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FIELD-TRIP GUIDEBOOK

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Cover: Fossil desication cracks in Eocene deposits, Lopar, island of Rab

Your hosts:


Danijela and Petar

Karmen and Alex



Vlasta and Tihomir

Jasenka and Renato

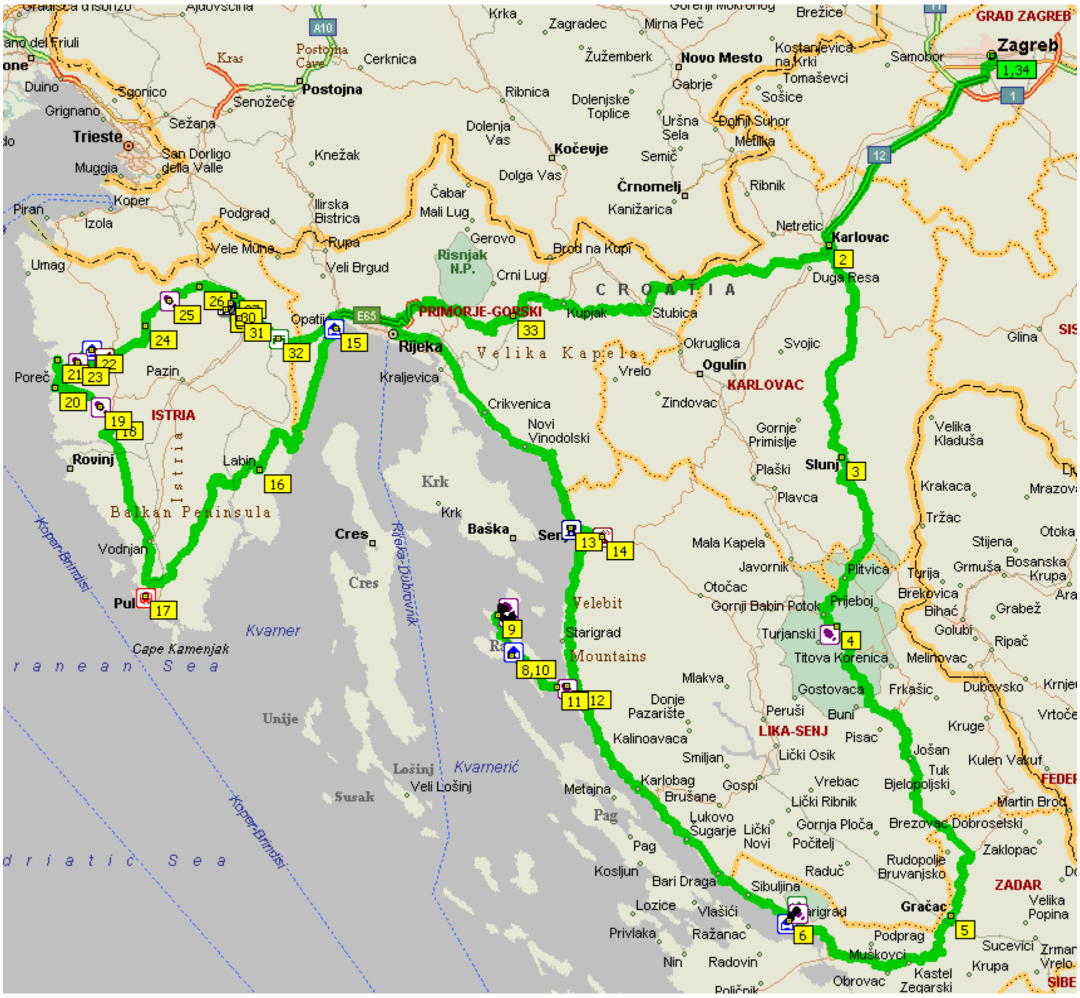

We wish you a very, very pleasant trip!

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 km2) 1,777 km of coastline with 1185 islands. There is 4,5 million of inhabitants.

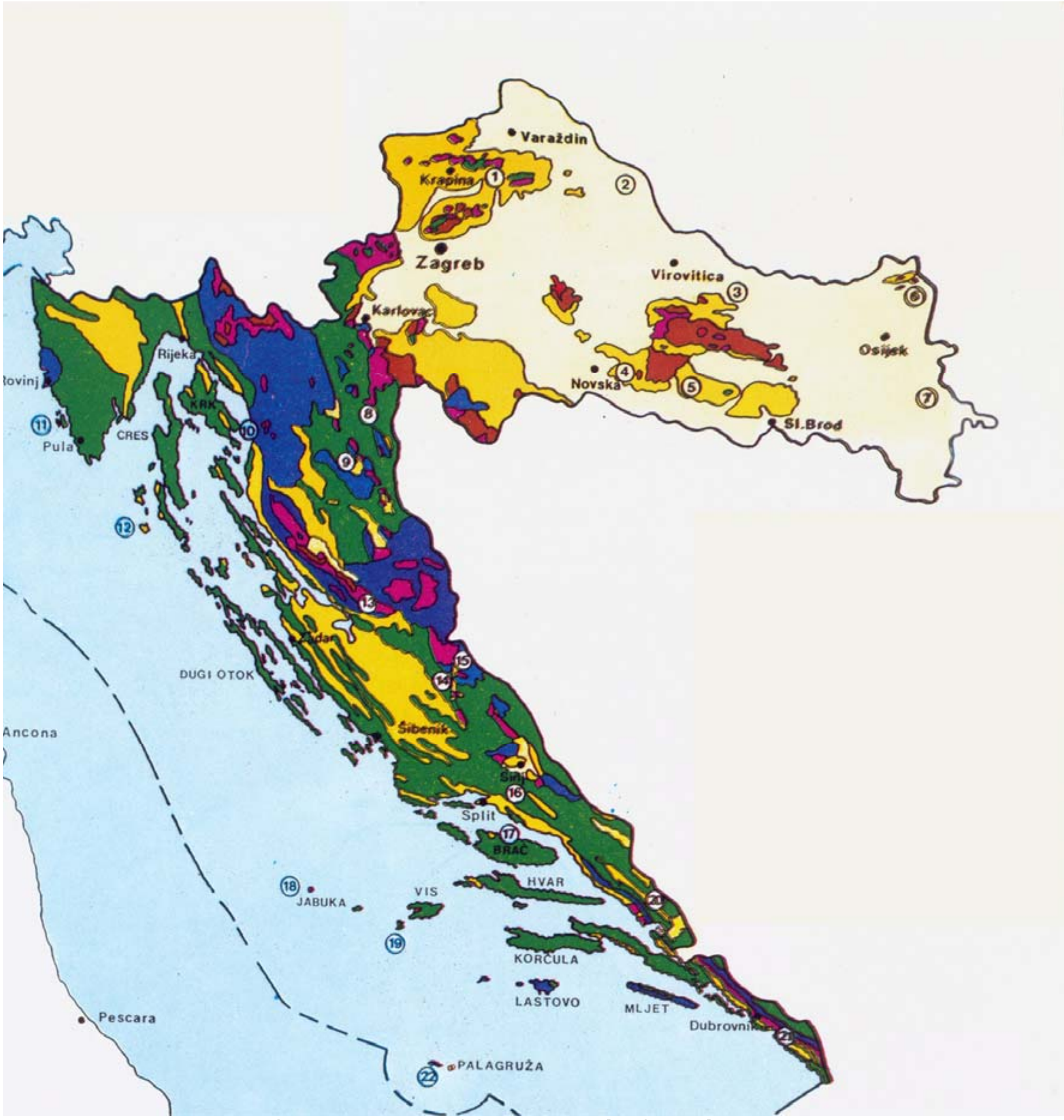


Our tour will start in Zagreb, go towards the SSE across the Dinaride mountain chain, visit some beautiful and interesting places along the coast and on Rab island, cross over Istria peninsula, and pass through Gorski Kotar region on return.

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 sratigraphic 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.
sedimentation of the dolomites rich in onkolites and stromatolites. In Norian and Rhaetian there was a continuous sedimentation in the shallow sea, mostly represented by the so-called Main Dolomite (Hauptdolomit).
In Jurassic period a continuous carbonate sedimentation takes place with massive and well-bedded limestones. In Early Jurassic, carbonate sedimentation continues from the Upper 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 Svilaja Mt.



Geological map of Croatia, Velić,I. & Velić,J., 1992

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 the clastic beds, there is a continuous

Transition from Jurassic to Cretaceous is continuous transgressive. Cretaceous is mostly represented by limestones and dolomites, with some clastic sediments in the northern Croatian parts. In the Upper Cretaceous, rudist limestones dominate in the form of the reefs. 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 oppened the deeper parts. An interruption in the shallow sea sedimentation took place in Istria.
In Paleogene, there are some stronger tectonic movements. In Eocene, a transgression over very differentiated paleorelief resulted in significant facies changes over small distances. The sedimentations 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 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).

REFERENCE:

VLAHOVIĆ, I, TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. (2002): The Kartst Dinarides are Composed of Relics of a single Mesozoic Platform: Facts and Consequences. Geologia Croatica, 55/2, 171183.

3. DAY 0

CITY OF ZAGREB

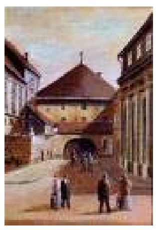
Petar Boromisa

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 beetwen 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 km2
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 centuries, 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. The 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 still 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 1960s on, the city spread out over the wide plains alongside the Sava River, where a new, contemporary business city has develop, 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

ROAD ZAGREB – KARLOVAC – SLUNJ

Karmen Fio

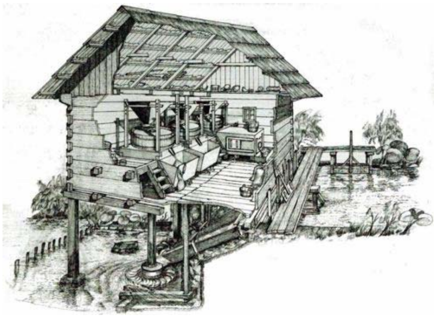
The capital of Croatia, **Zagreb**, is situated in the NW part of the Panonian plain with the Medvednica Mt. at north. It is set on the alluvial terace of the Sava river, with mostly unbanded sediments: pebbles, sands and clays of the Holocene epoch (Šikić et al., 1979).

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.

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. it 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

PLITVICE LAKES

Srećko Božičević and Karmen Fio

The Plitvice Lakes are the „karst phenomenon" situated in the central part of Croatia.

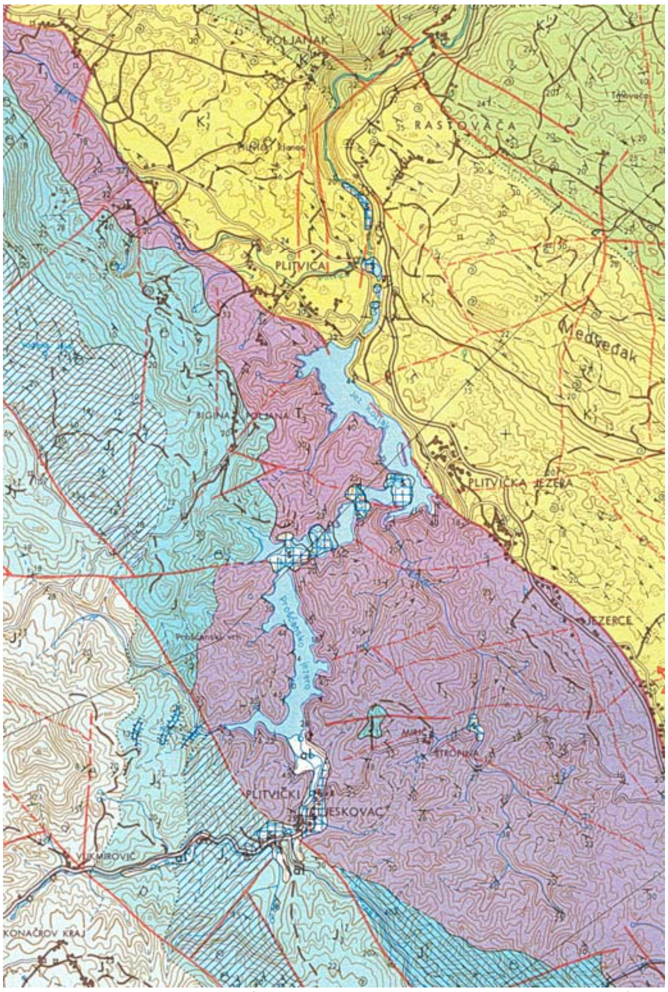


Fig.1. Detail from a geologIcal map of the Plitvice lakes, M 1: 100 000 (after Polšak, 1969)

Streams (Crna Rijeka, Bijela Rijeka, Rječica) are running from the southeastern mountain slope of Mala Kapela Mt. towards the Lakes, feeding them with water.
16 lakes are separated in two groups: Lower Lakes (Milanovac, Gavanovac, Kaluđerovo jezero, Jezero Novakovica brod) and Upper Lakes (Prošćansko jezero, Okrugljak, Batinovac, Veliko jezero, Malo jezero, Vir, Galovac, Milino jezero, Gradinsko jezero, Kozjak).
The Lower lakes (below Kozjak) are situated on the Upper Cretaceous rudist limestones, and the Upper lakes on the Upper Triassic Main Dolomite (Hauptdolomit) with the clastites underneath, which makes this karst water phenomena possible. Surface water-flows in the Lower lakes are explained by the downstream (northern) Upper Cretaceous (Turonian) marls and schists which are the natural barrier for the flowing water. Because of them, the canyon sides contain a lot of caverns, and the ground water flows towards the Korana river (Fig. 1, 2). The main cause for the occurence of the lakes in this area are the tufa

deposits (formed by precipitation from bodies of water with a high dissolved calcium content) and the sedimentation of tufa in this area is intensively investigated.

