autumn and spring holidays are the temperate climate, clean air and a lot of sun.

The tourist offer is completed by many excursions on sea and land, organized by tourist agencies. Besides organized tours around the cultural and historical sights of the city of Rab, very popular are the boat trips around the island, panoramic trips, fishing, picnics, night trips, excursions to the islands of Goli, St. Grgur, Lošinj, Pag, to the Zavratnica Cove in Jablanac, Plitvice Lakes, etc. Many excursions are also organized to Rab from other tourist resorts of the Kvarner Riviera, and Adriatic cruises always visit Rab.

HISTORY OF THE GEOPARK PROJECT

The scientific research on the Rab Island started already in 18th century, but was not continuous. The first report on Rab geology, though in a sketchy way, was provided by Alberto Fortis in 1774 (Bratulić 1984). Although several geologists worked on the island (Radimsky 1880, Schubert 1905, Poljak 1933), there seems to be no continuity. The first comprehensive accounts on the Rab Island geology were provided by Mamužić (1962) and Muldini-Mamužić (1962). The geology of Rab and neighbouring islands Goli, Grgur and Dolin was presented on the Rab sheet of the General geological map of SFR Yugoslavia in scale 1:100.000, and the accompanying explanation notes (Mamužić et al. 1969, Mamužić & Milan 1973).

The Rab island became our research target in 1986 when the Eocene clastics were studied for correlation with offshore boreholes. As sedimentology of these clastics was getting better known, it become clear that they greatly differ from the Adriatic flysch, what was their previous attribution (Marinčić 1981).

In 1995 we started the study of sequence stratigraphy of the Rab Island Eocene clastics by detailed logging, outcrop mapping and facies mapping. The results are summarised in several guidebooks (Marjanac & Marjanac 1997, 1999, 2004) and in a recent paper (Marjanac & Marjanac 2007).

High quality of outcrops inspired us to organize sequence stratigraphic workshops which were held in 1997 and 1998 for petroleum geology specialists, as well as field courses in Sedimentology and Basin analysis for the University of Zagreb students.

Good outcrops, good accessibility, preserved nature and cultural heritage inspired us to propose the Geopark project to the Rab Island municipality, already in 2003. The project was accepted, and its realisation started in 2004.

The Geopark project has several phases, some of which are already completed, some still in progress. The project involves:

1) documentation of the island geoheritage
2) selection of appropriate geo-stops

3) preparation of information plates to be placed in the field
4) preparation of information leaflets and a guidebook
5) preparation of application package for the European Geopark Network

The field reconnaissance soon showed that in spite of all previous research, additional studies will be necessary to fulfill our goals, and that the time frame allocated will not be sufficient. The work plan was adjusted to the financial constrains and the work progresses steadily.

The Geopark project envisages organisation of 4 geogardens and 9 geotrails with ca. 100 geostops, with possibilities for expansion as new trails will be designed in the future.

Fig. 7: The entrance to the Premužićeva Trail 1, at San Marino hotels resort in Lopar. This is intended to be a meeting and discussion-point for visitors of the geotrails.

The tourist community on Rab demanded all information plates and boards to be quadrilingual (in Croatian, English, German and Italian) which put space restrictions to the plate design. Each geotrail is designed to start at an easily accessible point, where the entrance information boards are placed.

The geostops are marked by concrete pillars which hold 35 x 35 cm information plates, or by 40 x 40 cm plates which are fixed directly to the rock wall.

So far 50 km of geotrails are put-up with 50 info-plates, some of which are in use already for more than a year, providing a live test of their resistivity.

In 2008, a City Light display was put up in a trading sub-centre of the Rab city, where it is seen by all locals and many tourists every day. The Lopar community dedicated a stone chalet in the San Marino tourist village for the Geopark info-centre, where we exposed geological maps, samples and fossils from the geotrails, and organized geology students to provide additional information to tourists. The plan is also

Fig. 8: Geostop marked by info-plate mounted on a concrete pillar.

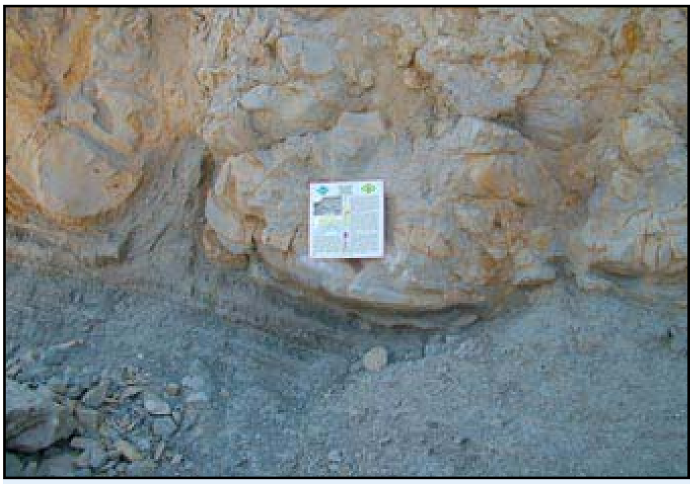


Fig. 9: Geostop marked by info-plate mounted directly on the rock.

Fig. 10: The "CityLight" display in trading centre in Rab. It is probably read by every inhabitant of the city, as well as majority of tourists.

to organize a Geopark info-centre in the old part of the Rab city.

The local community readily accepted the Geopark project in hope that it will provide extension of the tourist season, and enrich the tourist offer on the island.

LEGAL STATUS

The Rab Island is administrated by two municipalities; the Rab and Lopar, respectivelly. Only a small part of the Lopar Peninsula is legally protected as a landscape monument. The Dundo forest on the Kalifront Peninsula is also protected, as well as the Komrčar Rab city park which is protected as a monument of park architecture. The protected landscape of the Lopar Peninsula and Dundo forest are administrated by the "Priroda" public institution with headquarters in the Rijeka city on the mainland which is the County capital.

GEOMORPHOLOGY

The Rab Island is a lobster (or cactus) shaped island, which stretches NW-SE, 22 km in length and 11 km in its widest part. The highest landmark is 408 m high Kamenjak hill (also locally called Tinjaroša).

Fig. 11: The Rab Island in 3D, Google Earth.

The central part of the island is made of carbonate rocks, whereas the Lopar Peninsula as well as central longitudinal valley are built of quartz clastics. The Kalifront Peninsula

Fig. 12: North face of the Rab Island, view from Lopar.

is, however, also made of carbonates, but topographically low and flat.

Geological structure caused the island northern side to be very steep, whike pounding by strong northerly bora wind made it barren of all vegetation. This steep rock slope is cut by only a few very steep couloirs, and is practically inaccessible from the sea. Only one alluvial fan (Njivice) descends from the highest part of the island, but represents a fossil feature of the Pleistocene age.

Corrosion of carbonate rocks created nice karst features, like flutes, kamenitzas, but also ponors (pits, swallow holes) and caves. The Medova Buža cave is the most popular one. Although being partly submerged, and accessible only by scuba-diving, it is being visited by hundreds of tourists every year.

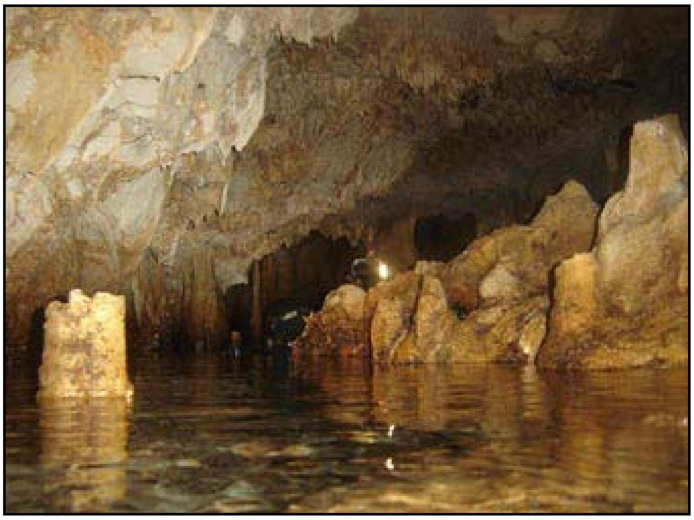


Fig. 13: Partly submerged Medova Buža cave can be accessed by diving or by rapelling through one of its chimneys.

The central, axial part of the Rab Island ridge structure hosts hidden Fruga valley, 2,5 km long and 0,4 km wide, which is filled with Pleistocene paleosols and aeolian sands. The valley sediments are partly eroded, and spectacular trenches are locally preserved. Contrary to the common belief, the age of trenching is not recent, as documented by remains of the Roman road which descends into the trench.

The southwestern slopes of the Rab Island main ridge is much gentler, although locally also very steep. This hill face is transected by several deep gorges and valleys, which document significant water discharge during their formation. Some of these gorges funnel occasional flash-floods which pose great threat to the nearby community.

The Rab Island lowlands are made of Eocene clastics. Resistant cemented sandstone bodies are exposed as linear hills or small ridges. Predominantly marly succession developed the lowest relief which is today occupied by salt marshes, but was utilised for salt harvesting during the Roman times (eg. in Supetarska Draga).

Poor oxygenation and decay of organic matter formed black clays in a part of the Lopar Bay, which was used for balneological purposes until 1980-es, when the melioration works infilled that part of the bay with construction waste and

Fig. 14: The Fruga valley hosts several fresh-water ponds with endemic biocenosis!

Fig.15: Remnants of the old salt pans in Supetarska Draga are still visible in central part of the figure.

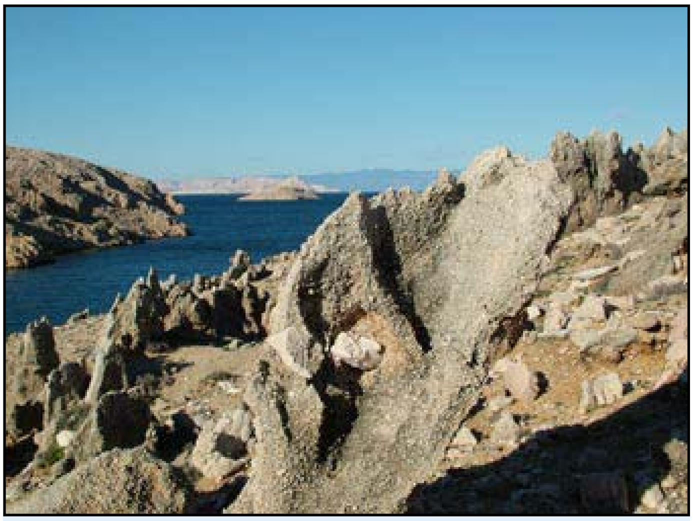


Fig. 16: Weathering of Pleistocene breccia in the Mag Cove.