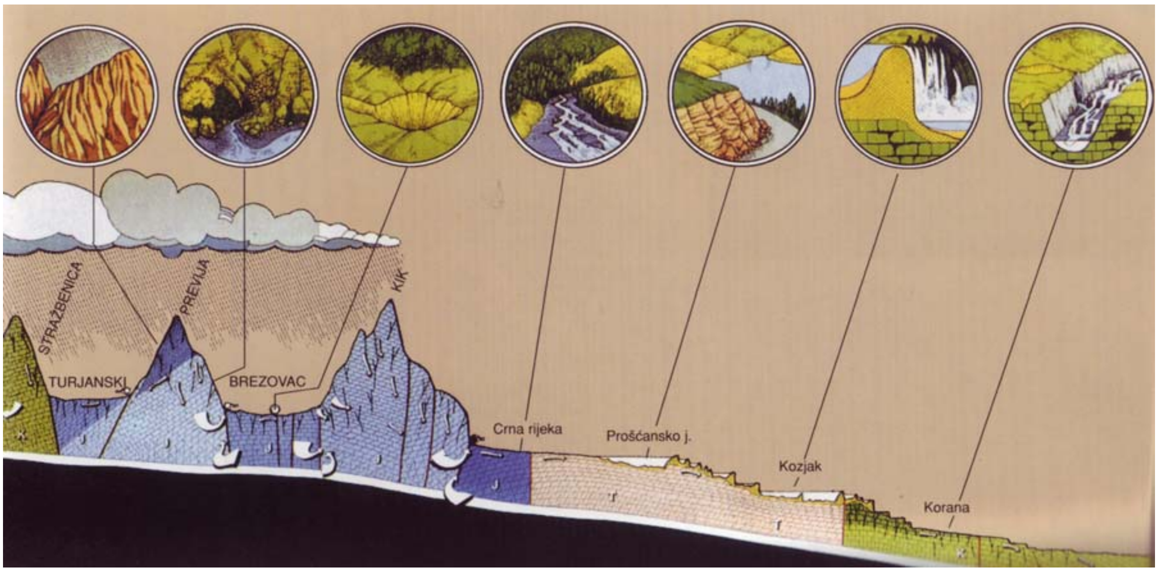


Fig.2. Hydrogeological profile with source area built up from karstified limestones with dolomite intercalations of the Jurassic age (blue colour). White arrows represent the flows of the subsurface waters towards the Bijela rijeka and Crna rijeka springs. Lakes between the Prošćansko lake and Kozjak are situated on Triassic dolomites (violet colour), and Lower lakes and Korana river lie on Cretaceous karstified limestones (From the "Plitvička jezera - Natural History Guide", 1998).

PARK HISTORY:

At the beginning of 20th century Croatian scientists started the complex investigations at Plitvice lakes. Professor Ivo Pevalek studied the biodynamics of travertine and processes of travertine barriers growth. Due to his efforts the first legal protection of the Plitvice Lakes was realized in the years 1928/1929.
Croatian Parlament declared the Plitvice Lakes a Natural Park in April 1949. UNESCO recognized the exceptional beauty of this area in 1979 and added the Plitvice Lakes to the list of World's cultural and natural inheritance.
Important enlargement of the park took place in 1997, when 266 km2 large drainage basin was incorporated in the protected area.

REFERENCES:

Polšak, A. (1969): Geological map of the Plitvice Lakes, 1:50 000.
Božićević,S. (edit) (1998): National park Plitvička jezera - Natural History Guide.
http://www.np-plitvicka-jezera.hr/default.aspx?lan=en
http://whc.unesco.org/pg.cfm?cid=31&id_site=98

ROAD PLITVICE-UDBINA-GRAČAC-STARIGRAD

Karmen Fio

After the structure in which Plitvice lakes are set, we pass through Lower Triassic (Campilion) 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, ca. 100 km2 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

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

5. DAY 2


2nd day
Starigrad
PRIMORJE-GORSKI
Rab
CROATIA
Balkan Peninsula
LIKA-SENJ
Velebit Mountains
Karlobag
Metajna
Pag
Lukovo Sugarje
Bari Draga
Tribanj-Krušica
Sibuljina
Ražanac
Vinjerac
ZADAR
Dalmatia
Gospić
Perušić
Otočac
Kvarnerić

GEOLOGY OF THE NATIONAL PARK „PAKLENICA“

Jasenka Sremac

Nationalni park „Paklenica“ is situated in the Velebit Mt., one of the geologically ang geomorphologically most interesting regions of Dinarides. (Fig.1).

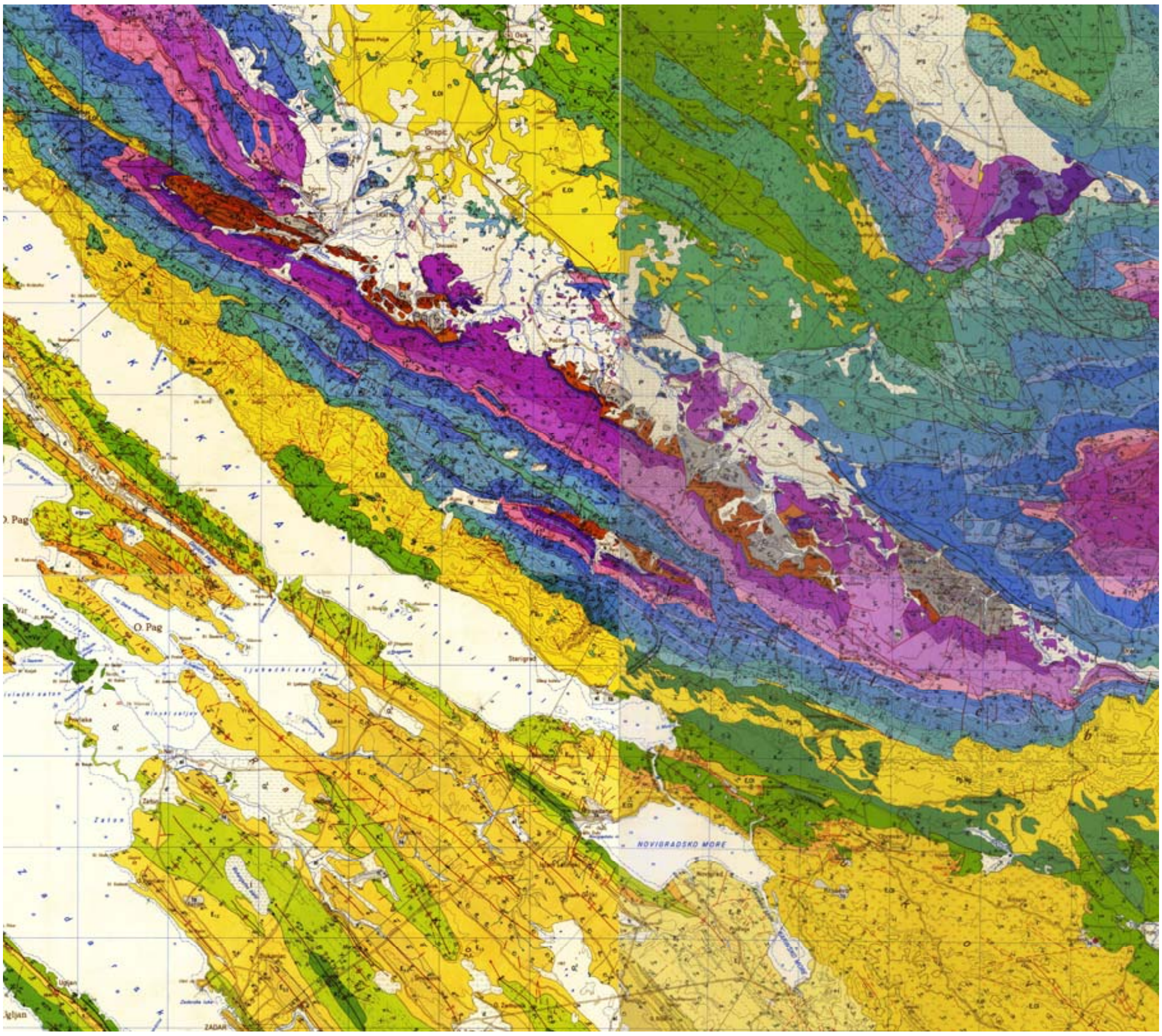


Fig. 1. Geological map of the wider area of Paklenica 1:100 000 (from the Basic Geological map of Yugoslavia, sheets Gospić and Zadar (Majcen et al., 1973; Sokač et al., 1976) . The oldest Permian rocks are brown and brownish-gray coloured. They are surrounded with Triassic (violet), Jurassic (blue) and Cretaceous rocks (green). Clastic Palaeogene rocks (yellow) are particularly well exposed along the Adriatic coast.

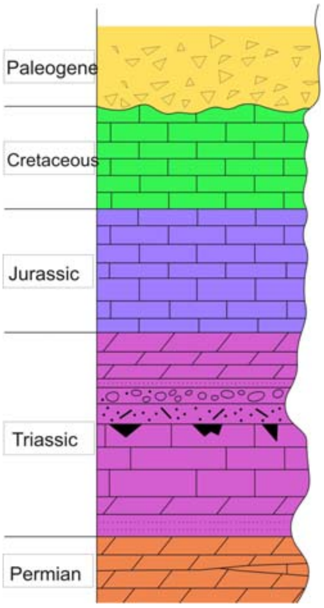


Fig. 2. Schematic geological column of the area of the National park Paklenica.

PALAEOZOIC
Permian

The oldest rocks in the area of the National park Paklenica belong to the Middle-Late Permian (Fig.2) Permian dolomites compose a core of the Velika Paklenica anticlyne, covering the area 9,5 km long and 1 km wide (Fig. 1). Minimum thickness of these rocks is 500 m, but the underlying horizon is not exposed on the surface (Salopek, 1952, from Sremac, 2005). Dolomites were deposited on the shallow bottom of the former tropical sea (Fig.3) in palaeoenvironmental conditions similar to the recent Bahama Bank. Within the Permian dolomites, intercalations of black limestones and shales occur sporadically, containing excellently preserved marine fossils.Rich and diverse shallow marine communities are composed dominantly of green and red calcareous algae, benthic foraminifera, calcareous sponges, bryozoans and brachiopods (Plate 1). Sporadically fossil molusks, sea lillies and echinoids occur. Some of the taxa were wide-spread in the Palaeotethys, but endemic species can be also found, particularly among brachiopods.(e.g. *Martinia velebitica*). Importance of the Velebit Palaeozoic microfauna can be recognized through the internationally accepted names of taxa, such as *Velebitella, Mizzia velebitana, Gyroporella likana;*

The most common Permian microfossil in the Permian of Paklenica is a small fusulinid foraminifera *Eoverbeekina paklenicensis*.

In the uppermost Permian horizons clastic intercalations become more common. These yellowish rocks were named „Transitional dolomite“ by Salopek, 1952. A presumed continuous transition into the Early Triassic was confirmed by recent geochemical and isotope analyses. Evidences of the end-Permian catastrophe were so far traced at two sections at the Velebit Mt. (Fio et al. 2006 a,b)

MESOZOIC

Triassic

The Early Triassic mixed clastic and carbonate rocks continuously overly the Permian transitional dolomites. The first evidences of life after the PTB are microbialites. 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. Ferruginous 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 ammount 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 indeks species *Gyroporella vesiculifera*. Three lithotypes can be distinguished in the Park: microbialites, dolomitized oolitic kalkarenites and pure crystalline dolomites.

Jurrasic

The highest parts of the Velebit Mt. Are built up of the Jurassic rocks, countinuously overlyying 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.

Middle Jurrasic deposits exhibit the visible environmental change. Fossil communities are less diverse, and dolomites can be well recognized in the field by their spotty outlook. Indeks 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, kalkarenites 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 fossils of mollusks, foraminifera (e.g. *Orbitolina* cf. *discoidea*) and calcareous algae.

CAENOZOIC

Tertiary

Calcareous breccias cover the large areas on southwestern slopes of the Velebit Mt. More details on their composition and origin can be found in a separate article (Vlahović et al.) in this Field Guide.

Quaternary

Glaciofluvial deposits, including the slope breccias, appear at several localities in the Park. Their are composed of angular carbonate fragments originating from higher parts of the Velebit Mt. Würmian age was presumed for these deposits.

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PERMIAN-TRIASSIC BOUNDARY IN THE VELEBIT MT.

Fio, K., Spangenberg, J., Sremac, J., Vlahović, I., Velić, I. and Mrinjek, E.

(*Causes of Permian/Triassic Mass Extinction at The Velebit Mt., Croatia: Geochemical And Isotopical Insights.* Reprint from 2nd Slovenian Geological Congress, Idrija, 2006)

A detailed paleontological, isotopic, organic and inorganic geochemical study, including major, trace and rare earth elements distribution, has been done for samples from the Rizvanuša locality, Velebit Mt. (SW Croatia), in order to explain environmental changes at the Permian/Triassic boundary. Continuous Permian/Triassic transitional beds in this area are mainly represented by early- to late-diagenetic dolomites. The most abundant fossils found within early-diagenetic dolomites are calcareous algae, foraminifera, calcisponges, bryozoans, brachiopods and mollusks. The drastic impoverishment of biota in the uppermost Permian is associated with a negative excursion at the transition of the $\delta^{13}C$ values of carbonates by up to 3‰ (P: −0.8 to +2‰, average +1.2±0.5‰; T: −1.3 to +0.9‰, 0.0±0.5‰), kerogen by up to 5‰ (P: −27.3 to −24.4‰, −25.8±0.9‰; T: −29.1 to −26.4‰, −27.5±0.4‰). The decrease in the $\delta^{13}C$ values in the carbonates and kerogens is synchronized with a drop in $\Delta^{13}C_{carb\text{-}ker}$ by 2‰, indicating lower productivity at the P/Tr transition. The $\delta^{15}N_{ker}$ values vary between −2.4 to +8.2‰ (P: +3.7±2.8‰; T:

+3.8±2.0‰), suggesting mixed contribution of ^{15}N-rich marine (~7‰) and ^{15}N-depleted terrestrial (~0‰) organic materials or cyanobacteria (−2 to +4‰).
REE concentrations in the Upper Permian rocks show a range from 3.7 to 82.4 ppm (average 18.54 µg/g), while the Lower Triassic dolomites have noticeable lower values with range from 8.7 to 15.4 ppm (average 11.21 µg/g). In the uppermost Permian rocks, approximately 10 m below the boundary, there is enrichment in most REE. This enrichment is associated with a negative Ce anomaly (1.1 to 0.5), suggesting increased oxidizing conditions in Late Permian sea water and more anoxic conditions towards the boundary (increasing values of Ce/Ce*). The highest REE concentrations at the immediate boundary, with both positive (La, Ce, Pr, Nd, Sm, Eu, Gd, Tm, Lu) and negative (Tb, Dy, Ho, Er, Yb) shifts of the REE, parallel the positive shift of REE concentrations described in the Idrijca Valley section in Slovenia (Dolenec et al., 2001).
At the boundary there is a substantial decrease in redox sensitive elements (2 µg/g V, 4 µg/g U, and 4 µg/g Cr), which coincides with the maximum of the Late Permian marine regression. The higher concentrations after that event (up to 25 µg/g V, 6 µg/g U, and 23 µg/g Cr) probably indicate the change in redox conditions in Early Triassic, which again led to oxygen deficiency.
The variations in the distribution of *n*-alkanes (C_{13} to C_{34}), acyclic isoprenoids (C_{21} to C_{28}), hopanes and steranes, indicate input of bacterial and algal biomass. The occurrence of odd long-chain *n*-alkanes (maximizing at C_{26}) and C_{39} steranes in all samples indicate a contribution of continental material. The first results of compound specific C isotope analyses of alkanes indicate a ^{13}C depletion towards the boundary, supporting the lowering of primary productivity.

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JELAR BEDS

Igor Vlahović, Ivo Velić, Josip Tišljar & Dubravko Matičec

(*Lithology and Origin of Tertiary Jelar Breccia within the Framework of Tectogenesis of Dinarides*, reprint from Field-Trip Guide Book, IAS Lecture Tour 99).

Jelar breccias represent one of the most interesting and most complex regional problems in Dinarides, covering large areas of Velebit Mt. flanks (see Fig. 1 in VLAHOVIĆ et al., this Vol.), as well as parts of Lika, northern Hrvatsko Primorje, etc. They were named by BAHUN (1963) after the type locality - Jelar Mt. in western Lika (hinterland of Velebit Mt.).

LITHOLOGY: Jelar deposits are represented by massive, unbedded calcareous breccia (rarely breccio-con-glomerate), composed of variable, angular (rarely subangular to rounded), weakly sorted fragments in gray to reddish carbonate matrix. Clasts belong to different stratigraphic units: the most common are fragments of Cretaceous limestones and dolomites and Jurassic and Palaeogene limestones, although clasts of Triassic carbonates, small bauxite grains and clasts of Palaeogene flysch deposits and Promina conglomerates and cherts can also be found. Size of clasts is very variable, ranging from few mm to several dm, although blocks of several meters, and even dozens of meters in diameter have been found. However, most of the grains are ranging from 1-10 cm in size. Although clasts originated from rocks of different age are usually mixed up, there are also areas characterized by clasts derived from only one stratigraphic level, as a consequence of simple geology of the source area. In some areas, e.g. some parts of the Velebit Mt. flanks, stratigraphic inversion of clasts was determined within the breccia succession (from the bottom to the top of the sequence fragments are originating from successively older rocks), as the result of weathering of deeper and deeper levels of the host rock. Although breccia deposits are usually grain-supported there are also some parts with matrix suport.

Jelar breccias cover different stratigraphic members, mostly tectonically deformed Jurassic (predominantly Malm), Lower and Upper Cretaceous carbonates and Palaeogene foraminifera limestones. Their thickness is very variable, ranging from several meter thick erosional remnants to more than 300 m (as proved by deep wells in southern Velebit area - MATIČEC et al., 1999).

STRATIGRAPHIC POSITION: Since the matrix of Jelar breccia usually contains no fossil remains it is not possible to directly determine their age. Concerning the fact that the youngest grains are usually of Eocene age. they were mostly determined as younger Palaeogene-Neogene deposits. However, recent investigations enabled some more precise determinations: according to the superposition of deposits in the Drniš area their age was estimated between the upper Lutetian and Bartonian, and in Hercegovina to Lutetian (SAKAČ et al., 1993). Eocene age was also indicated in the area of Cicarija (hinterland of Istria), where there are interbeds with Eocene foraminiferal assemblage within the succession of Jelar beds and sporadic foraminifera in the matrix (PRTOLJAN et al., 1995). In the area of Omiš (SE of Split) Jelar breccia are positioned between Promina deposits (uppermost Middle Eocene - Oligocene, IVANOVIĆ et al.,

1969) and Miocene marls, and were determined as Oligocene in age (MARINČIĆ et al., 1977).

INTERPRETATION OF ORIGIN: BAHUN (1974) connected the origin of Jelar deposits with reverse and nappe tectonics. HERAK & BAHUN (1980) concluded that rock masses were thrusted over already eroded terrains composed of rocks of different age, and fragmented parts of different rocks were gravitationally transported on different distances from nappe fronts and anticline cores. These authors also indicated penecontempora-neous age of Jelar with Promina deposits (i.e. upper part of the succession of gradual filling of former flysch basin formed during the Palaeogene within the Adriatic Carbonate Platform: from basinal deposits, shelf, coastal environments to alluvial fans and braided-river system), but also on the simultaneous deposition of Jelar breccia and most of the flysch deposits.

Although there are somewhat different opinions on the origin of the Jelar breccia, it may be concluded that their origin is a consequence of tectonic disturbances during *the* Tertiary tectonic cycle, which resulted in the uplift of Dinarides. During that period intensive compressional movements caused formation of numerous reversed structures, and in their frontal parts rocks were very intensely fractured. This process resulted in production of huge amounts of tectogenic material (grains, pebbles, cobbles and blocks) which was transported down steep slopes, forming abundant rockfall breccia fans. Part of this unsorted material was imported into water-filled sedimentary basins. Although the type of the basin cannot be determined on the basis of the matrix analysis it may be supposed that most of the material was deposited in lakes formed in the lower parts of the intense continental relief, and only minor part of the material was deposited in marginal NE parts of the contemporaneous marine environments. The other part of the rockfall breccia represented the source material for braided-river systems and alluvial fans of the Promina formation.

The aforementioned interpretation of their origin may explain both major problems of complexity of Jelar breccia: different timing of their formation and complex lithology differing from place to place. Different timing is the consequence of formation during relatively long-lasting Tertiary tectonic cycle, which was characterized by, through time, variable amounts of tectonic activity in different parts of the Dinarides. Complex lithology of Jelar breccia is primarily caused by intense tectonics -compression resulted in direct contacts of different units of the former Adriatic Carbonate Platform and enabled production of very variable source material, and formed very intense palaeorelief, resulting in formation of complex pattern of laterally different environments.

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JABLANAC

Ljerka Marjanac & Tihomir Marjanac

(*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 (AI) and the hotel site (A2), and younger section below the church plateau (B) (Fig. 1).

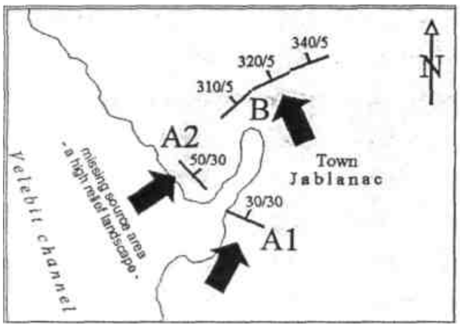

Fig. 1. Location of outcrops. Black arrows show paleotransport.

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.

Fig. 2. Location Al. Colluvial debrisflow deposits.

The colluvium sediments are exposed in sections Al (Fig. 2) and A2 (Fig. 3) 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.

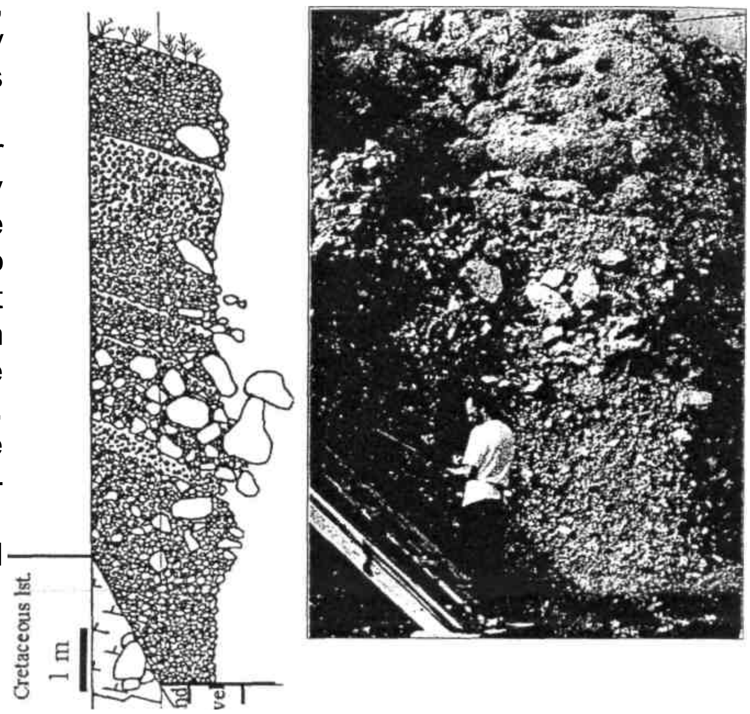

Fig. 3. Location A2. Debrisflow deposits: matrix-supported breccia below and clast-supported breccia above. The sediment log on the left shows contact with the base rock.

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.

Fig. 4. 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.

Fig. 5. Red soil horizons in alluvial succession at location B. An inverse graded, open-work gravel bed in the middle is a grainflow deposit

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.

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 (Fig. 1). 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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RAB

Rab is one of the islands of the Kvarner Bay archipelago in the north of the Croatian Adriatic Sea. In addition to the ancient town of the same name, there are seven other idyllic places scattered over the island: Barbat, Banjol, Palit, Kampor, Mundanije, Supetarska Draga and Lopar.

The town of Rab also boasts a long recorded history that dates back to the year 10 BC, when it is mentioned in an old Roman document by which the Roman emperor Octavian Augustus proclaims it a muncipium and grants it independence.
A long time ago Rab got honorary title „FELIX“ (happy); it bears witness to the fact that Rab was already fully developed and civilised at the time, providing amenities such as running water, baths, temples, a theatre, and a network of streets, to mention just a few.
More than 17 centuries ago a boy by the name Marin was born at Lopar. He learned the craft of stonemason, in search of a job left his home, crossed the Adriatic Sea and landed at a place near today’s Rimini on the Apennine peninsula.
His diligence and virtue soon earned him the sympathy of the Christian community he was living in, so bishop Gaudentium made him his deacon. Presecuted because of his propogation of Christianity, Marin fled to the hardly accessible hill Titan and built a small church there.
It was to become the foundation of a new city and state, today San Marino, in which the remains of the saint are still kept.

http://www.tzg-rab.hr/index_eng.php

7. DAY 3

GEOLOGY OF THE RAB ISLAND

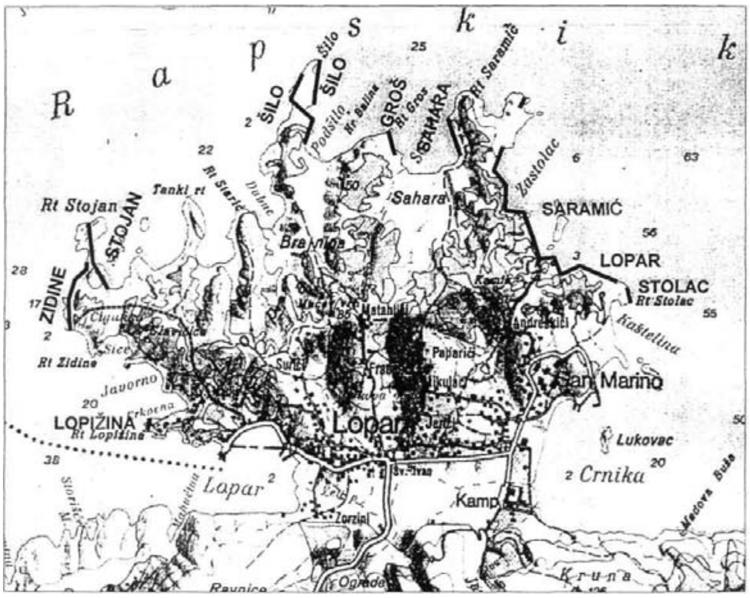
Tihomir Marjanac & Ljerka Marjanac

(*Eocene elastics of the Rab island*, reprint from Field-Trip Guide Book, IAS Lecture Tour 99).

The Island of Rab is one of the few places where we can study almost undesturbed Eocene elastics and where the relief of the Lopar peninsula allows almost 3-D study of sedimentary bodies. By excellent exposures of Eocene sandstones Lopar is exceptional in the whole Adriatic region, and so is the sedimentology of exposed elastics.
Its vicinity to the mainland, mild climate with 2417 sunny hours per year and mean winter temperature of 10°C, reliable connections by a ferry, and a good hotel network makes Rab attractive destination in every part of the year.

1. GEOLOGICAL FRAMEWORK OF THE ISLAND OF RAB
The Island of Rab comprises two Cretaceous anticlines and two Eocene synclines (Fig. 1) with NW-SE strike. The Kalifront anticline extends to the

Island of Dolin on the southeast, and on the north a part of the Lopar syncline is extending to the Island of St. Grgur. The island is characterized by normal relief, so we recognize synclines as valleys where only harder sandstone beds stand out. Excellent exposures of Eocene sediments are located on coastal cliffs of the Lopar peninsula.



Locations of sections studied on Lopar peninsula.

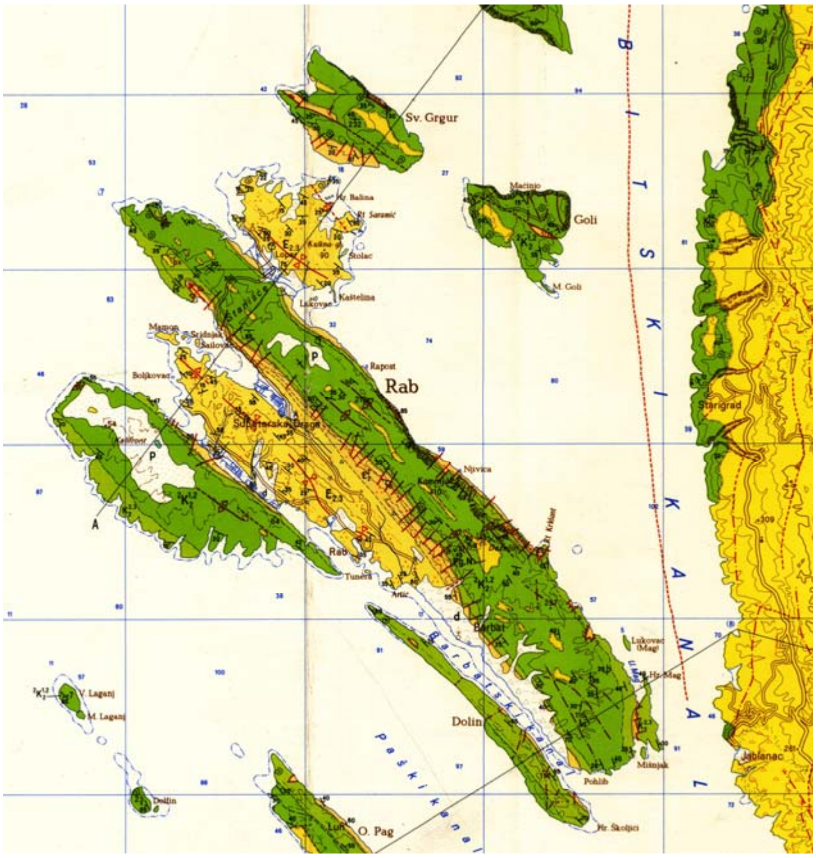


Fig. 1. Geological map of the Island of Rab (Mamuzic & al. 1996).