Fig. 17: Weathering of Plaistocene paleosols on the Lopar Penisula created a "bad-lands" scenery.

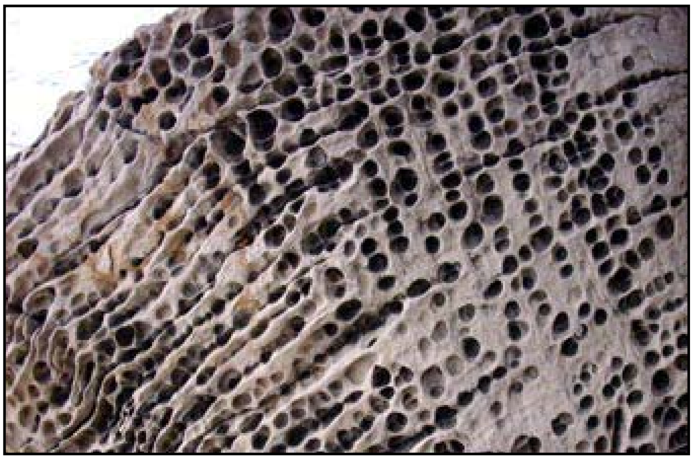


Fig. 18: "Honey-comb" holes in sandstones.

rocks.

Locally preserved Pleistocene fine-grained breccias form extraordinary landscapes, such as in the Mag Cove and along the Barbat coast. Weathering of the Pleistocene paleosols and Holocene aeolian sands created badlands-type landscape on the Lopar Peninsula, which is today protected as a geomorphological monument.

Differential weathering of Eocene sandstones commonly forms honey-comb holes in the exposed sandstones, eg. in the St. Eufemija Cove, and on the Lopar Peninsula.

The vegetated area around the Fruga valley as well as on a large part of the Kalifront Peninsula is covered by “stone forest”; loose well rounded limestone blocks > 1 m across, which were shaped by subsoil corrosion. The subsoil erosion is also responsible for the creation of the “Stonehenge” formation marked on the geotrail Premužićeva-1.

Vegetation cover on the island is very different, giving occasional visitor a false impression of a barren island (viewing from the north and east), or a green island (viewing from the south and west). However, a part of the island was artificially forested. The result is now vegetated Lopar Peninsula, which was practically barren before. However, the forestation destroyed previous desert environments which were unique in the Adriatic.

Modern geomorphological processes include wave action along the coast (waves initiated by storm sirocco wind may reach several metres in height, just as can do bora wind generated waves), aeolian processes of sand-blasting and deposition on the Lopar Peninsula, corrosion and early cementation in karst, and local gravitational transport. Tidal processes are also characteristic, particularly along the low-gradient sea-bottoms in some of the Lopar Peninsula coves, where the water-line may shift landward/seaward for more than 100 m, exposing or submerging large part of the upper shoreface. The Lopar Peninsula coves with sand beaches thus represent a perfect natural laboratory for the study of the beach processes, particularly the processes on tide-dominated coasts. However, periodic strong winds and large waves modify the sedimentation pattern, temporarily creating typical wave-dominated coasts.

Fig. 19: Ebb (low tide) in the Ciganka Cove, Lopar.

Interested reader will find much more data about the island, in four languages, in Stančić (1992).

GEOLOGY

CRETACEOUS

The oldest deposits on the Rab Island are Cenomanian-Turonian limestones with dolomite interbeds (Mamužić & Milan 1973). These comprise grey-brownish-coloured well-bedded limestones and white to yellowish poorly-bedded crystalline limestones. Dolomites occur in the lower part of the succession where they interbed with thin-bedded grey-brownish limestones with rare chondrodont bivalves. The upper part of the succession is dominated by white crystalline limestones with rudists, nerineans and chondrodonts. The fauna indicates stratigraphic range which comprises large part of Cenomanian and smaller part of Turonian.

These Cenomanian-Turonian limestones are normally overlain by light grey, white- and yellowish-coloured rudistid limestones with hippuritids and nerinean gastropods of Turonian-Senonian age span. Near the top of the succession numerous exposure surfaces are marked by sudden change in biota, formation of intraclastic breccias, bird-eye structures, and stromatolites. The sediment colour oscillates between grey, yellowish and red, locally pink, which also indicates oscillations in the sea-level.

Fig. 20: Nerineans on the Premužić 1 geotrail.

Near the top of the Cretaceous succession, reddish-coloured limestones become more frequent indicating significant shallowing as a precursor to the K/T boundary.

The K/T boundary on the Rab Island is marked by small bauxite pockets and accumulations, which were mined in the early 20th century. Cretaceous limestones are karstified and this topography is filled with yellow and red bauxites. Bauxite

Fig. 21: K/T boundary on the Premužićeva 2 Trail. Eocene foraminiferal limestones (left) are in contact with Cretaceous limestones (right). NB. the beds are overturned!

also filled some apparently deep solutional cavities with vadose speleothems which may have been formed during one of major sea-level falls which marked the end of the Cretaceous period.

PALEOGENE

The K/T boundary bauxites are covered by several metres of carbonate breccia, which is in turn overlain by grey Foraminiferal limestones of the Eocene age.

The Foraminiferal limestones on the Rab Island are attributed the Middle Eocene age (Mamužić et al. 1969). In the lower part they contain Miliolidas (Mamužić 1962), which are in vertical section followed by Alveolinas and finally Nummulites. The Foraminiferal limestones are grey coloured, usually massive and comprise occasional echinoderms. They become marly towards the top of the succession, as a consequence of relative sea-level change, which is followed by increase in planktonic biota. The uppermost part of the Foraminiferal limestones is glauconitic and nodular, with abundant large fossils, like big foraminifera, Conoclypeaus echinoderms, and pectenid bivalves. These nodular limestones are quite thin and mark the transition from purely carbonate deposition into clastic deposition which followed above. For that reason, these nodular limestones are commonly called "Transitional Beds".

Fig. 22: Foraminiferal limestones.

Eocene clastics on the Rab Island were considered a part of Adriatic flysch (Mamužić & Milan 1973, Marinčić 1981), but were reinterpreted in terms of shallowmarine deposits with pronounced tidal influence (Marjanac & Marjanac 1991, 2007, Zupanič & Babić 1991).

It is possible to identify two depositional suites within the Eocene clastics. The lower, predominantly marly suite was called "Lower Flysch", whereas the upper predominantly sandy suite was called "Upper Flysch" by Mamužić (1962). These two sedimentary successions were later renamed, and reinterpreted in lithostratigraphical sense as San Marino Marls and Lopar Sandstones, respectivelly (Marjanac & Marjanac 1997, 1999, 2004, 2007).

San Marino Marls are generally unexposed, although they cover rather large area and attain thickness of several tens of metres, and can be seen only in construction site trenches. They contain just a small amount of sandstones and form flat, wet lowlands which are commonly marshy. The planktonic fauna is dominated by Globigerinas, whereas the macrofauna is poorly preserved, all indicating relatively deep water environment (Muldini-Mamužić 1962).

Lopar Sandstones is a depositional suite composed of several metres thick yellowish-coloured sandstone packages in alternation with bluish-coloured more-or-less bioturbated sandy marls. The sandstones are composed of medium-grained quartz grains, generally well cemented, and heavy mineral composition indicates provenance in magmatic and metamorphic Alpine sources (Magdalenić 1972).

Two types of sandstone bodies can be recognized; shallowmarine lower-, middle- and upper shoreface sandstones which commonly occur in progradational and thickening-upward fashion, and estuarine (incised-valley) sand bars or ridges (aka sand waves) which are built of migrating sand dunes.

Shoreface sandstones were deposited under dominant influence of storms, and hummocky cross stratification (HCS) and swaley cross stratification (SCS) structures are locally very nicely exposed.

Fig. 23: Hummocky cross-stratification (HCS) structure.

Estuarine sandstones were deposited under dominant influence of tides, and diagnostic structures such as herring-bone stratification, tidal bundles, and sigmoidal bedding are locally well exposed. These sandstones lack any body fauna, and comprise only ichnofossils which invaded the sediment from its upper surface.

Fig. 24: Herring-bone structure.

Subordinate, there also occur thin chert pebble conglomerates which occur as interbeds in estuarine sandstones, and coarse skeletal layers with large sandstone clasts. The former clearly represent extrabasinal debris with very distant provenance as indicated by good rounding of chert pebbles, whereas the latter represent intrabasinal debris which is a product of erosion of the underlying sediments. Both coarse sediments document deposition during significant sea-level falls when fluvial systems expanded far basinward, and base-level fall initiated incision of the incised valleys.

Fig. 25: Extrabasinal chert conglomerates.

Also subordinate facies is skeletal tempestite which is almost entirely composed of Nummulite tests which overlie the estuarine sandstones, and mark the increase of storm intensity as a consequence of relative sea-level rise.

Sandy marls are commonly fossiliferous, they comprise relatively abundant Nummulite tests, agglutinated foraminifera, locally common turritelid gastropods, scaphopods, brachiopods and irregular echinoderms, in addition to a great variety of ichnofossils.

The succession of Lopar Sandstones is composed of several complete depositional sequences, which are bounded by Type-I sequence boundaries. All major bounding surfaces can be recognized at the Lopar coastal cliffs; sequence boundary (SB), tidal and wave ravinement surfaces (TRS and WRS), regressive surface of marine erosion (RSME), flooding surface (FS), as well as maximum flooding surface (MFS) which is, strictly speaking, preserved as several tens of centimetres, or less, thin zone instead of a surface. For more detailed discussion see Marjanac & Marjanac (2007).

Fig. 26: This sharp contact is combined seqence boundary (SB) and tidal ravinement surface (TRS).

The Lopar Sandstone succession also hosts several beautiful synsedimentary rotational slumps which were probably triggered by high-magnitude earthquakes.

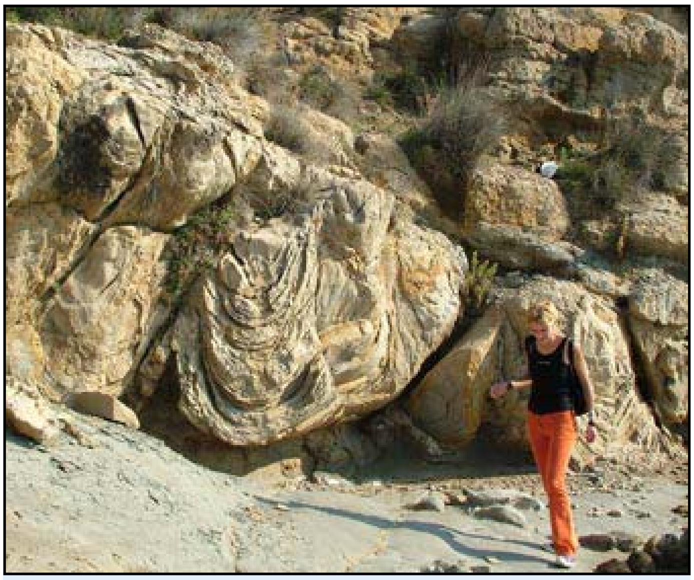


Fig. 27: Rotational slump. Lopar Peninsula.

AGE

Muldini-Mamužić (1962) attributed the Island of Rab clastics to the uppermost Middle Eocene and possibly to a part of the Upper Eocene.

Benić (1983) determined nannofossils of the Discoaster tani nodifer nanno-zone (NP16) in the San Marino - Marl, stating that there were no resedimented forms in the studied samples. However, in samples of the Lopar - Sandstone more resedimented than autochthonous species were found, and no stratigraphic age was possible to determine. Benić believed that the resedimented nannofossils (zones NP 6-7, NP 7-9, NP 9-10 and NP 10-12) originated from flysch which was contemporaneous to Foraminiferal Limestones.

QUATERNARY

Quaternary deposits on the Rab Island are represented by Pleistocene carbonate breccias; mostly finegrained rudites which form large alluvial fans and fan deltas in the Barbat-Pudarica, and Mišnjak areas, as well as Njivice fan on the northern side of the island.

The bedding style indicates the provenance of this debris must have been in the Velebit Mt. area. The debris was transported in shallow braided channels, but also in several sinuous channels, and apparently filled the Barbat Channel, before it was eroded by late Pleistocene sea level rise and associated ravinement. On the contrary, the Njivice fan is almost perfect alluvial fan built by debris fed from the Kamenjak hill.

Fig. 28: Njivice alluvial fan on northern face of the island.

Locally, there also occur coarse cobble interlayers within poorly cemented alluvial fan rudites which were probably deposited during flash floods.

Coarse cemented carbonate breccia locally drapes the modern topography and probably represents fossil slope aprons. The breccia consists of lithologically and stratigraphically very varied clasts, in wide range of sizes, the largest reaching almost 1 m across. The fabric of breccia is chaotic, grain-supported, with only minor amount of arenite-grade “matrix”. Large clasts are commonly in-situ fractured, what indicates their rapid deposition and overloading. The youngest clasts, which provide their maximum age frame, are clasts of Eocene foraminiferal limestones and sandstones. Thus the age of breccia might be constrained to post-Eocene, possibly Pleistocene. The debris composition indicates local sources, whereas large clast sizes and chaotic structure indicate rapid mass-flow de-

Fig. 29: Sedimentary breccia. The youngest are clasts of Eocene "flysch" sandstones.

position. Their true nature and mode of emplacement is still under study.

The Fruga valley and Lopar Peninsula host paleosols of presumed Pleistocene age which show abundant rhizoid traces. The rhizoids document lush vegetative cover on top of paleosol, and consequently a humid climate. Paleosol is overlain by aeolian quartz sand of presumed Late Pleistocene or early Holocene age, which documents dry climate and lack of high vegetation.

Fig. 30: Rhizoids (fossil roots) in Fruga valley paleosol.

The Lopar Peninsula is also a site of discovery of numerous Palaeolithic, Mesolithic and Neolithic tools (Malez 1987), though no human remains, nor animal bones have been found so far.

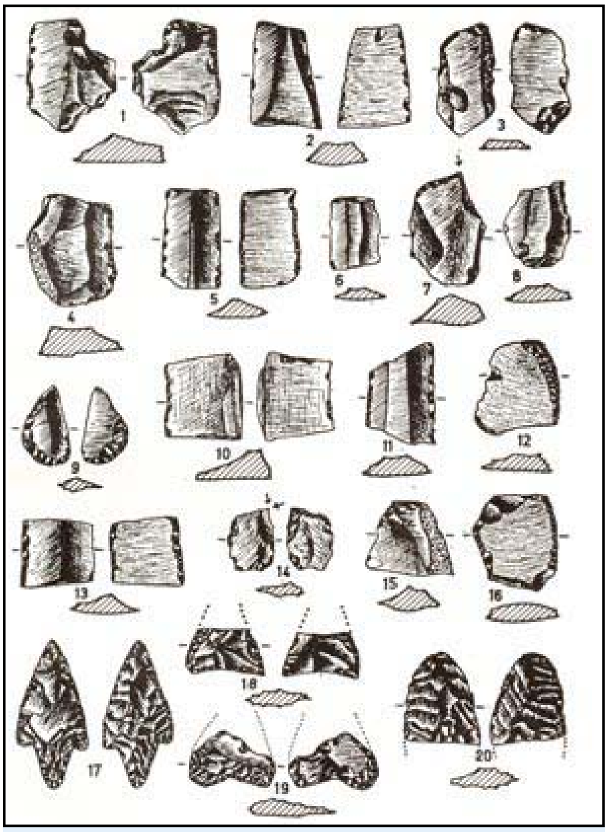


Fig. 31: Artefacts from the Lopar Peninsula, Malez (1987).

Holocene deposits are aeolian sands which cover parts of the Kalifront and Lopar Peninsulas, and were blown from the beaches by the prevailing winds. Artificial forestation on Lopar, however, obscured these sands which are now visible only in construction site trenches and some gullies.

TECTONICS

The Rab island is structurally formed on two synclines and two anticlines which form normal relief. Both anticlines and synclines are cut by Dinaric-striking steep faults which are transected by NE-SW striking younger vertical faults with predominantly horizontal slip.

The Lopar Peninsula syncline hosts several small, but well-exposed monoclines, and numerous normal faults. The monoclines were probably formed by propagation of blind thrust faults. The latter are also responsible for local thrusting. Block tectonics is best expressed along the coastal cliffs what complicates physical correlation of facies.

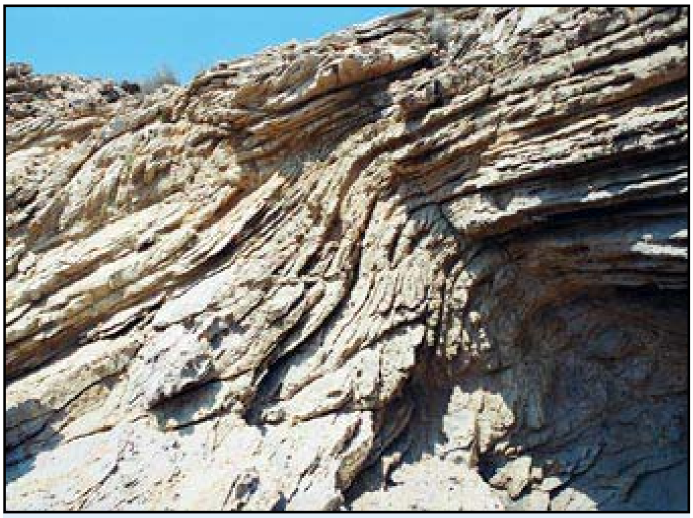
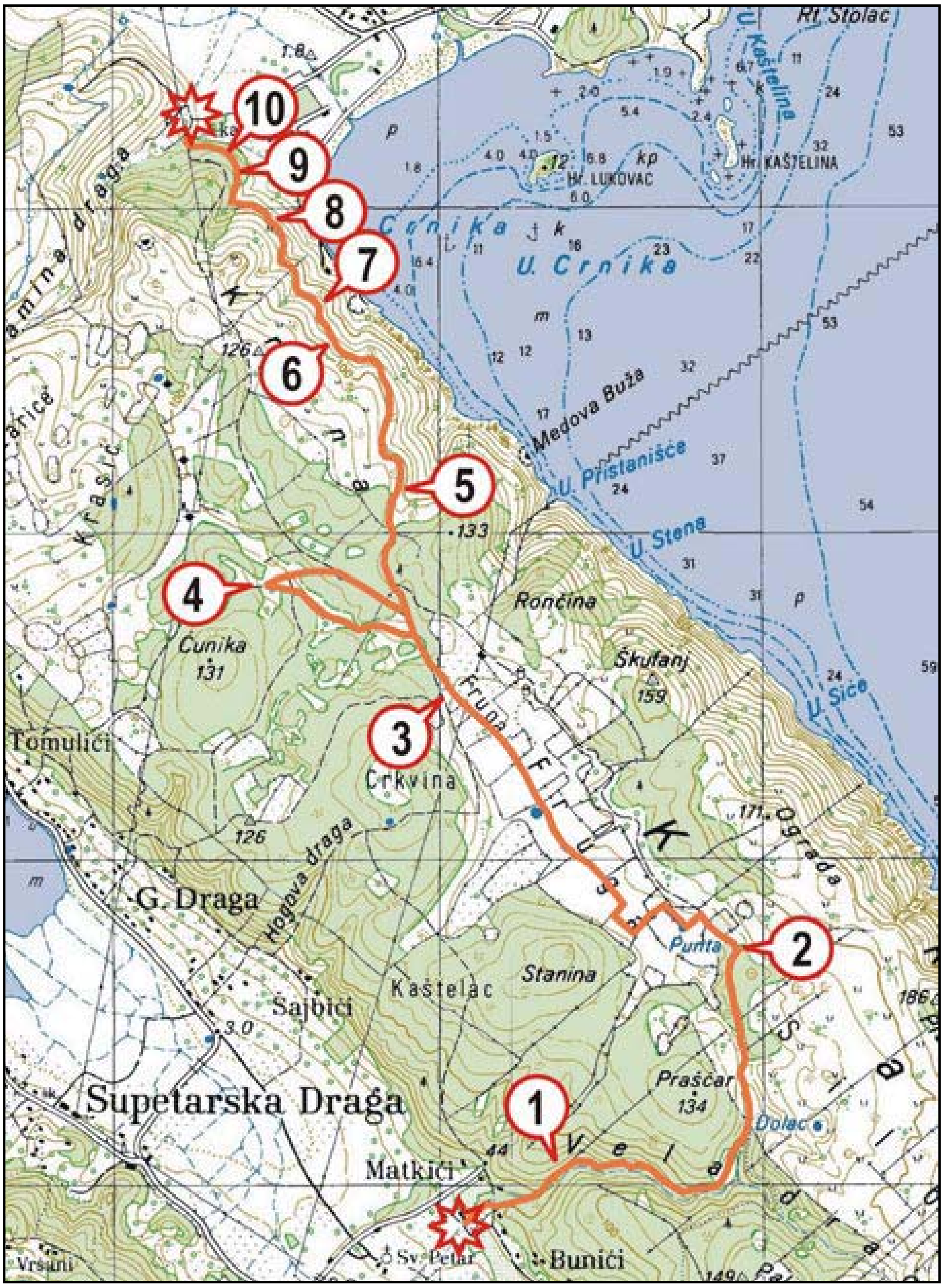


Fig. 32: Monocline, Lopar Peninsula.