1.1. Cretaceous

Cretaceous deposits are represented by Cenomannian - Turronian and Turronian - Senonian rudistid limestones (Figs.I and 2) (Mamuzic & al. 1969). The former are brown-colored and contain poorly preserved rudists and chondrodonts. These are normally overlain by white to yellowish-colored rudistid limestones with hipuritids and gastropods of Turonian - Senonian age. Mamuzic (1962) wrote that thickness of the Cretaceous deposits reaches about 700 m.

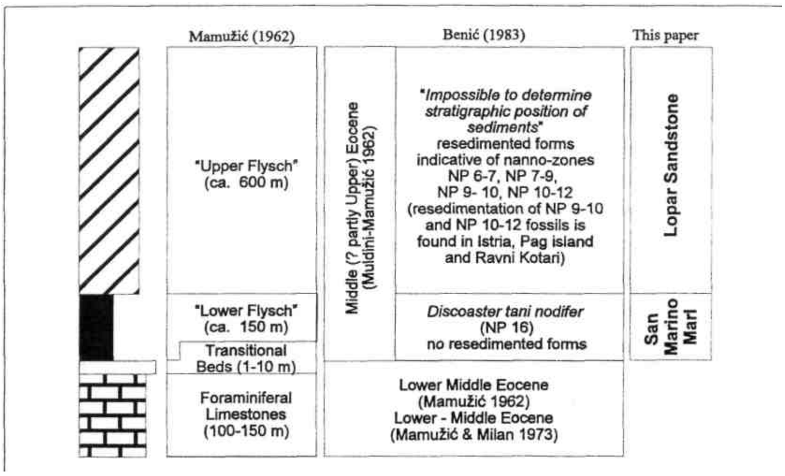


Fig. 2. Schematic stratigraphic column of the Rab island geology, and age attribution of various authors.

1.2. Paleogene

According to the Mamužić & al. (1969) Paleogene deposits on the Island of Rab are composed of Middle Eocene Foraminiferal Limestones (below), and "marls and sandstones" (namely "flysch marls and sandstones", Mamuzic & Milan 1973) (above) (Fig. 2). A more detailed subdivision of the Paleogene deposits of the Island of Rab was provided by Muldini-Mamuzic (1962) and is given in Fig. 3.

	Sediments	Microfauna	Sample localities
U.Eocene	Breccia and conglomerates		
Middle Eocene	Yellowish-brown finegrained hard sandstones	Small foraminifers disappear topwards, nummulites become more abundant	Lopar 16-20
		Rare recrystallized small foraminifers, nummulites frequent	Lopar 8-15
	Brownish limy-sandy marl	Rare calcareous, poorly preserved small foraminifers, agglutinated forms and nummulites more frequent	Lopar 3-7
	Brownish very sandy marl	Rare small foraminifers, more frequent nummulitids	Lopar 2
	Grayish-yellow limy marl	Calcareous small foraminifers in a smaller number, agglutinated forms somewhat more frequent. First occurrence of small nummulitids.	Lopar2a
	Gray limy marl	Lagenids and globigerinids predominate. Frequent rotaliid forms. Occurrence of typical Eocene species -*Hantkenina.* Agglutinated forms very rare. No nummulitids.	Kampor1 Krklanta 1 Krklanta 4 Mag 6
	Narrow zone of nodular limestones with glauconite Foraminiferal Limestones		

Fig. 3. Subdivision of Paleogene deposits of the Island of Rab (Muldini-Mamuzic 1962).

1.2.1. Foraminiferal Limestones

The contact between Paleogene and Cretaceous limestones is characterized by indistinct angular unconformity with rare bauxite occurrences. In places with no bauxite it seems that Cretaceous bedrock is karstified, but no real transgressive breccias have been found (Mamužić 1962).

The oldest member of the Foraminiferal Limestones are the Miliolide Limestones, which may be only 1-2 m thick, according to Mamužić (1962).

The Miliolide Limestones are followed by poorly bedded Alvelolina and Nummulite Limestones. These two members are petrographically similar, but differ in faunal content and habitus, meaning that Nummulite Limestones are

"denser, more compact and harder than Alveolina Limestones which are softer, even flowery" Mamužić (1962). Mamužić (1962) measured thickness of about 100 m for Foraminiferal Limestones, while Mamužić & Milan (1973) stated thickness of 100-150 m.
According to very rich fauna Mamužić (1962) determined the age of Lower to Middle Eocene, while Mamužić & Milan (1973) stated the age of the Lower to Upper Eocene.

1.2.2. "Transitional Beds"

Stratigraphically between Foraminiferal Limestones and "Flysch" there occur glauconitic nodular marly limestones and marly limestones. Mamužić (1962) stated that they represent *"a transition from Foraminiferal Limestone into flysch marls"* and included them into Foraminiferal Limestones. Because of their stratigraphic position, these limestones are usually treated as informal stratigraphic unit "Transitional Beds". Their thickness is very variable in the Adriatic region, and on the Island of Rab they attain 10 m in thickness (Dordevic 1984).

1.2.3. Clastics

The Eocene clastics of the Island of Rab have been, until present, variously interpreted:
a) Mamužić (1962) diveded the Eocene clastics into "Lower-" and "Upper Flysch". His "Lower Flysch"
is composed of marl with sandstone interlayers, while the "Upper Flysch" is an alternation of marls and sandstones. Mamuzic think": that the "Uupper Flysch" is transgressive on the "Lower", because the contact is marked with pebbels of "Lower Flysch" visible in the Kampor Bay.
b) Muldini-Mamužić (1962) had interpreted the "Lower Flysch" as deep-marine, based on microfossils,
and the "Upper Flysch" as of shallow-marine, even coastal environment.
c) Mamužić and Milan (1973) differentiated "Flysch marls" in thickness of ca. 150 m, and about 600 m
thick "Flysch marls and sandstones".
d) Marinčič (1981) held that the Eocene clastics of the Island of Rab are proximal facies of the flysch
basin which he reconstucted as spreading from Italy to Albania.
e) Marjanac and Marjanac (1991) reinterpreted the "upper flysch" sandstones as tidal sand waves that
migrated towards southwest.
f) Zupanič and Babić (1991) have indipendantly concluded the same and interpreted the cross bedded
sandstones as complex dunes built under influence of tidal flows, and concluded that the major part of the outer Dinaric clastic area in Eocene was covered with shallow tidal sea.
Within the Lopar elastics two different sedimentary units can be differentiated; the older unit is marly with only thin sand interbeds, whereas the younger unit is predominantly sandy. For the benefit of simplicity and to avoid genetic conotations, I propose to call the older unit the SAN MARINO - MARL (instead of an informal, but specific name "Lower Flysch") and the younger unit the LOPAR -SANDSTONES (instead of "Upper Flysch") (Fig. 2).

1.2.3.1. San M a r i n o - M a r l

San Marino - Marl is poorly exposed and therefore is has not been studied in detail. Due to larger content of marl, these deposits are easily affected by weathering and erosion. Muldini-Mamužić (1962) wrote that these marls contain poorly preserved macrofauna composed of rare echinoderms and crinoid stems, but very rich microfauna, which indicates a deepwater environment.

In the lowest part of the San Marino - Marls there occur gray limy (calcareous) marls with predominating calcareous foraminifers *(Lagenidae)* and rare agglutinated forms. Due to abundance of globigerinas these marls are sometimes named "Globigerina Marls". The overlaying sediments are grayish-yellow calcareous marls with poorly preserved microfossils and first tiny numulites, and brownish, very sandy marls with numerous large forams and very few small ones.

According to Mamužić (1962) San Marino - Marl is about 150 m thick.

1.2.3.2. L o p a r - S a n d s t o n e

Lopar - Sandstone consists of sandstone packages a few tens of metres thick, divided by bioturbated sandy marls. These sandstones are more resistant to weathering so they usually stand out in relief forming the Lopar peninsula and the morphological crest which extends along the whole Supetarska-Barbat syncline, on which the town of Rab is built. The Lopar - Sandstone on the Lopar peninsula is exposed perpendicular to its strike, but along the strike, too. This enables more efficient study than in the area of Rab where it is exposed only along its strike.

Analogous sandstones are also exposed on the Island of Pag, croping out in both limbs of the Pag syncline and extend further towards Ravni Kotari. Their characteristics laterally change and it is difficult to establish true stratigraphic correlation due to lack of physical correlation.

Mamužić (1962) held that the "Upper Flysch" is transgressive on the "Lower", because the contact exposed in Kamporska Draga is marked by pebbles of the "Lower Flysch" sandstone, and occassional pebbles of the Miliolida Limestones. At the top of Lopar - Sandstones Mamuzic found limestone pebbles (of walnut-size) and chert pebbles (0,5-2 cm in diametre), which he interpreted as indication of *"certain oscilations of the sea floor".*

Muldini-Mamužić (1962) stated that these deposits contain abundant macrofauna (although poorly preserved) and poor microfauna, and that small forams disappear topwards and large numulites start to predominate, what indicates a shallow-marine environment. In the lower part there occur brownish calcareous-sandy marls with rare and poorly preserved small foraminifers, more frequent agglutinated forams and frequent *Nummulites.* Yellowish-brown sandstones with large forams and rare unrecognizeable small forams follow above.

The thickness of the Lopar - Sandstone reaches about 600 m (Mamužić & Milan,1973).

1.2.4. The age of Rab clastics

Muldini-Mamužić (1962) analyzed the "flysch" fauna and concluded that the "Lower Flysch" is more fossiliferous, and that the "Upper Flysch" contains large foraminifers. Based on these large foraminifers she interpreted the age of the Rab "Flysch" as the uppermost Middle Eocene and possibly a part of the Upper Eocene.

Benic (1983) also analyzed the Rab elastics and determined nannofossils of the *Discoaster tani nodifer* nanno-zone (NP16) in the "Lower Flysch" (San Marino - Marl), stating that there were no resedimented forms in the studied samples. However, in samples of the "Upper Flysch" (Lopar -Sandstone) more resedimented than autochtonous species were found, so he concluded that *"it was impossible to determine stratigraphic age of deposits"* (p. 105). According to supperposition he assumed that the "Upper Flysch" deposits can belong to the same or a younger biozone. The resedimented nannofossils are key-fossils of the zones NP 6-7, NP 7-9, NP 9-10 and NP 10-12 (Take a note of this record! Lopar - Sandstone ("Upper Flysch") is exactly the object of our interest, and as visible at the outcrops, there prevails abundant allochtonous macrofauna).

. The last two allochtonous assemblages have also been determined in Istria, on the Pag island and in Ravni Kotari. Benic believed that these resedimented nannofossils originate from flysch which was contemporaneous to the Foraminiferal Limestones.

2. SEDIMENTOLOGY OF LOPAR - SANDSTONES

Lopar - Sandstones comprise the following facies (members): a) sandy marls, b) sandstone -marls alternation (heterolithic packages), c) sandstones, d) biocalcarenites, e) conglomerates and f) slumps.

2.1. **Sandy marls**

Sandy marls at the Lopar peninsula are several metres thick. Their color is bluish-gray, commonly dark gray when fresh. Sandy marls contain dispersed quartz grains of fine sand- and silt size, scattered *Nummulites* and occassionally oyster shells. Occassionally they also contain scattered coal debris, and carbonized plant debris. Usually, sandy marls are intensively bioturbated so the primary bedding is destroyed. Faint bedding is visible only locally, due to variations in sand content. There commonly occur several ichnospecies; *Skolithos, Thalassinoides, Ophiomorpha* and *Gyrolites.* Ocassionally there occur *Teredolites* bundles in primary position (Kajmic 1995). The intensity of bioturbation changes throughout the thickness of the sediment; it commonly disappears somewhere in the middle part and intensifies upwards again. The size of ichnofossils in sandy marls is also variable, so they are smaller in less bioturbated, than in strongly bioturbated intervals. The middle, unbioturbated to poorly bioturbated marl interval is 0,5 - 1 m thick, commonly dark-gray coloured.

Gutter-cast textures occur locally in sandy marls. They are ca. 20 cm wide and deep, and filled with *Nummulites.*

Origin and environment

Bioturbated sandy marls were deposited on relatively shallow shelf, which is indicated by macro-and microfossil assemblages with associated *Skolithos* and *Cruziana* ichnofacies. Intensive bioturbation indicates good aeriation of the environment, slow deposition rate and relatively insignificant terrigenous input. Depositional environment was probably deeper lower shoreface, as indicated by intensity of bioturbation, large size of boring organizms and episodic input of sand, probably a product of storm events (indicated by gutter-cast textures). Relict bedding suggests that the sediment was originally an alternation of cm-thick sand beds and marls, which was subsequently completely destructed by intensive bioturbation. Thus, the sand grains originated from sand beds, although some may be aeolian in origin.

Poorly bioturbated sandy marls with smaller ichnofossils and without sand interbeds was deposited during periods of better isolation of the sedimentary environment and poor aeriation of bottom water, as indicated by lower bioturbation rate and smaller size of ichnofossils. The depositional environment was probably an open shelf (offshore).

3.2. Heterolithic packages (Sandstone-marl alternation)

Heterolithic packages are composed of mediumgrained sandstones and marls in rhythmic alternation. The thickness of sandstone layers is up to 35 cm (5-35 cm), and marls are 10-20 cm thick. Bedding planes of sandstone layers are flat, and internal structures are rarely well visible. In some places,
some structures are visible due to selective weathering; parallel lamination, wave ripples, HCS (hummocky cross stratification, it is formed by combined flows (Arnott 1993, Nattvedt & Kreisa 1987)) and occassionally SCS (swaley cross lamination occurs in upper shoreface by storm induced processes like scour-and-drape (Walker & al. 1983). SCS beds have been described by Dott & Bourgeois (1982, 1983) as "amalgamated hummocky sequences" – HHH). Ichnofossils are common in this type of sediment, they penetrated through marls and their shafts are filled with sand. Escape traces *(Fugichnia)* simmilar to *Rosselia (Cylindrichnus)* with the largest diametre of 10 err. and over, and length over 0,5 m are locally visible.