Fig. 33: Normal fault, Lopar Peninsula.

EXCURSION ST. PETER CHURCH – SAN-MARINO (LOPAR)



The excursion will start near the St. Peter church in the Matkići village, and will follow the Premužićeva-1 geotrail in reverse order of stops.

The trail is easy and only light footwear and appropriate clothing is needed. However, there is no water along the trail, except in several ponds which we do not recommend for drinking.

STOPS

1. Vela Draga — No. 10
Retention dam

The retention dam was constructed in 1960-es for the protection of the Matkići village against the flash floods. However, the dam elevated the base level, causing the backward shift of the stream graded profile which eventually enhanced erosion upstream, and caused deposition of a large amount of coarse debris which soon filled the dam basin. Today, the sediment filled the dammed gorge to the dam top, and the protective role of the dam is lost.

Fig. 34: Vela Draga retention dam.

2. Fruga Valley — No. 9
Erosional remnant - The "Mushroom"

The isolated rock is an erosional remnant of once widespread breccia, which is made of various limestone fragments. The breccia was initially subjected to subaerial weathering and buried under thick soil which was vegetated by higher plants. The water in soil as well as humic acids released by plant roots corroded the breccia and formed this odd-shaped rock.

Fig. 35: The "Mushroom".

3. Fruga Valley — No. 8
Soil erosion

Thick soil which infills the Fruga valley was partly eroded by rapids and flash floods. The incised trenches exposed fossil soils (paleosol) of presumed Pleistocene age, white aeolian quartz sands and modern (Holocene) clayey soil. The paleosol shows numerous rhizoid casts which document lush vegetative cover which died out before the deposition of white sands. The trenches were incised presumably before the Roman times, since the remains of the Roman road descend into the trench.

Fig. 36: Erosional trench, now antropogenically modified.

4. Fruga Valley — No. 7
Karstified rocks - The "Stonehenge"

These rocks were also shaped by subsoil corrosion, which was caused by carbonic and humic acids under thick vegetated soil. The overlying soil was later eroded and the rocks are exposed to modern weathering and corrosion which formed small flute-karren on the rock surfaces.

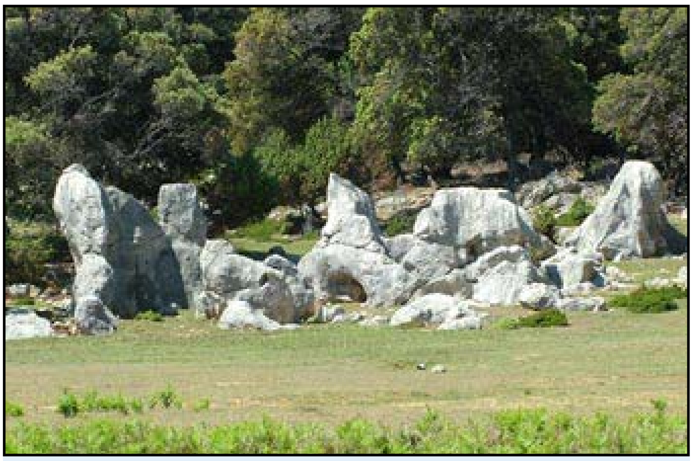


Fig. 37: The "Stonehenge"

5. "Green Door" No. 6
Solution pan - Kamentza

Solution pans (also known as kamenitzas) are pan-like depressions which are formed by biochemical corrosion of the exposed rock. Kamenitzas keep rain and mist water which supports growth of algae and fungia which further dissolve the rock and expand the kamenitza forming the overhang walls and leaving clayey residuum at the bottom. Kamenitzas may be of any size, ranging from such a small one to several metres deep and tens of metres wide pans.

Fig. 38: Small solution-pan - kamenitza in a wet season.

6. Premužić-Trail No. 5
Fossil gastropods - Nerineans

The Senonian age limestones host well preserved gastropod biostromes which indicate shallow and warm depositional environment. The red tint of these gastropod shells is caused by migration of iron during the diagenesis in an oxydized environment. This monospecific biostrome suggests nevertheless a stressed environment which was not suitable for other contemporaneous fauna such as rudists.

Fig. 39: Nerinean gastropods.

7. Premužić-Trail No. 4
Fossil aberrant bivalves - Rudists

Rudists were common dwellers in the Late Cretaceous (Senonian) seas, and lived partly buried in the soft bottom sediment. Their present position, parallel to the bedding is a result of a strong storm which caused erosion of the sea-bed. The rudists were excavated from their position and tossed around the bottom, forming piles of flat-lying shells. The water depth was small, as indicated by reddish colouration of the sediment, which is caused by minute amount of haematite. The beds are overturned in this section.

Fig. 40: Rudist coquina.

8. Premužić-Trail No. 3
Foraminiferal Limestone

Foraminiferal limestones of Early to Middle Eocene age are biomicrites rich in Nummulites and Assilina tests. Both sexual (A) and asexual (B) generations are present in normal 10:1 ratio, what indicates normal ecological conditions, which prevailed all over the eastern Adriatic region at that time.

Fig. 41: Foraminiferal Limestone. Nummulites and Assilina.

9. Premužić-Trail No. 2
Bauxite pit

Bauxites mark the Cretaceous/Tertiary boundary and are accumulated in paleokarst depressions which were formed in the upper Cretaceous limestones. This type of the K/T boundary is common in Istria, Dalmatia and Herzegovina. However, the boundary on the neighbouring Krk Island (48 km away) is characterized by neptunian dykes, whereas at Novi Vinodolski (35 km away) the boundary is represented by several metres thick very coarse breccia with vadose cement. Bauxite was mined in many places on the island, and much larger mines are located on the Sorinj Peninsula. Although the bauxite is a major aluminium ore, this bauxite was probably never used for its production, but instead as an additive or colourant.

Fig. 42: Bauxite pit.

10. Premužić-Trail No. 1
Breccia

The coarsegrained carbonate breccia comprises great variety of clasts; Cretaceous limestones predominate, but clasts of Eocene Foraminiferal limestones and younger Eocene sandstones also occur. The clasts are unrounded, commonly sharp-edged, and frequently in situ fractured. The breccia has a chaotic fabric, and no stratification nor grading is apparent. Compositionally this breccia differs from the Jelar Breccia which is widespread along the Velebit Mt. coastal side. Sometimes, this breccia is called the "Rab Breccia", particularly the variety with the red carbonate matrix which was widely used for building churches on the island, the Rab Cathedral in particular. This breccia is interpreted as a slope apron, because it is draped over the modern topography. Its chaotic fabric and in situ fracturation of clasts indicates very rapid deposition and great loading. This breccia also occurs on the Kamenjak hill, as well as all over the island.

Fig. 43: Breccia. Note *in situ* fragmented clasts, and slope-draping character of the deposit.

EXCURSION 4B
Rab

Geoheritage of Lopar, Island of Rab

LEADERS:
Tihomir Marjanac & Ljerka Marjanac

The excursion is organized in two parts. The first part of the excursion will start near the San Marino auto camp in Lopar, and will follow a part of the Premužićeva-1 geotrail which was not visited during the Excursion 4A. The second part will follow a part of the new Lopar geotrail. This part of the excursion will start from the info-centre in San Marino and head north to the sandy Saramić Cove, better known as Sahara. From there the trail will take you along the coast with deep shallow coves which are modern tidal flats during the low tides.

The second part of the excursion will end in the Zidine educational and recreational camp.

The trail is easy and only light footwear and appropriate clothing is needed. However, there is no water along thetrail.

STOPS

1. Jamina Draga No. 11
Aeolian sands

This sand was transported by wind which was blowing from the north, and was deposited all over the Lopar field. Once much more extensive sand cover is now preserved only in this vegetated remnant. The sand is predominantly composed of quartz grains which were eroded from the Eocene sandstones nearby, but also contains small foraminifera which indicate that the sand was actually blown form the beach. The vegetation eventually stabilised the sand accumulation and prevented its erosion.

Fig. 44: Aeolian sands, blown from the beach, and now vegetated.

2. Jamina Draga No. 12
Jamina spring

This periodic spring is located on a fault zone in Cretaceous limestones. It is 8 m deep, and divers reported that the pit continues in a narrow passage. The water level does not singnificantly oscillate during the year, although it is springing out after heavy rainfall. Thus, it is likely controlled by the water-table. The spring is very likely a part of the Kruna hill drainage basin.

Fig. 45: Jamina spring, in a dry season.

3. Kruna hill No. 13
Mladenova Buža cave

This is one of a few known caves on the island. It is only 26 m long, and though it looks as a part of the Roman water supply tunnel, it is actually a natural karst feature. The cave is significantly devastated by irresponsible visitors, who painted numerous signatures on the walls, and it is currently known after the most common"Mladen"signature as the Mladen's Cave ("buža" in local dialect). The cave was visited by occassional visitors already in 1931, as indicated by their signatures. The cave is currently dry, except for local dripping from the cieling, but remains of thick stalactites indicate their growth during a much more humid climate. The cave awaits detailed archaeological exploration.