Origin and environment

Heterolithic sediments were deposited above the storm wave base, under influence of storms and waves as indicated by HCS and SCS structures in sandstones. Storms alternated with relatively long fair-weather periods with only sedimentation from suspension, and the sea bottom was recolonized by benthic organizms. The depositional environment was probably a proximal part of open shelf, namely upper part of the lower shoreface, as indicated by a large number and overall thickness of storm-beds.

3.3. Sandstones

Lopar - Sandstones are medium- to coarse-grained, and occur in sharp contacts with bioturbated sandy marls or heterolithic sediments in the base. Sandstones form cross-bedded sedimentary bodies which are typically several metres thick. Sandstone bodies are commonly characterized by large-scale forset-lamination (Fig. 4) which is sometimes organized in bundles. The internal organisation of sandstone bodies is usually quite complex (Fig. 5),

because several thinner cross-bedded packages can be distinguished, each of them incised by erosional (reactivation) surface. Cross-bedded packages indicate migration of bed-forms over the first order bedding planes that are locally erosive and represent the base of migrating dunes.
Cross-bedded sandstones sometimes show grouping of laminae into packages - tidal bundles (Fig. 6), whereas some cross-laminated/bedded packages are interlayered with thin finergrained sandstones or thin mud laminae.

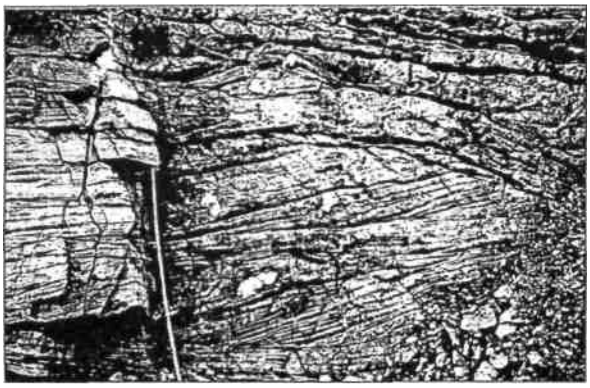


Fig. 4. Foreset-bedded sandstone body reveals migration of large dunes. E sandstone unit at Zidine-2 section.

In the lower part of cross-beds, interlayering with fine-grained sediments can form double mud drapes which disappear upwards due to erosion by sand.

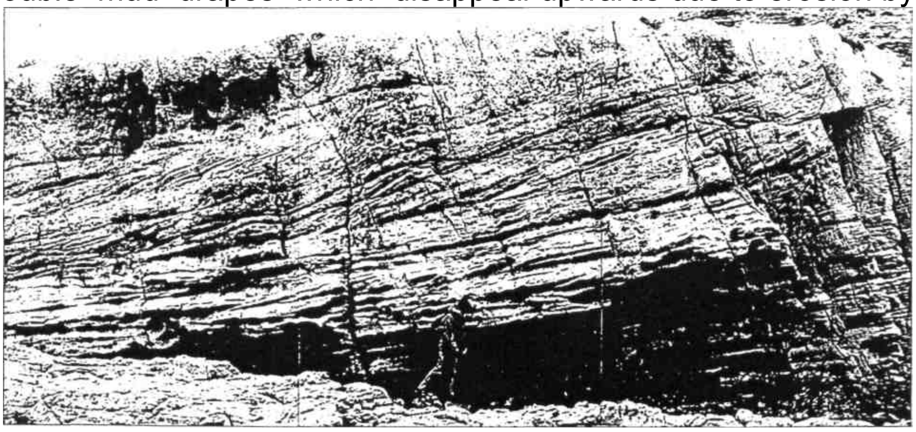


Fig. 5. Thick bodies are usually compound and comprise severalpackages of foreset-laminated sandstones which originated by migration of smaller dunes. Sandstone unit B at Lopar section.

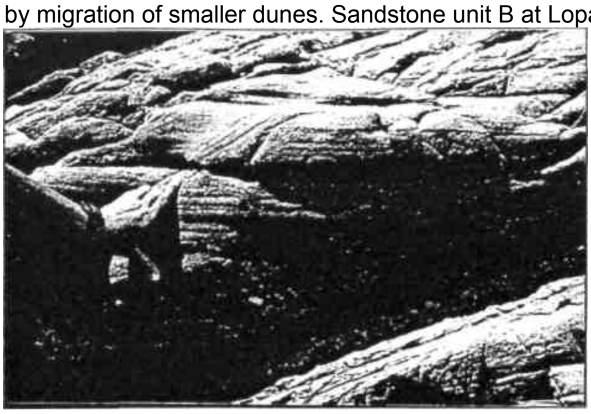


Fig. 6. Tidal bundles in sandstone body HI at Silo-1 section

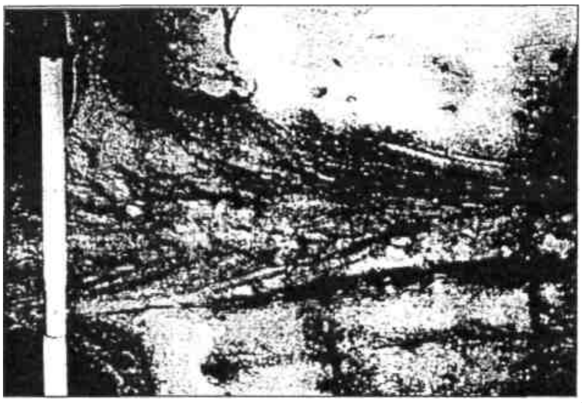


Fig. 7. Herring-bone structures in F sandstone unit at the Dubac Cove.

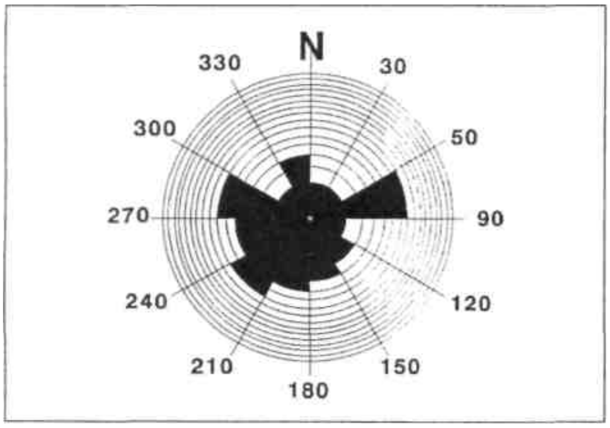


Fig. 8. Paleocurrent rose for foresets in sandstone bodies studied. One bedform per record. N= 39.

Foresets are tangential, and sandstones gradually wedge-out down the foresets and turn intolow- angle to horizontal bottomset packages in wich sandstones alternate with sandy marls. This type of bedding was named sigmoidal by Mutti & al. (1984), and individual packages were called sigmoidal packages (SBS). Some sandstone beds also show herring-bone structures (Fig. 7).

The orientation of foresets indicate major flow direction, and that one was quite consistent within the same body. However, data from all studied bodies show a circular paleocurrent distribution (Fig. 8)

Sandstones are poorly bioturbated to unbioturbated. We find here ichnofossils of *Skolithos-type,* large *Ophiomorphas* (which occassionally reach diametre of 3 cm and 1 m in length) (Fig. 9), frequent *Gyroides,* and rare *Thalassinoides.*

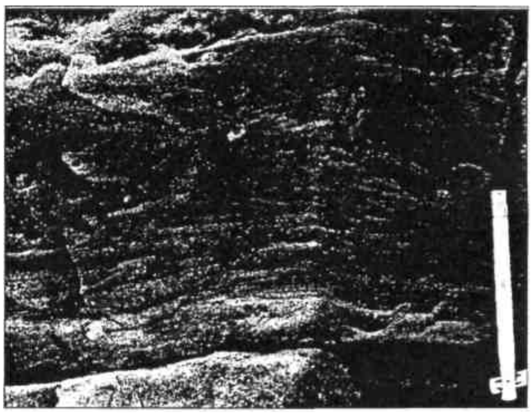


Fig. 9. *Ophiomorpha* burrows in C4 sandstone unit at Stojan section.

Relatively thin layers of biocalcarenites rich in Nummulites locally occur within some sandstone bodies, but most commonly they cap the bodies. In the latter case they comprise also gastropods and occasional bivalves.

Origin and environment

Migration of dunes produced large-scale cross-bedded sandstones, and variation of migration intensity and periodical erosions formed large complex sedimentary bodies that are usually referred to as sand waves, and can be included into Allen's (1984) type 2 and 3 bodies (Fig. 10). This type of sediment bodies was called a "complex dune" by Zupanič & Babić (1991) in the sense of Ashley (1990).

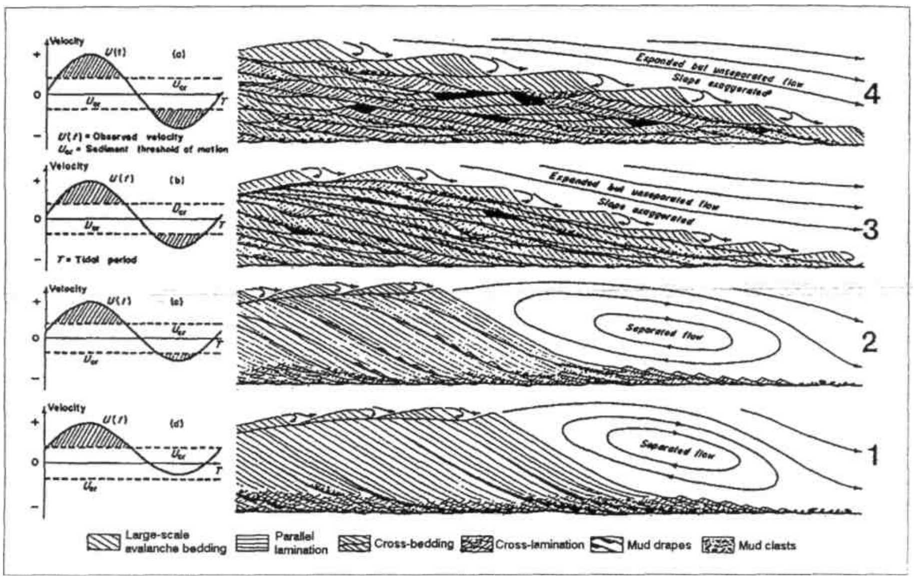


Fig. 10. Major types od sandstone bodies. (Allen 1984)

Tidal bundles (grouping of laminae in packages that are devided with finergrained or thinner sandstone) are considered diagnostic for tidal processes (Visser 1980, Roep 1991), as well as double mud drapes and herring-bone structures. Thicker packages of cross-laminae are interpreted as a product of spring tides, while the thin sandstone laminae develop during neap tides. Erosion can start during low tides, thus the low tides can reflect in sediments only as reactivation surfaces (Collinson 1970). During the high tide still-stand mud from suspension is deposited forming a mud lamina. Depending on simetry/asimetry of high tide and low tide flows, transport and sedimentation can be a result of a flooding high tide, tide retreat or both.

Tide amplitudes are low at the open sea, but increase in funnel-shaped straits, such as in La Manche (they attain 3-5 metres there), and large bays and estuaries (where amplitude may exceed 10 m). The sand bodies explored in the Gironde estuary, east Atlantic coast and south North Sea (Berne & al. 1989, 1991, 1993, 1994) are characterized by asimetry of the depositional body and predominance of a single transport direction (Fig. 12). It is obvious, from all of the studied cases, that high tide amplitudes are a prerequisite for generation of tidal sandstone bodies such as dunes, sand waves and bars, and that is conditioned by funnel-shaped topography. What did Eocene Kvarner Bay paleo-topography look like, we do not know yet because of the lack of explorations. Zupanic and Babic (1991) have interpreted a shallowmarine realm which they called a tidal sea, although they admitted that analogous depositional bodies also occur in estuaries. Because the tides had to be amplified, the depositional environment must have been within a deep funnel-shaped bay or estuary.

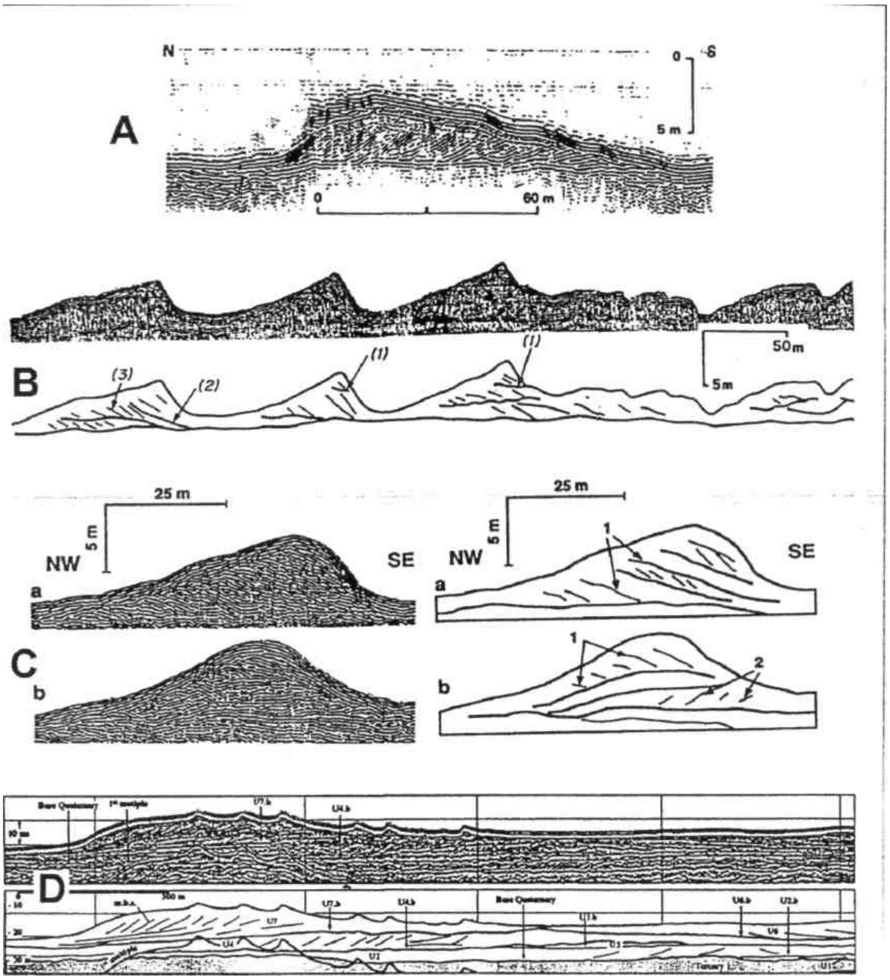


Fig. 11. Dunes and sand waves imaged by high resolution acoustic logs. A) Surtainville, France (Berne & al. 1989), B) Bay of Bourgneuf, France (Berne & al. 1991), C) Gironde estuary, France (Berne & al. 1993), D) Middelkaerke Bank, south North Sea (Berne & al. 1994)

3.4. Biocalcarenites

Biocalcarenites are usually few tens of centimetres thick, but in exceptional cases their thickness may reach up to 5 m. They are almost exclusivelly composed of foraminiferal skeletal debris (Fig. 12). where *Nummulites* predominate, subordinately there also occur *Discocyclinas,* scattered large ovsters, gastropods and rare irregular echinoderms. Biocalcarenites almost completely lack terrigenous component, although they may comprise up to 1 m long sandstone lithoclasts.

The lower boundary of biocalcarenites is sharp, sometimes characterized by ca. 10 cm wide and deep nummulite-filled gutter-casts, but sometimes poorly expressed. Where ichnofossil shafts occur below biocalcarenites, they are commonly filled with *Nummulites* tests.

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Fig. 12. Biocalcarenites with gutter-cast structures at the base. Lopar section.

Their upper boundary is generally flat, mostly devoid of any visible relief, and is sharply overlain by sandy marls. The upper biocalcarenite boundary of the C2/C3 units is symmetrically (wave-) rippled (Fig. 13).

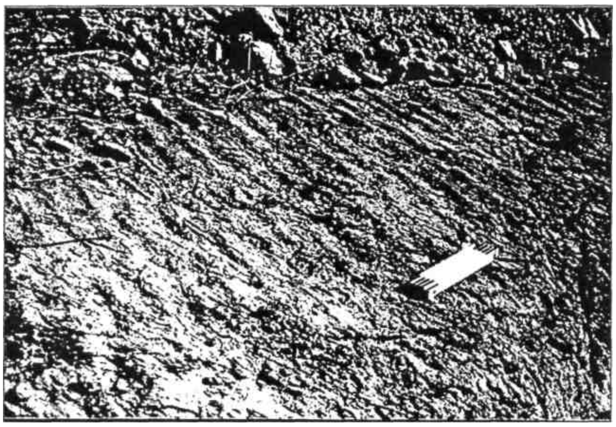

Fig. 13. Rippled upper boundary of the C2 units. Stojan section.

Origin and environment

Biocalcarenites were interpreted as skeletal tempestites (Marjanac & Marjanac 1991) which occured during exceptionally strong storms. However, they may also be a consequence of ravinement erosion which affected the underlying litihified sands.

Storm origin is indicated by gutter-casts which were formed by local vorteces in a storm surge. It is unlikely that the storm will create erosional relief deeper than a few decimetres to a meter or two. Even then, the deepest erosion will occur in less protected areas.

Ravinement is created by impinging waves which eroded the bottom, and the depth of erosion is known to reach several metres, and up to tens of metres. Lithoclasts which are identical to the underh ing sandstones document relativelly deep erosion, down to the level where the sand was already cemented. Supports interpreted ravinement origin.

Abundant foraminifers and larger skeletal debris (oysters and corals) were probably introduced from lateral sources, and partly remained as a coarse lag after erosion of poorly lithified sediments.

However, it seems that skeletal debris does not originate from the underlying sediments, because there we do not see identical fossils in their primary position, nor the fossil assemblage looks natural because abundant *Nummulites* occur along with big broken (!) oysters. It may be assumed that this skeletal debris originated from lateral environments as mentioned above. Wave (symmetrical) ripples on top of biocalcarenites document very shallow depositional setting in any case.

3.5. Conglomerates

Conglomerates occur only at the bases of units A, B and CI in lower part of the Lopar section. Gravel does not form individual beds, but occurs within cross-bedded sandstones in form of thin lenses and interbeds and sometimes they line the foresets. Gravel interbeds are some 10 cm thick, with erosional bases, they sometimes fill gutter casts and even some ichnofossil shafts. Gravel locally occurs scattered in sandstones, and locally occurs in some biocalcarenite beds, along with skeletal debris.

Clast diameter reaches 10 cm, and rounding as well as sphericity are generally good (Fig. 14). Clast lithologies are odd with regards to the External Dinarides seting, because they are mostly represented by various cherts and silicified arenites, and no carbonates (!), so their provenance is still unknown.

Fig. 14. Gravel interbed at the Stojan section.

Origin and environment

The grain size of gravels indicate considerably high fluid velocity, and good rounding (despite resistant lithologies) document their long fractional transport. Predominating silicified lithologies indicate that they represent the most resistant lithology in the hinterland. Since the cross-bedded sandstones are interpreted in terms of tidal sand bodies (sand waves), it is possible that this coarse sediment was deposited in low topography, eg. tidal channels.

Because of significant grain size difference, the coarse debris could not be transported and deposites simultaneously with medium sand by normal traction flow, which created the dunes and sand waves. Thus, gravel-size debris was probably reworked from hypothetical underlying coarse lag. which was most likely a fluvial deposit.

3.6. Slumps

Slumps frequently occur within Lopar - Sandstones, they are characterized by lensoid geometry and nice slump folds (Fig 15). Their thickness ranges from 0 to 6 m, and they occur within marly intervals as well as within sandstones. Slump folds are commonly made of sandstones and sandy marls, and occur in a sandy marl "matrix". The slumped sandy marls contain scattered *Nummulites,* oyster fragments and gastropods, and small scattered chert gravel.

Some slumps have started within the marly interval and got incised down to the underlying sandstones, so they may be overlying sandstones locally. The lower slump boundary is clearly erosional, whereas the upper is generally flat. The sediments overlying the slump are found to onlap its top boundary (Fig. 15).

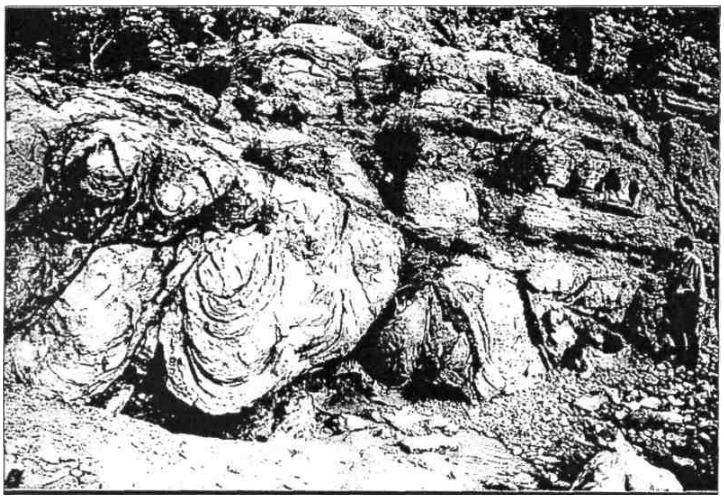

Fig. 15. Slump folds at the Stojan section. Note onlapping of the overlying sediments.

Origin and environment

Slumps indicate slope instabilities, regardless its gentle dip. Marls must have facilitated slumping and got remolded in "matrix" which surrounds the slump folds. Slump failures may have been initiated by slope oversteepening, slope overloading, liquefaction, hydraulic shocks, or earthquake shocks. It seems that overloading due to high deposition rate may have initiated slumps within some sandstone bodies. whereas slumps related to marly intervals may have been initiated by liquefaction or high-amplitude seismic shocks.

4. SEQUENCE STRATIGRAPHY

4.1. Boundaries

4.1.1. Sequence boundary - SB

Sequence boundaries (SB's) are developed at bases of sandstone bodies. Owing to good exposures, it was possible to trace laterally some of the boundaries. Sequence boundaries are characterized by marked basinward shift of facies, what is their key recognition criterion (Van Wagoner 1990). None of the studied SB's is characterized by traces of pedogenesis nor rootlets, although the sediments are locally rich in coal debris.

We can study lateral variations in the unit B SB characteristics along the Lopar section. It is locally characterized by coarse debris lag, composed of large sandstone lithoclasts (some exceeding lm in diameter) and abundant oyster skeletal debris and numulites (Fig. 16). Sandstone lithoclasts are compositionally identical to those of older units, and bear lithofagal borings. This coarse lag attains a thickness of up to 1,5 m, but laterally it thins-out and lithoclasts disappear, so there remains only abundant skeletal debris. The erosional character of a SB is well visible where coarse debris occurs, but is indistinct where laterally equivalent skeletal sands overlie sandy marls. Here, SB is characterized by increased concentration of oyster and *Nummulite* skeletal debris. This skeletal sediment is identical to biocalcarenites which commonly overlie cross-bedded sandstones. Correlation of two lateral detailed logs reveals incision in the base of unit B of 2,7m.

The sediments underlying the unit B sequence boundary are nodularly cemented, what is possibly caused by vadose cementation during exposure episodes.
Sometimes, cross-bedded medium-grained sandstones directly overlie shoreface sandstones (or offshore marls), only with small angular unconformity as observed at larger outcrops (Fig. 17).

Fig. 16. Sequence boundary in base of the unit B, Lopar Section. Note large semi-contemporaneous sandstone lithoclasts and abundant oyster fragments.

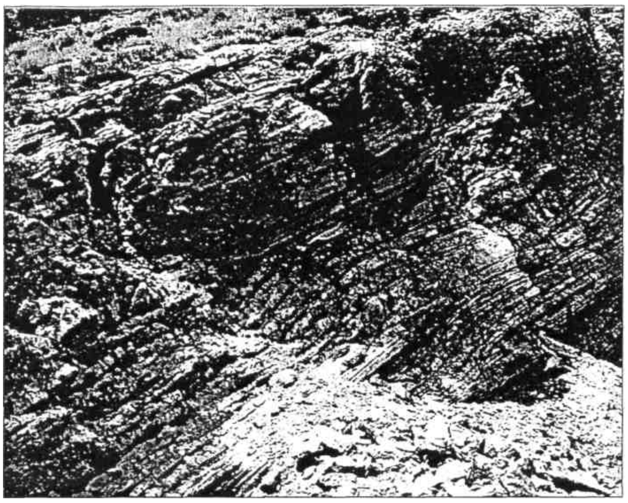

Fig. 17. The contact of D sandstone unit and underlying shoreface sandstones is characterized by angular unconformity. Groš Cape.

4.1.2. Regressive surface of marine erosion - RSME

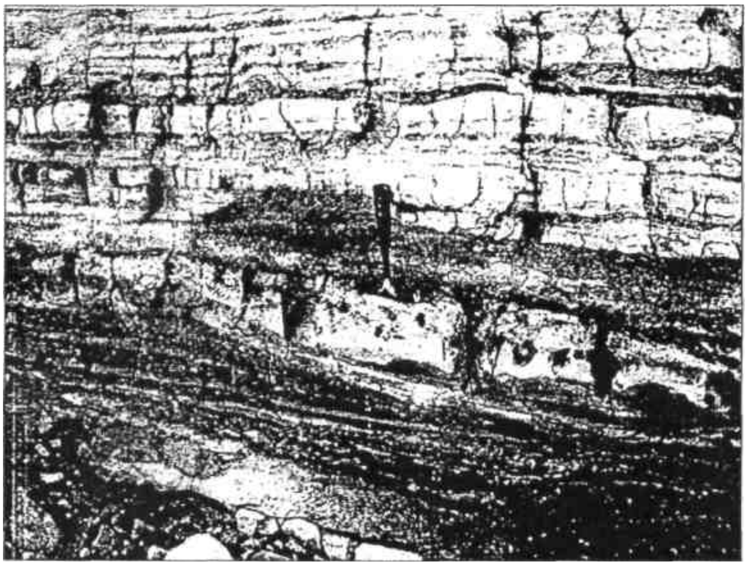

Fig. 18. Tempestite interpreted as a RSME underlies unit C2 shoreface sandstones, and overlies offshore marls. It is predominantly composed of skeletal debris (small bivalves and abundant numulites). Stojan Section.

Regressive surface of marine erosion is usually developed in the base of prograding shoreface deposits. It is most commonly characterized by numulite-filled gutter casts, or first thicker tempestite bed (Fig. 18) which overlies offshore deposits and document accelerated sea-level fall. Gutter casts are up to 20 cm deep and wide, and form laterally persistent horizon. RSME - tempestites are usually lensoid.

4.1.3. Flooding surface/Transgressive surface - FS/TS

Flooding/transgressive surfaces (FS/TS) are developed on top of biocalcarenites which overlie cross-bedded sandstones. They are overlain by more-or-less bioturbated sandy marls. The top biocalcarenite surface is generally flat and featureless, except at the Stojan section where it features regular wave ripples (Fig. 13).

4.1.4. Ravinement surface - RAV

Ravinement surface (RAV) is typically developed just above the cross-bedded afossiliferous sandstones. It is characterized by erosion a few tens of centimetres deep or with gutter-cast structures. This relief is filled with abundant numulites, some bivalves, solitary corals and rare sandstone lithoclasts (Fig. 19). Sandstone lithoclasts reach few decimetres in diameter, and document erosion of lithified sands. Traces of pedogenesis are never observed at the RAV surface.

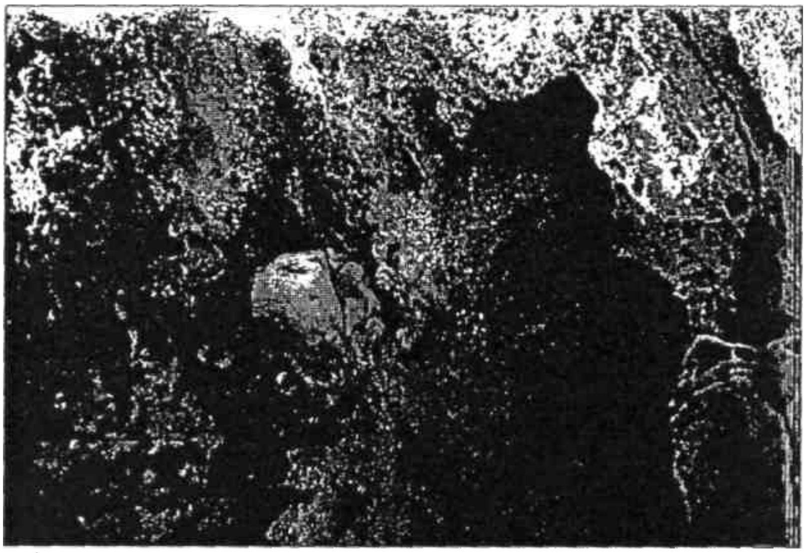

Fig. 19. RAV surface is characterized by gutter casts, and is overlain by nummulitic biocalcarenite which locally comprises scattered sandstone lithoclasts. Unit B, Section Lopar.