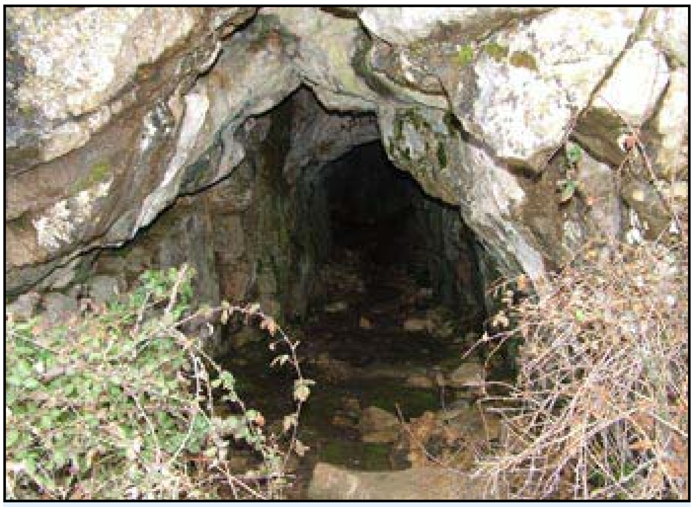


Fig. 46: Mladenova Buža cave, from the entrance.

4. Kruna hill — No. 14
Breccia

This outcrop shows a thick chaotic limestone breccia, which is composed of various limestone clasts which range in size from small rudite to almost 1 m across. The breccia is poorly cemented and forms a slope apron. Larger clasts are fractured by numerous fissures, what indicates significant postdepositional loading. There seems to be no sorting or organization of the debris, so the mode of emplacement is interpreted in terms of catastrophic mass flow.

Fig. 47: Coarsegrained mass-flow breccia.

5. Saramić Cove — No. 5
Sand ridge

The Lopar Sandstones comprise several sandstone bodies (ridges, sand waves) which were deposited in an incised valley or estuary. The outcrop shows a contact of bluish-coloured sandy marls below and brownish-coloured sandstones above, with a slump horizon in between. The sandy marls were deposited in an offshore position, well below the storm wave-base where the only sands were deposited from gravity flows as a distant echo of major topical storms which have mobilized the sand in a shallow sea. The oxygenation of the bottom waters was poor, as indicated by bluish colour of the sediment, which is a consequence of dispersed pyrite in the sediment. The overlying deformed sediments were formed by submarine slumping of unconsolidated lower shoreface sand and mud. The slumped interval is directly overlain by quartz sandstones of a tidal sand ridge. The sand ridge was deposited in a tide-dominated estuary which was constructed by erosion during a significant relative sea-level fall, when the fluvial systems extended far basinward, and provided the quartz debris from some northern sources, possibly Northern Alps. The sand ridge was deposited, however, during the subsequent sea-level rise and transgression which flooded the alluvial valley forming an estuary or an incised valley.

Fig. 48: Section shows offshore marls and sandy-mars of distal shoreface, sharply overlain by slumped sandstones (probably middle shoreface, and sharply overlain by incised-valley (estuarine) tidal sandstones.

6. Saramić Cove (Sahara) — No. 8
Aeolian sand dunes

This part of the Saramić Cove is widely known as Sahara because of its drifting sand which was much more pronounced before the artificial forestation in 1950-es and later. The quartz sand is blown from the beach by even moderate wind. Sand deposition forms “sand shadows” behind even small obstacles like the Nummulite tests, as well as behind bushes. Strong steady winter winds may form small longitudinal dunes, but weaker winds commonly create parabolic dunes right on the beach. Subordinate winds are responsible for small sand ripples which are superimposed on larger bed forms. These dunes have low preservation potential because they are destroyed every year by tourists.

Fig. 49: Aeolian sand dunes are created by migrating sand blown by bora wind.

7. Sturić Cove No. 13
Cyanobacterial mat

Colonies of cyanobacteria here live on sandy substrate in high intertidal zone. Their mucus is daily being covered by the wind-blown and water-laid sand, which forms a thin sand lamina. The cyanobacteria start rapid growth during the period of wetting, when they grow over the sand lamina, and are eventually covered by a new sand layer. In this way successive growth of cyanobacteria and sand deposition creates laminated sediment analogous to stromatolites of the tropical seas. The cyanobacteria selected this narrow ecological niche because of sufficient wetting, and as a protection from gastropods, their natural predators.

Fig. 50: Modern cyanobacterial mats bond wind-blown sand, silt, and marine mud and form stromatolite-type lamination. Seasonal dessication forms dessication cracks. Bacterial mat reduces oxygenation of the sediment, so the underlying layers are commonly anoxic.

8. Sturić Cove No. 14
Sand ridge

The sand ridges are built of sand which was transported by tidal currents, as indicated by herring-bone lamination which was formed by migration of small bed forms (ripples) during alternating flood and ebb flows. The whole sand ridge has rather complex composition, and is typically built of several superimposed

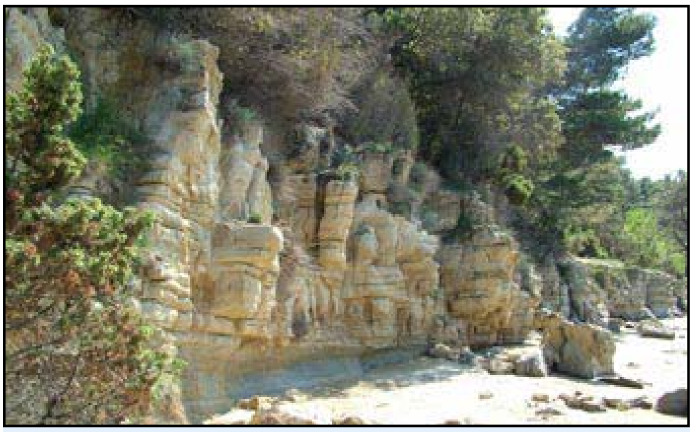


Fig. 51: Tidal sand bar in cross-section.

migrating dune trains.

9. Zaškoljić Cove No. 16
Flooding surface

The deposition of estuarine sand ridges is aborted by accelerated relative sea-level rise which eventually flooded the estuary and its sand ridges. The sediments on flooded estuary bottom were affected by strong tropical storm which formed large sand ripples on the sea-bed. The sea-level continued to rise causing deepening below the storm wave-base and deposition in poorly aerated environment, as indicated by the dark sediment colour.

Fig. 52: Flooding surface (FS) is developed above a storm layer rich in skeletons of foraminifera. The storm layer is undulated in form of megaripples, which were probably created by a major storm (hurricane).

10. Stojan Cove (Ciganka) No. 18
"Badlands" soil profile

The erosional remnants of once widespread thick soil cover are known as "Lopar pyramids". Thick soil was developed by chemical and mechanical weathering of the underlying sandstones. Three soil horizons are vis-

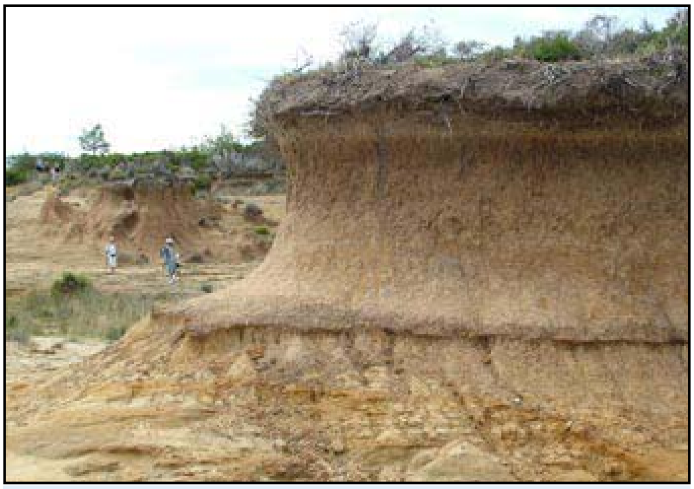


Fig. 53: Soil profile. Paleosol is overlain by grey wind-blown quartz sand.

ible at this outcrops, from the top downwards; "0" horizon is an organic layer on the top of the section, just below the vegetative cover, "A" horizon which is a leached zone caused by action of humic acids and pore waters, "B" horizon with clayey minerals, iron oxides and calcite, and "C" horizon which suffered least degree of weathering and is in transitional contact with the base rock.

11. Stojan Cove (Ciganka) No. 20 Sand ridge

The outcrop shows a sharp contact of the grey- to ochre-coloured cross-bedded sandstones (above) with bluish-coloured massive sandy marls (below). This sharp contact is interpreted in sequence stratigraphic sense as a combined sequence boundary (SB) and tidal ravinement surface (TRS). The bluish-coloured marls were deposited during period of relatively high sea level, which in combination with subsidence created large accommodation space which could be filled only with suspended mud. Significant relative sea-level fall caused lowering of the base-level and deep incision of alluvial valleys which destroyed a large thickness of the underlying sediments, reaching down to older offshore sandy marls. The amount of erosion at this boundary is hard to estimate, but it might have been more than 100 m. The alluvial valley was probably filled with deposits which were eroded by ravinement during the subsequent sea-level rise. This ravinement was caused by tidal currents flowing in and out of the estuary, therefore the resultant erosional surface is called a tidal ravinement surface (TRS). In this way, the contact between the tidal sandstones and underlying sandy marls is a composite surface created by relative sea-level fall (in a broad sense) and subsequent sea-level rise. The sand ridge shows composition of several superimposed migrating dunes which are all well expressed by foreset cross bedding. However, the accommodation space was limited, and the currents strong, so the body suffered significant synsedimentary erosion and lateral deposition of a new sand ridge.

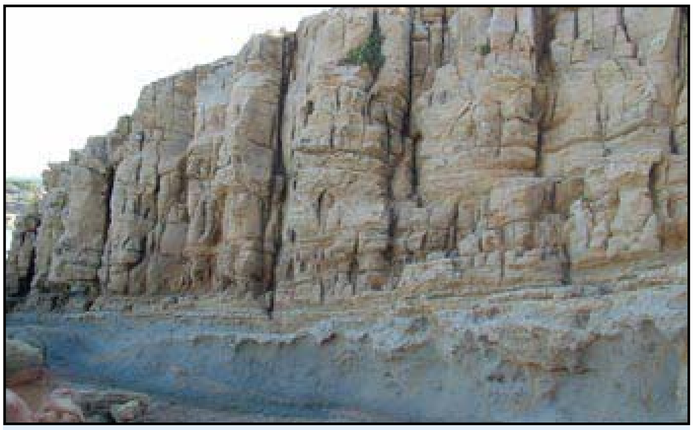


Fig. 54. Sharp contact of tidal sand ridge sandstones with underlying offshore sandy marls is a sequence boundary, and documents an episode of relative sea-level fall.

12. Power Line No. 24 Sand ridge

The internal structure of this sand ridge reveals its composition which consists of several superimposed dunes, some of which were migrating in apparently opposite directions, which was controlled by bedform topography and available accommodation space. The bottom contact with the underlying sandy marls is also a composite SB+TRS surface. The sand is faunistically sterile in terms of body fauna, but nice burrows (Ophiomorpha, Gyrolites) which can be seen on the outcrop were probably excavated by calianassan shrimps which colonized the tidal sand ridges when the sea-level rose and flooded the estuary, and provided the normal water salinity.

Fig. 55: Tidal sand ridge is composed of several sand dunes, which migrated in apparently oposite directions.

13. Zidine No. 26, 27 Monocline

This monocline was formed by propagation of a reverse fault from below, which deformed the overlying strata but did not penetrate to the surface. Since the fault is not visible, it is called a "blind fault". The continuation of the outcrop a few tens of metres away, reveals small-scale thrusting which is caused by a fault which is apparently normal to the "blind fault". These two faults form a synthetic and antithetic fault pair.

Fig. 56: Zidine monocline.

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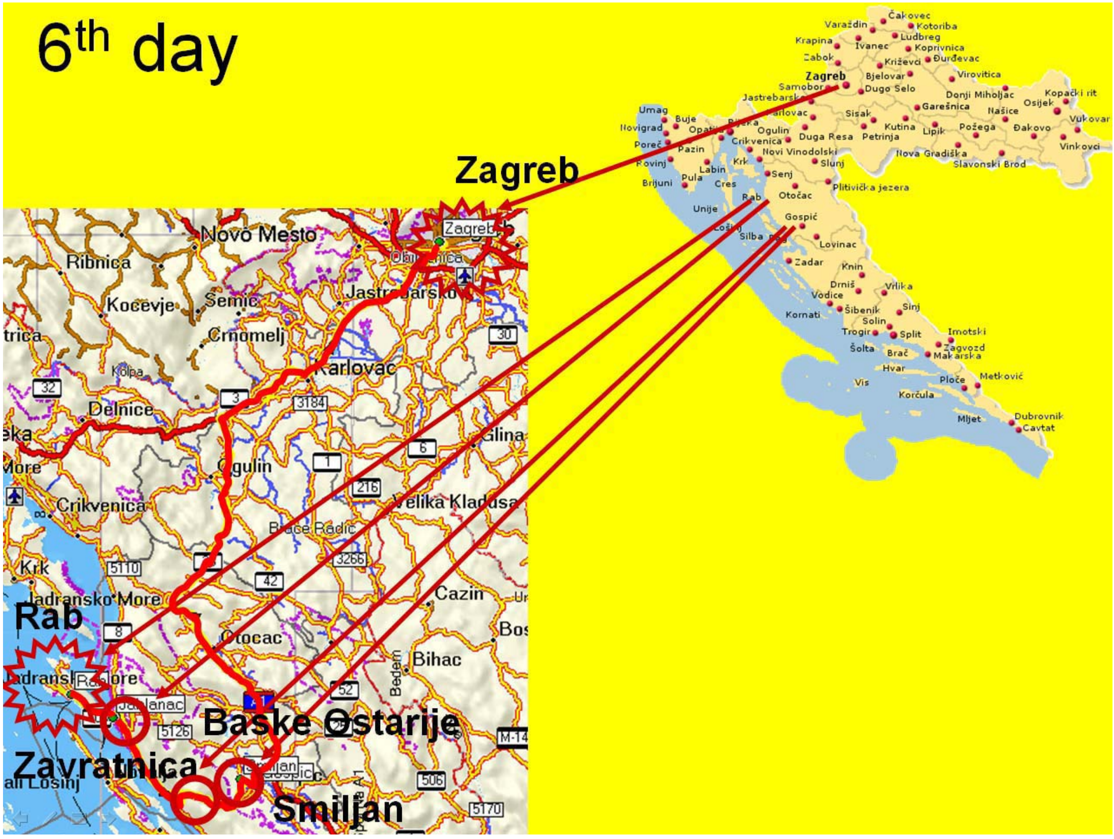
9. DAY 6

Carbonate Platform Deposits of the Central Velebit Mt.

Jasenka Sremac



STOP 1: ZAVRATNICA

Zavratnica fjord-shaped bay, is one of the most beautiful geomorphological phenomena of the Adriatic coast. It is situated 2.5 km south from Jablanac. Bay represents an ancient torrent valley, filled with sea-water after the rise of the sea level in post-glaciation time. A prehistoric settlement was discovered above the bay, at Klasnica locality. During the Second world war a german ship sunk here, and can be approached by divers at the depth of 8–10 metres.
Zavratnica is almost 1000 m long, 50–150 m wide, with canyon walls more than 100 m high. Locality was popular among the tourists since the beginning of the 20th century. Due to its natural beauty it was proclaimed a „protected landscape" in 1964. Since 1981 it became a part of the „Velebit Park of Nature".

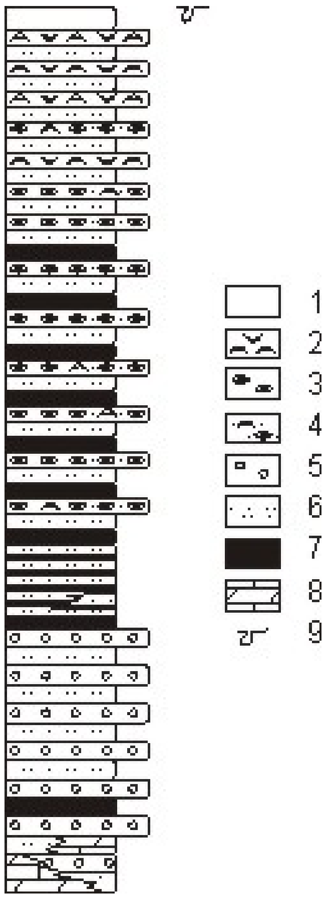
http://www.pp-velebit.hr/zavratnica.htm
http://www.dmmedia.com/izleti/zavratnica_hr.htm

STOP 2: KUBUS

Kubus is a pass situated along the road Gospić – Karlobag, marked with a stone cube monument from which a gorgeous view to the Adriatic sea and the Island of Pag.

A stone cube monument at the Kubus pass in the Central Velebit Mt.

Travelling along the winding road towards Karlobag, vertical carbonate beds of Jurassic age are exposed, at some places containing numerous fossils.
Open profile is all together 270 m long, presenting carbonate rocks of 5 different lithofacies (TIŠLJAR et al., 1991).



Detailed geological column through the Lower Jurassic deposits NW from the Kubus pass. Lithofacies types are marked with letters A-E.
Legend: 1. Stained limestones, 2. Lithiotid coquinas, 3. Onkoids, 4. Intraclast bioclastic grainstone, 5. Ooid grainstone, 6. Peloid wackestone, 7. Mudstone, 8. Late diagenetic dolomite, 9. Bioturbated (Partly after Tišljar et al., 1991).

1. FACIES A

Rhytmical deposition of madstones, wackestones and ooid grainstones is typical for this facies. Base of these sediments is composed of conglomerates composed of underlaying Ladinian rocks. Early diagenetic fenestral dolomites with stromatolites, with scarce fossils prevail in the lower portions. Upper layers are often grainstones, with numerous remnants of bivalves, crinoids, calcareous algae and benthic foraminifera (*Paleomanycina termieri* (HOTTINGER), *Lituosepta recoarensis* CATI, *Planisepta compressa* (HOTTINGER), *Mesoendothyra* sp., *Everticyclammina* sp., *Glomospira* sp., *Amijela amiji* (HENSON), *Palaeodasycladus mediterraneus* (PIA), *Saccocoma* sp., *Lithiotis problematica* GÜMBEL).
Deposits of Facies A were deposited in peritidal environment during the Lower Jurassic time.

2. FACIES B

Mudstones of Facies B contain intercalations ow wackestones/packstones and floatstones, with following microfossils: *Paleomanycina termieri* (HOTTINGER), *Lituosepta recoarensis* CATI, *Planisepta compressa* (HOTTINGER), *Haurania deserta* HENSON, *Amijela amiji* (HENSON) and *Palaeodasycladus mediterraneus*

(PIA). These rocks were deposited in a lagoon or shallow subtidal environment during the middle part of Lower Jurassic.

3. FACIES C

Dark grey to black carbonate rocks of this facies present rhythmical exchange of mudstone/wackestone and grainstone/rudstone type of sediments. The following microfossils were determined: *Lituosepta recoarensis* CATI, *Orbitopsella primaeva* (HENSON), *Orbitopsella praecursor* (GÜMBEL), *Orbitopsella dubari* HOTTINGER, *Paleomanycina termieri* (HOTTINGER), *Amijela amiji* (HENSON), *Mesoendothyra* sp., *Haurania deserta* HENSON, *Amijela amiji* (HENSON), *Glomospira* sp., *Palaeodasycladus mediterraneus* (PIA). Larger remnants of *Lithiotis problematica* and gastropods are also common.
Carbonate rocks of Facies C were deposited in a lagoon or shallow subtidal during the Lower Jurassic.

4. FACIES D

Deposits of Facies D can be clearly recognized in the field, due to numerous macrofossils. They appear at several levels within the exposed profile. Shallow subtidal lagoonal limestones (pelete, pelete-skeletal wackestones to packstones, 30 to 150 cm thick, with microfossils and brachiopods) alternate with 30-160 cm thick lithiotid tempestite coquinas.