Skeletal debris probably derives from erosion of fossiliferous sediments which are not preserved at the sections studied.
Ravinement surface is not everywhere expressed equally well, so that erosion in biocalcarenite base is locally not visible.
The occurrence of RAV between cross-bedded tidal sandstones (below) and offshore marls (above) documents its origin at the time of relative sea-level rise, or deepening.

4.1.5. Maximal flooding surface - MFS

The surface of maximal flooding (MFS) is rarely developed as a *surface,* but comonly as a zone (at the outcrop scale). At the sections studied it is developed as an interval of unbioturbated to poorly bioturbated marls. Bioturbation typically decreases from the base of marly section to the interval which we interpret as a MFS-zone, and from that one upwards the bioturbation rapidly increases upwards and the sediment becomes almost homogenized. Clay content of these marls is usually somewhat higher than in the section

below and above, and the color is darker (dark gray to black). In some depositional units (interpreted in terms of depositional sequences) MFS-intervals are characterized also with thin clayey interbeds. Although we commonly refer to marls, the sediments studied are quite silty and sandy, and so are the MFS-intervals. The thickness of MFS-zone may be different, but commonly attains about 0,5 m.
The direct evidence of a MFS is lacking, except for poor bioturbation within overall bioturbated section, so a MFS is attributed to the best candidate-surface or interval, and that is the one with least bioturbation. Lack of bioturbation in the Lopar Peninsula sections is most likely a consequence of poor aeration, probably due to increased depth.

4.2. Composition of regressive intervals

Regressive intervals are recognized as sediment packages which overlie interpreted MFS-intervals, and are characterized by increase in bioturbation of marls, and increase in sand content. Some regressive intervals are characterized by increase in thickness of shoreface sandstones, and their gentle downlapping on the MFS-zone. Coalified plant debris also becomes more abundant upwards, as well as invertebrate macrofossils. Regressive intervals, where MFS-zone, or offshore marls are directly overlain by coarsegrained tempestites, gutter casts, locally slumps, and relativelly thck poorly bioturbated shoreface sandstones are interpreted as *forced regression* intervals.

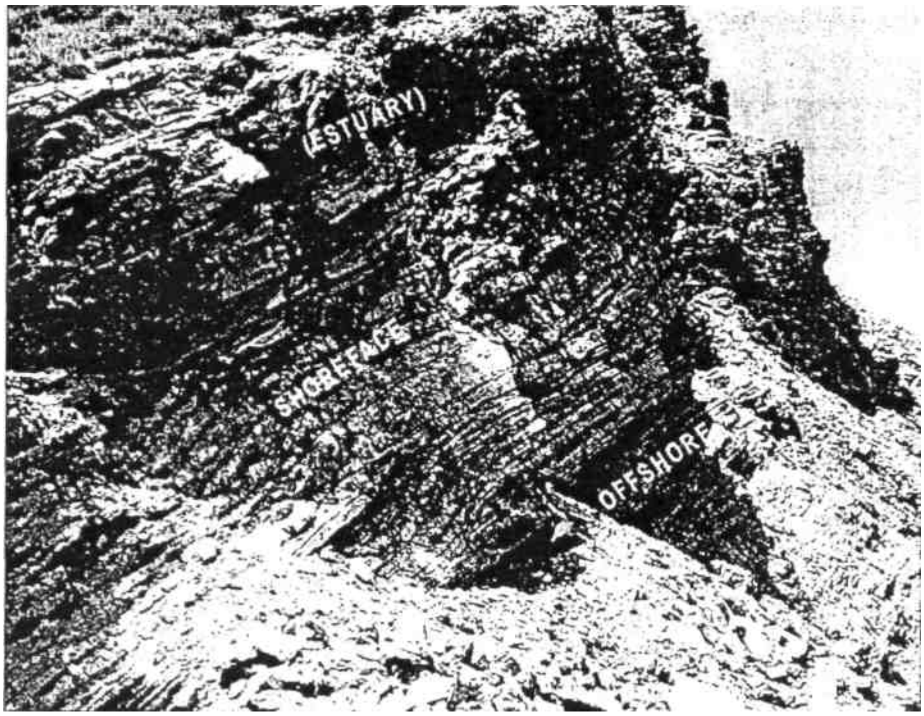

Fig. 20 Regressive sediments comprise from the base (MFS) upwards: offshore bioturbated mars and shoreface sandstones. Gros Cape.

4.3. Composition of transgressive intervals

Transgressive intervals are developed in all of the units studied, and are sometimes thicker than the regressive counterparts. They typically comprise two parts; unbioturbated to poorly bioturbated cross-bedded tidal sandstones and bioturbated sandy marls. Sandstones are sometimes unbioturbated in their lower part, and bioturbated in the upper. The bioturbation is generally increasing upwards. Skeletal biocalcarenites commonly occur at various levels within the transgressive intervals. They may occur near the base, at various levels witnin the sandstones, at their top and sometimes as interbeds in overlying sandy marls. Sandy marls of transgressive intervals are typically bioturbated, and commonly show coarse-tail fining upward trend. Sandyness of these marls is most likely a product of pervasive bioturbation which "homogenized" the sediment that originally comprised interbeds of sands.

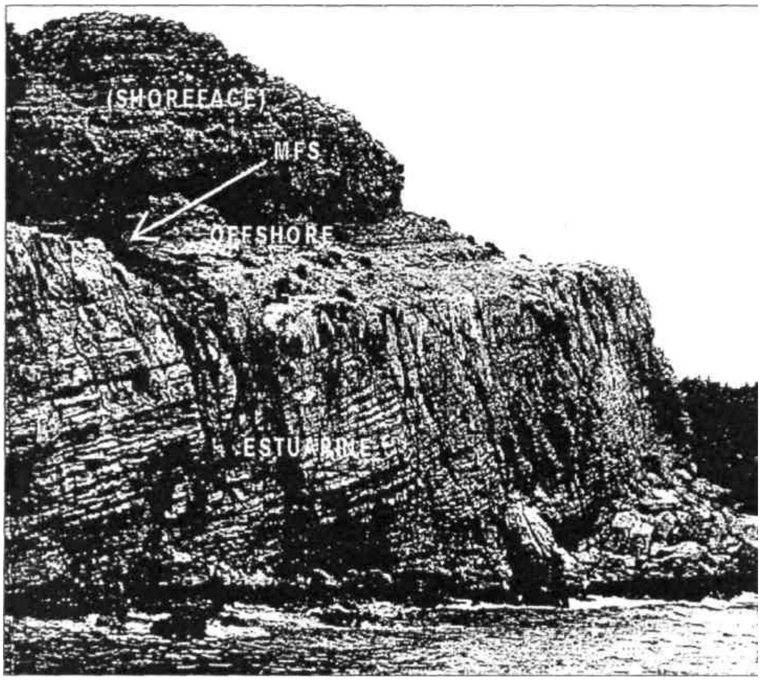

Fig. 21. Transgressive interval comprises tidal estuarine sandstones and offshore marls below MFS. Lopar Section.

4.4. Parasequences

Only a few parasequences are developed in the Lopar - Sandstones, and two (A 1 and A2) are recognized in the Lopar section. They are bordered by flooding surfaces (FS's) (Fig. 22.).

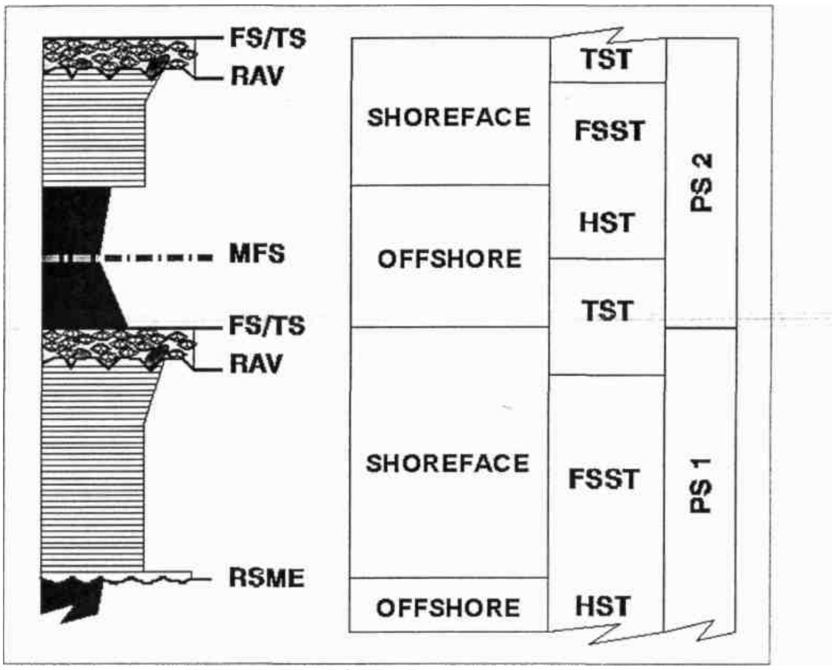

Fig. 22. Architecture of idealised parasequences

4.5. Sequences

Sequences are bordered by sequence boundaries (SB's) and 13 of them are recognized in the Lopar - Sandstones. They typically comprise lower transgressive-, and overlying regressive intarval.

The bases of all sequences (SB's) are characterized by basinward shift of facies, whereas their erosional character was recognized in only a few cases. Coarsegrained lag which directly overlies the SB was recognized only in one sequence. Where exposures permitted, angular unconformity between cross-bedded sandstones and underlying shoreface sandstones was recognized (Fig. 17). Flooding surfaces (FS's) are recognized in all sequences, except where unexposed. The MFS-interval is recognized in most of the sequences, although in some cases that was not possible due to pervasive bioturbation.

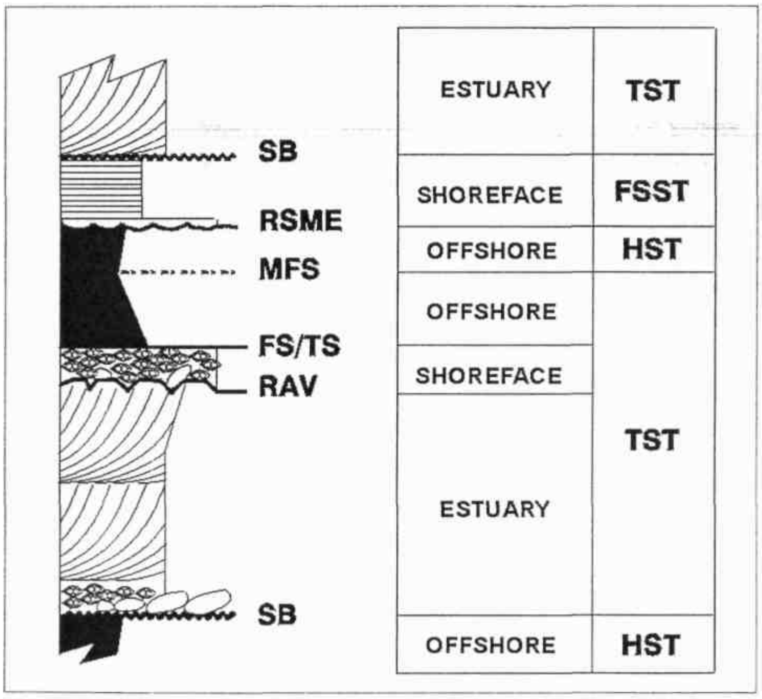

Fig. 23. Architecture of an idealised sequence.

5. CONCLUSIONS

The Lopar-Sandstones are unique in the Eastern Adriatic realm by their silicic composition and shallow-marine origine. The sediment succession documents several episodes of sea level rise and fall, so we can distinguish transgressive and regressive intervals.

Sandstones which build sandstone bodies were deposited by currents and we interpret them as sandwaves or complex dunes which have been deposited in an outer estuary setting. The provenance of sand was outside the present Dinaric range, probably in the Alps.

Sandstones that occur as sheet-like bodies, composed of numerous storm beds, are interpreted in terms of a shoreface deposit, that was incised by the base of sandstone bodies. The shoreface sandstones document facies progradation by gradual increase of thickness of individual beds and reduction of the number of marl interbeds. In those cases where thick shoreface sandstones overlie offshore marls, and their base is sharp and marked by thick tempestites, we have interpreted the forced regression.

Sandy marls were deposited in a lower shoreface where relicts of storm sandstones are preserved, or offshore where the sand was admixed by a pervasive bioturbation.

Succession of offshore sediments and overlying shoreface is interpreted as a regressive interval, whereas succession of estuarine sandstones and offshore sediments is interpreted as a transgressive interval. Both are parts of complete depositional sequences.

Frequent oscillations in sea level forced basinward and landward shifts of facies, so we believe the depositional environment was a paralic sea where a succession of incised valleys was formed during relative sea-level falls.

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7. DAY 4

ROAD JABLANAC-SENJ-RIJEKA-OPATIJA

Karmen Fio

Part around **Jablanac** is characterized by the Jelar beds. Going north-west, towards Senj, from St. Jura and in the area around **Senj** we encounter Upper Jurassic limestones, dolomites and breccias (Mamužić et al., 1973). Going on, towards **Crikvenica,** we pass through Upper Cretaceous (Cenomanian-Turonian) clastites, limestones and hornfels in an anticlinal structure (Grimani et al., 1973).

Going on, we come to the Bakar bay with still prevailing Upper Cretaceous sediments. The area of city **Rijeka** is mostly of Upper Cretaceous sediments, with some Paleocene limestone outcrops and some Upper part of the Lower Cretaceous (Albian) clastites, dolomites and limestones going on to the west towards **Opatija**, and entering the structure of the Istrian Peninsula.

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

SENJ

Senj is an old settlement which was founded on the hill Kuk, east of the town more than 3000 years ago. In the pre-historic times under the fortificated settlement, on the place where the brook flows into the sea bay, there was a port and a trade cener, a place where people coming from different directions (inland, islands and the coast) could exchange their goods. As the importance of the place gradualy grew, the settlers from the hill moved nearer and nearer to the sea forming there a new place which was mentioned for the 1st time in 4th century B.C. It was the Greek sailor and a writer Pseudoskilaks who mentioned the place under the name of Attienities.