Lithiotid tempestite coquina

Lagoonal limestones contain the following microfossils: *Paleomanycina termieri* (HOTTINGER), *Amijela amiji* (HENSON), *Mesoendothyra* sp., *Haurania deserta* HENSON, *Glomospira* sp., *Planisepta compressa* (HOTTINGER), *Pseudocyclammina liassica* HOTTINGER, *Everticyclammina* sp. and *Palaeodasycladus mediterraneus* (PIA).
Coquines are composed of numerous shells of *Lithiotis problematica,* digged ot from the sea floor during the tempest, and deposited after the stress phase. They were deposited in middle part of the Lower Jurassic.

5. FACIES E

Lithofacies E is represented with «stained limestones». Bed thickness varies from 10 to 60 cm, and the whole series is ca 50 m thick. Limestones are in most cases

mudstones to Wackestones, intensively bioturbated. Feeding traces are more light colored than the rest of the limestone, due to the decreased organic content, thus resulting in typical stained pattern.
Besides the ichnofossils, foraminifera (*Haurania deserta* HENSON, *Ophthalmidium martanum* (FARINACCI), *Pseudocyclammina* sp.) and pelagic crinoids (*Saccocoma*) were found in these deposits.
Limestones of facies E were deposited in calm, spacious shallow environments, with low deposition rate. They do not contain index taxa, but it presumed that they were deposited during the upper part of Lower Jurassic.

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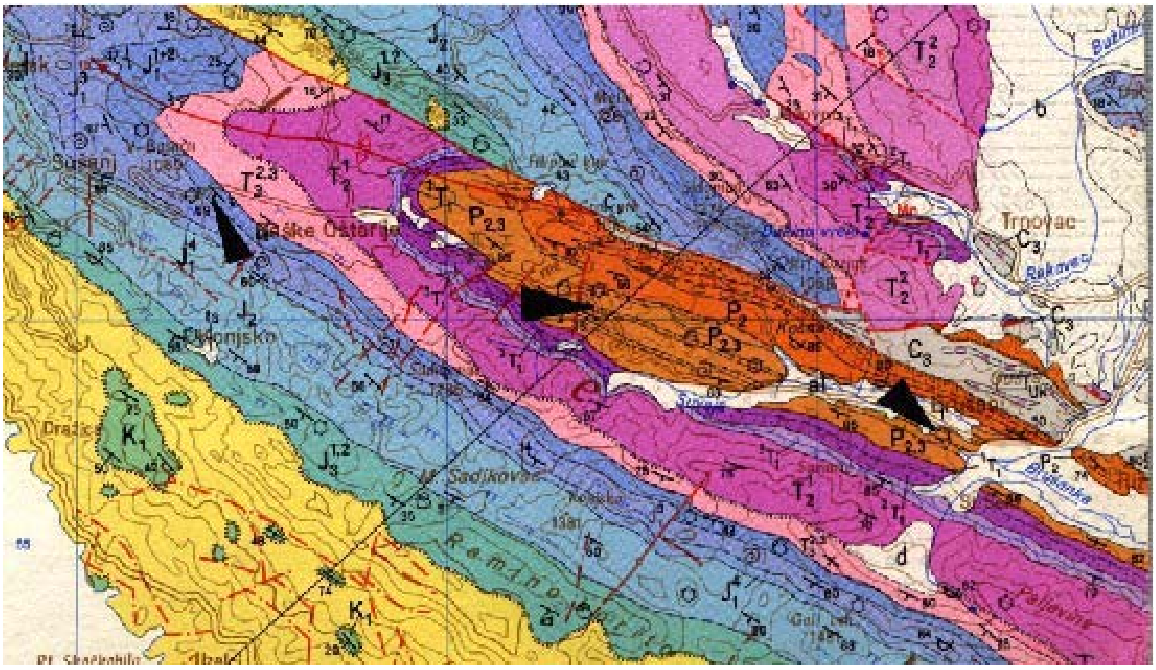
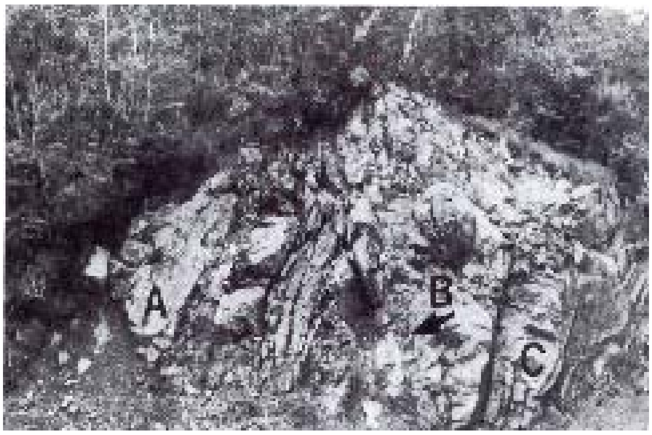
STOP 3: PARIPOV JARAK

Middle to Late Permian platform carbonate rocks are well exposed along the regional road Gospić-Karlobag. They represent a core and a SW wing of the Velebit anticline, and are in most cases steeply inclined towards the south-west.



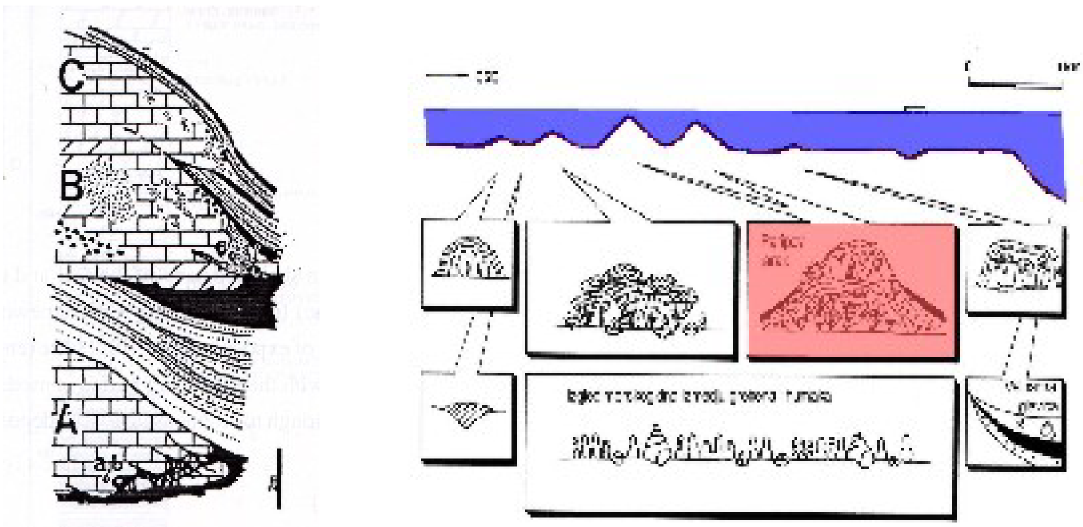
Geological map ot the area Brušane-Baške Oštarije. A detail from the Basic Geological Map of Croatia. The position of stops is marked with black arrows. Stop Kubus is at the West side, stop Paripov Jarak in the middle, and stop Kalvarija at the East.

A particularly interesting exposure was found at the Paripov jarak (Horse Trench) locality. A complex patch-reef structure of the Middle Permian age (Zone Neoschwagerina craticulifera) is today a part of the Educational Route of the Velebit Park of Nature (Sremac, 2003), and a proposal was sent to the UNESCO to protect the outcrop as the international geological heritage. Outcrop is cca. 12 meters wide and 8 meters high.



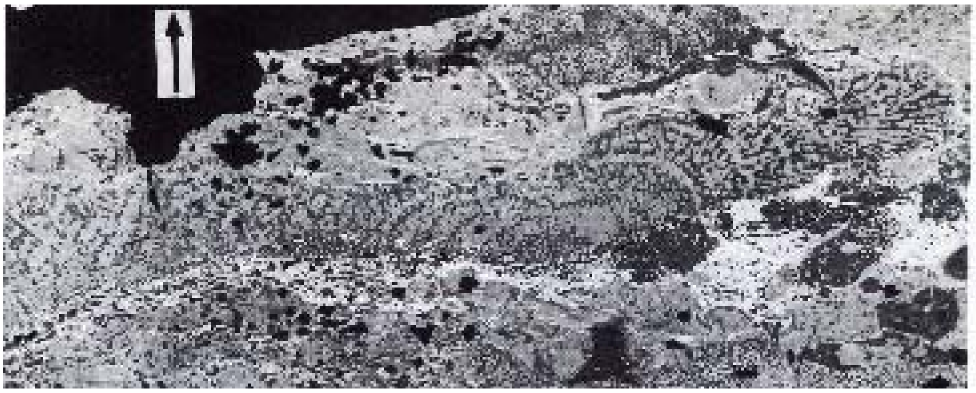
Patch reef with 3 reef bodies (A-C) along the road Gospić-Karlobag. Deposits are tectonically disturbed, and layers are almost perpendicular to the road. After Sremac (1991).

Reef structures have been rotated for cca. 180 degrees due to the tectonic processes.



Reef and platform reconstruction. After Sremac (1991) and Marjanac & Sremac (2000).

In the base of the reef body, dark grey mudstone was found. Large fenestellid bryozoans were the first colonizers of the muddy substrate (Sremac, 1991; Marjanac & Sremac, 2000). Their large fans represented a base for growth of diverse sessile benthic biota – other bryozoans and small calcareous sponges. The first colonizers probably lived in a very shallow, nearshore environment, with important role of cyanobacteria in the community. Microbial crusts cover the whole basic part of the patch-reef. On this consolidated base, large calcisponges (*Colospongia, Waagenella, Sinocoelia, Guadalupia* and many others) started to produce the main part of the reef framework.



A thin section through the reef frame-work with calcisponges (after Sremac, 1991).

We can conclude that the sea-level slightly rose, thus enabling the formation of the bioherm. Several taxa of invertebrates choosed these patch-reefs for their favourite niches. The most common among them were the large endemic brachiopods *Martinia velebitica* and *Enteletes salopeki*. Up to 100 specimens of *M. velebitica* were found within a patch-reef (Sremac, 1986). Reef structure of the body A is partly covered with a floatstone type of bioclastic limestone, probably representing the average process of reef decomposition. Sea level oscillations, rather common in Middle and Late Permian, influenced these processes. At least three episodes of reef-growth can be observed at the outcrops. Reef growth was most probably interrupted by sea-level drop, and again initialized when the optimal conditions were restored. It is interesting that all 3 reef bodies (A, B and C) exhibit the same pattern of colonization, with fenestellids and incrustants at the base, and large calcisponges in the main part of the framework.

During the storms, the surrounding sediment and biota were uplifted from the sea-bottom, transported over the reef, and filled the reef cavities. These structures can be observed in the field, due to the different color of the reef structure (grey) and infill (yellowish-grey). Among the biota, calcareous algae are very common (*Mizzia, Gymnocodium, Permocalculus*), together with ball-shaped *Neoschwagerina* which could be easily transported without damage of the test. During the very strong storms, possibly hurricanes, even surrounding *Tanchintongia* settlements were influenced. These large and thick shells were destroyed and fragmented, and can be found in coquinas between the reef bodies.

The reef was finally burried in mud, and typical algal dolomites overly the reef body C.

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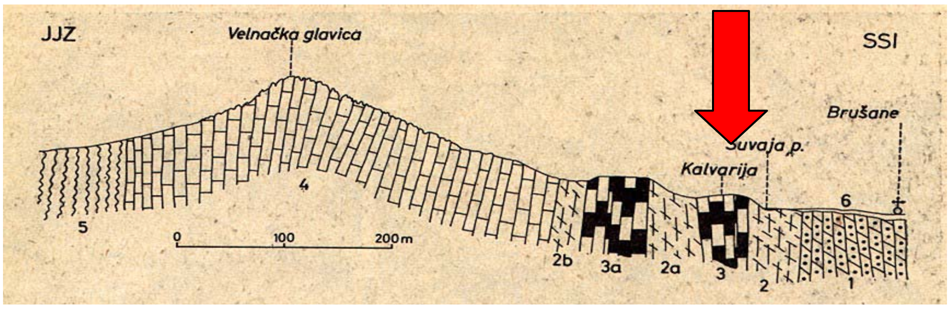
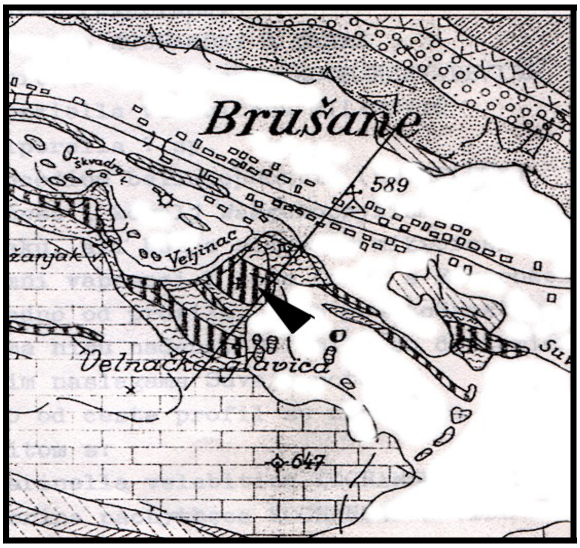
STOP 4: KALVARIJA (VELNAČKA GLAVICA)

Profile from Brušane village to Velnačka glavica hill, crossing a small hill Kalvarija, is well known for a well exposed succession of sedimentary rocks ranging in age from the Middle Permian to the Lower Triassic (Salopek, 1942; Kochansky-Devidé, 1971; Sremac, 1991, 2005).



The first published reconstruction of geological profile Brušane - Velnačka glavica (after Salopek, from Kochansky-Devidé, 1971).
1. Dark spotted dolomite (Middle Permian).
2a., 2b. White crystalline massive dolomite (Middle to Upper Permian).
3. Black limestone and shale; Zone Neoschwagerina craticulifera (Middle Permian).
3a. Black limestone and shale; Zone Yabeina syrtalis (Upper Permian).
4. Transitional dolomite (Upper Permian-Lower Triassic).
5. Sandstone (Lower Triassic).



A detail from the first large scale geological map 1:12 500 (after Salopek, 1942). Spotted Permian dolomite is presented with wave lines, black limestones of 2nd and 3 rd zone with black vertical marks, and transitional P/Tr dolomites with blocks. Position of the locality is marked with black arrow.

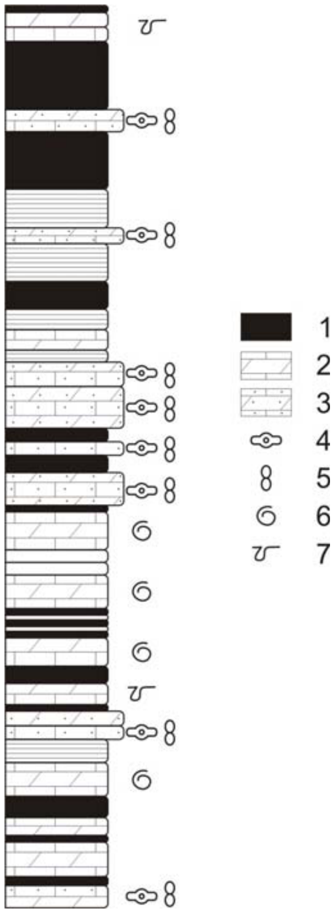
During the Second World War Italian army dug out a trench for heavy artillery, accidentally situated perpendicular to the bedding, and thereby opened a geological profile through the Middle Permian deposits (Zone Neoschwagerina craticulifera).

Numerous Permian fossils were collected at this locality, including cyanobacteria, calcareous algae (*Vermiporella nipponica* (Endo), *V. longipora* Praturlon, *V. serbica* Pia, *Vermiporella* sp., *Atractyliopsis* ? sp., *Velebitella triplicata* Kochansky-Devidé, *Goniolinopsis* sp., *Mizzia velebitana* Schubert,
M. yabei (Karpinski), *M. cornuta* Kochansky & Herak, *Salopekiella velebitana* Milanović, *Salopekiella* sp., *Connexia* sp.,*Gymnocodium bellerophontis* (Rothpletz), *Gymnocodium* sp., *Permocalculus tenellus* (Pia), *P. fragilis* Pia, *P. plumosus* Elliot, *Permocalculus* sp., Solenoporaceae gen.indet.), foraminifera: (*Glomospira* sp., *Pachyphloia* sp., *Palaeonubecularia* sp., *Climacammina* sp., *Globivalvulina* sp., *Kahlerina pachytheca* Kochansky & Ramovš, *Ozawainella* sp., *Reichelina* sp., *Staffellla cf. elegantula* Kochansky-Devidé, *Staffella* sp., *Nankinella waageni* (Schwager), *Nankinella* sp., *Sphaerulina croatica* Kochansky-Devidé, *Schubertella* sp., *Dunbarula nana* Kochansky & Ramovš, *Chusenella velebitica* Kochansky-Devidé, *Dunbarinella velebitica* Kochansky-Devidé, *Eoverbeekina cf. paklenicensis* Kochansky-Devidé, *E.* cf. *salopeki* Kochansky-Devidé, *Neoschwagerina craticulifera* (Schwager), *N. occidentalis* Kochansky & Ramovš, *N. rotunda* Deprat, *Neoschwagerina* sp., *Yabeina syrtalis* (Douvillé), *Agathammina pusilla* (Geinitz), *Agathammina* sp.div., *Hemigordiopsis renzi* Reichel, *Hemigordius irregulariformis* Zaninetti, Altiner & Catal, *H. cf. ovatus* Grozdilova, *Hemigordius* sp.div., *Baisalina pulchra* Reitlinger); microproblematica (*Tubiphytes obscurus* Maslov, *T. carinthiacus* (Flügel)); porifera (*Guadalupia cyllindrica* Girty, *Peronidella* ? sp.); corals (*Waagenophyllum* sp.); bivalves (*Shikamaia ogulineci* Kochansky-Devidé, *Edmondia permiana* Simić); gastropods (*Bucania kattaensis* Waagen, *Pleurotomaria* sp., *Murchisonia (Cerithioides)* sp.); cephalopods, bryozoans (*Fenestella* sp.), brachiopods (*Martinia velebitica* Sremac); echinoderms (crinoids tams, radiolae); ichnofossils (*Zoophycos*).

Almost vertical layers of Middle Permian deposits in a canom trench at Kalvarija locality (a part of Salopek's profile to Velnačka glavica hill).

Middle Permian deposits at this locality were deposited by down-slope transport in an intraplatform depression (Sremac, 1991). Together with clastic material, numerous remnants of shelf biota (mostly foraminifera and calcareous algae, sporadically with sponges, mollusks, bryozoans, brachiopods and echinoderms). Fine grained material from the suspension was deposited between the stress episodes, containing food particles for deposit-feeders.

***Zoophycos* bioturbations at Kalvarija locality. Acetate peel. X2. (after Sremac, 1991).**



Simplified geological column through Middle Permian deposits at Kalvarija locality presenting several repeated phases of down-slope transport. A full cycle comprises biokalkarenites (3), black shales (2) and bioturbated dolomites (1). Biokalkarenites contain numerous remnants of foraminifera (4), calcareous algae (5), sporadically with brachiopods, bryozoans and echinoderms. Dolomites contain mollusks (6) and ichnofossils (7).

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SMILJAN – BIRTHPLACE OF NIKOLA TESLA

Memorial Center „Nikola Tesla“ in Smiljan village was open 10th July 2006, at 150th anniversary of birth of Nikola Tesla. It is a part of the Museum of Lika Region. The main idea of the center was to present different aspects: science, art and tourism, and therefore be suitable for a wide range of visitors, from little children to specialized scientists.

The most interesting parts of the center are: Tesla's birth house, church of St. Peter and Paul, cemetery, sculptures of modern artists and models of some important Tesla patents and discoveries: Test station from Colorado Springs, turbine and a remote controlled ship.



Model of test station with high antenna from Colorado Springs (1899–1900) exhibits Tesla's experiments in lightning energy, wireless energy transport and high-frequency electric power.

Turbine is constructed of parallel discs. Its movements can be followed by a led-indicator in a water-mill.

Ship was constructed in 1898 and was wirelessly radio-operated. Visitors can see it on Vagancica creek, between the two bridges.

http://www.gospic.hr/info/Mem_centar_Nikola_Tesla.asp

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MAPS

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