In the 2nd century B.C. the Romans came and little by little they overtook the control over the town which was at that time known as Senia. From Senia they could easily attack the Japods and other Illyrian tribes whichwere in the inlad. But, the Romans didn't lead only wars. They continued to buikd the town especially from the second half of the 1st century B.C. till the 4th century. During that period Senia become the most important port and the main trading, cultural centre of this part of Adriatic coast. The Town hall, an aqueduct, thermes, temples (to the Gods and Godesses Diana, Magna Mater, Kibela and Liberus) and many other objects build at that time which we can trace in numerous archeological findings such as stone monuments, sculptures of Gods and Godesses, pieces of architectural works and tomb stones.
During the 5th, 6th and 7th centuries, when the Migration took pleace, many Barbarian tribes from the East invaded the town breaking its golden age. Due to the danger of the Barbarian invasion, the number of inhabitants decreased and the economic power of the town was dropping more and more. It was the era of tension and disorder. There was no more prosperity and it was, most probably, robbed and burned down during thease Barbarian attacks. We cannot be sure which tribe did it but it was very likely that West Ghots started the process of destruction which was completed by the Avaris and the Slavs at the begining of the 7th century.

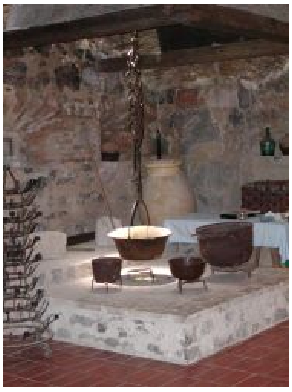
Fig.1. Senj, coppergraving. J.W. Valvasor from the year 1689.

In the 17th century, the Croats along with the Avars settled down on the ruins of the Roman Senia and they established the mediaeval settlemant called Senj which in its name preserved the Roman tradition. This part of history from the 6th to the 10th century is not known. Center of the Mediaeval Croatian state was moved to the south (in Dalmatia) and Senj lost its omportance.Much later, after graviting Pacta Conventa in 1102. The political power moved towards the North, Senj become once again prosperius town. It was a part of the Ugro-Croat kingdom. In 1169. The diocese was established and it clearly points on the importance of the town.
In 1184., owing to the Hungarian king Bela the 3rd who gave Senj as a present to the Templares, the order of priests and knights, the town was in their possession for the next seventy years. After the Templares, from 1271. on, Senj was ruled by the Dukes of Krk who were later renamed the Frankopans. The town becomed prosperious both in its economic and cultural life. A large number of sacred and profane structures were built not only in the tiwn but in its surrounding as well.
In the Mediaeval age Senj is known for its glagolic alphabet, the alphabet which had alredy been created in the 9th century for the need of the Slavs. From the 12th century on the glagolic alphabet exsisted only on the Croatian soil and it was particulary developed in the area of Senj. In 1248. The Bishop of Senj got a permision from the Pope Inocent the 4th and become the only Bishop who was allowed to use the glagolic alphabet and the people's language in his liturgy service. This fact influenced the development of the glagolic alphabet during the 14th and 15th centuries so we have many glagolyan stone board and hand written books and documents. A glagolic printing press was established in Senj in 1494. Which was one of the earliest printing press houses in southeast Europe. Two incunabues "The Glagolic Missal" and "Spovid općena" were printed at that time. In the middle of the 15th century the millitary forces of the Hungarian-Croatian king Matija Korvin came to town. In the 1469. Senj became a center of its captaincy, established because of danger which was coming closer and closer from the Turks but also with the aim to defend from the policy of Venice. The Ottoman campaigns to this area were especially during the firs half of the 16th century. At that time the neighbouring places were totally devasteded and the town became the refuge for a large number of refuges from the occupied areas. The millitary units were formed of the refuges. They were the famous Uskoks who successfully defended Senj till the twenties of the 17th century and who managed to cause hard lossesto the armed forces of the Ottoman Empire and Venice. In 1558. A construction of the fortress Nehaj, on the hill Trbušnjak, was finished for the needs of defence. The Uskoks was placed there. Because of the heroic resistance to much stronger enemy, these brave worriors got into the legend and folk songs. In the 17th century they became disturbance and a danger to a new peaceful policy of the Habsburg Monarchy towards the Ottoman Empire and Venice, and were evacuated to the other places in Croatia
Peaceful times enabled a restoration of trade in Senj and with that economic prosperety of the town wes provided. That was especially expressed in the second half of the 18th century and in the first half of the 19th century, when the great constructive works were being taken out (construction of the new Josephina's road, restoration of the port, construction of the big imperial

depot, regulation of the strong current and similar works). At that time started the golden age of the town which became one of most important in the country. The import of salt and export of grain and wood were passing through that port. The sailors fromSenj sailed on their ships all over the world and they traded especially intensive with the Mediterranean countries. The entrepreneurs and labour came to that properus town; the comercial and shipbuilding companies, chamber of commerce, chamber of trades were founded and the important cultural activity was developed. Also the town music society, the reading club and other cultural organisations were founded. Senj became an important cultural center and its intellectuals and inhabitans were bearers of the Croatian national ideology. The most famous Croatian writers and poets were born and lived there: Silvije Strahimir Kranjčević (1865.-1908.), Vjenceslav Novak (1859.-1905.), Milutin Cihlar Nehajev (1880.-1931.) and Milan Ogrizović (1877.-1923.). Their busts can be seen in the Poet's Park in Senj.
The construction of the railway line Karlovac- Rijeka (1873.), which went round Senj, had the disastrous consequences for the economy and comertial meaning of the town. The traffic in the port was very reduced and the goods took another direction to Trieste and Rijeka. These two towns were connected with the hinterland by the railway-lines. The rde of Senj was reduced just to an export port for wood. The obscene of the economic prosperety and marginalization of the traffic direction had a negative effect on the town life and the life of the neighbourhood. In the late 19th century a migration of the inhabitants started. It was very intensive in the 20th century, especially after the end of the World war II, when political reasons were added to the economic reasons. The old town center suffered a great damage in bombing, when many of the extraordinary valuble cultural inheritance desappeared. But still many are preserved to the present days and they make Senj worth visiting both for domestic and foregin tourists.

Nehaj Fortress

The Nehaj fortress, the symbol of Senj, was built in 1558. Under the supervision of the captain and the general of the Croatian military area Ivan Lenković and the captain Herbart the 8th. It is built of the material of the ruined churches, monasteries and houses which were situated out of the city walls.It is of square shape and its angles point to each side of the world. The fortress is 18 meters high and 23 metres wide. You could enter it by the steps and over the wooden bridge through the narrow double-doors. The walls are 2 - 3,30 meters thick. Toward the top they become narrower and narrower, and they end with the crown on which corners there are five little towers. There are about hundred loop-holesand eleven big cannon openings in the walls. In the inner yard there is a well and above it there are three coats-of-arms: on the left there is the coat-of-arm belonging to the captain Ivan Lenković with the the year of the construction of the fortress; in the middle there is the coat-of-arms of the Austrian archduke Ferdinand who was at that time the ruler of the town, and on the right the one belonging to the captain Herbert the 8th Auerspeberg Turjaški. On the ground floor on the right side there was a fire place and the rooms for the soldiers and the weapons were all around. Here you can see the base of the little church of St. George in early-romanic style built in the 11th century.

On the first floor there were the rooms for the officers and the commander of the fortress. On the second floor there were eleven heavy cannons, but today it is a place where many cultural and music performances, scientific meetings and other social events take pleae. The top of the fortress is a viewing pleatou. From there the guards could watch over all the roadways leading to Senj both from the continent and the sea and they could receive the warning fire and smoke signals from their companions From the top of the fortress you can enjoy a beautiful view on the Croatian coast and the islands Rab, Goli, Prvić, Cres and Krk; on the mountains of Gorski Kotar, Učka and Velebit. A collection of the Uskoks of Senj (their costumes, armour and weapons), a permanent photo-exhibition of the churches of Senj through centuries; an exhibition of the citizens and noble’s coats-of-arms from Senj and the Coastal captaincy of Senj are all set in the fortress.

www.senj.hr

SENJSKA DRAGA

Ladislav Palinkaš

(*Magmatism Within the Peri-Adriatic Region of the Outer Dinarides, Another Example (Vratnik, Senjska Draga, N from Senj, Croatia*, reprint from Field-Trip Guide Book, 22nd IAS Meeting of Sedimentology, Opatija, Croatia, September 17–19, 2003).

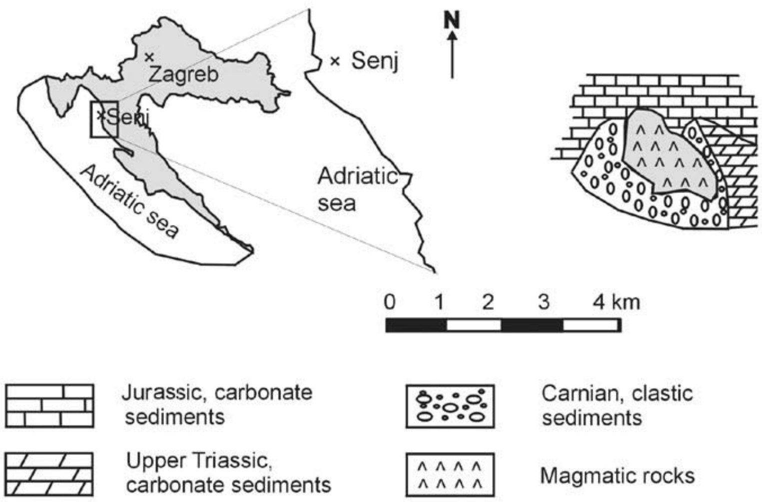


Fig. 7.1 Simplified geological map of the Vratnik igneous body, near Senj (after MAMUŽIĆ et al. 1969).

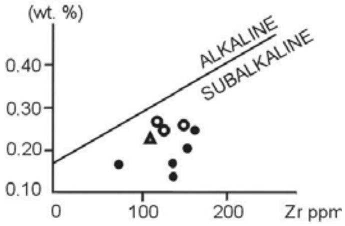
TRIASSIC MAGMATISM OF THE DINARIDES

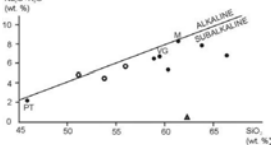
The Triassic plutonic and volcanic rocks frequently crop out in the Dinarides (Fig. 5.1). They are of metallogenic significance because they are associated with numerous, economically important mineral deposits of Fe, Mn, Pb, Zn, Sb, Hg and Ba. The Dinaridic Triassic igneous rocks and adjacent sediments stretch without a break, northwestwards to the Southern Alps and southeast towards the Helenides in Albania. In the Dinarides they occur along the inner and outer margins of the Mesozoic Carbonate Platform (MCP), often accompanied with volcanic-sedimentary formations (Fig. 5.1; PAMIĆ, 1984).

According to the studies of PAMIĆ (1984), KNEŽEVIĆ (1975), GRAFENAUER (1980), and others, the Triassic magmatism of the Dinarides was of a polyphase nature. It took place over a period of about 50 Ma during an advanced stage of rifting of the Mesozoic Wilson cycle. The earliest phase of the Tethyan rifting process, attributed even to Upper Permian time, gradually developed into oceanization in the course of Jurassic, with formation of a spreading ridge. The Triassic magmatism is represented by basic, and more voluminously by intermediate and acid plutonic and volcanic rocks with calc-alkaline affi-nity. Plutonic rocks occur most frequently as varieties of granite, diorite and gabbro in the Central Dinarides. Extrusive rocks are present with varieties of basalt, spilite, andesite, keratophyre, dacite and quartz keratophyre with pyroclastics. The lava was formed by partial melting, and altered by different degrees of fractional crystallization and assimilation, which played a secondary role. According to field observations and geochemical data, intrusions and extrusions of lavas happened at the inner and outer edges of the Mesozoic Carbonate Platform or within the carbonate platform itself, underlain by the rocks of the passive, African continental margin (Fig. 5.2; PAMIĆ, 1984).

MAGMATISM ALONG THE CARBONATE PLATFORM MARGINS

Regional tectonic features must have controlled Triassic magmatic processes, i.e. existence of deep faults, which provided channels for magma emplacement. The initial phase, related to the Upper Permian thermal doming, gave rise to large-scale uplift. Adiabatic decompression caused partial melting of the upper mantle with numerous plumes, which initiated extension and initial rifting within Hercynian continental crust. The beginning of the Alpine intra-continental rifting cannot be precisely determined, but the boundary between the Hercynian and Alpine cycles is marked by a long-lasting terrestrial phase, when the Val Gardena (Groeden) clastic deposits were accumulated. The thermal disturbance, followed by relatively weak volcanic activity along the future opening of the rift, promoted formation of numerous, sub-terrestrial, hydrothermal siderite–barite–poly-sulphide deposits in the Dinarides (Ljubija, Trgovska Gora, Petrova Gora, Samoborska Gora, etc.). Formation of the horst–graben structures during the Lower Triassic, initiated stronger subsidence and a subsequent ubiquitous transgression, with a larger influx of terrigenous material. A carbonate ramp, forming the foundation of the Mesozoic Carbonate Platform (MCP), was established at the very beginning of the Anisian (ALJINOVIĆ & TIŠLJAR, 2001). The strongest magmatic activity took place during the Ladinian, mostly at the MCP outer edge, in isolated basins, accompanied by sedimentation of cherts, pelites and limestones. The inner margin of the MCP accommodates scarce igneous rocks along the line Sinj–Velebit–Fužine, and along its southeastern extension on the Montenegro coast. Peculiar occurrences of igneous rocks on the Dalmatian islands Vis, Jabuka and Svetac, are also probably connected with the inner margin of the MCP (PAMIĆ, 1984).





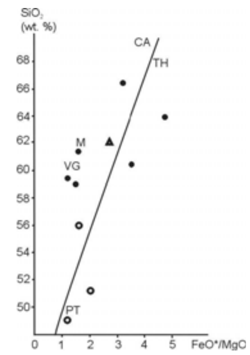


Fig. 7.2 (N2O+K2O)–SiO2 diagram according to analyses recalculated to 100% on an H2O and CO2 free basis.

Fig. 7.3 The boundary line between the alkalic and subalkalic fields given by MACDONALD & KATSURA (1964); Analytical data plotted from LUGOVIĆ & MAJER (1983).

Fig. 7.4 SiO2–FeO*/MgO diagram (MIYASHIRO, 1975). The symbols: CA = calc-alcalic rock series, TH = tholeiitic rock series, and FeO* = FeO + 0.9×Fe2O3 (after LUGOVIĆ & MAJER, 1983).

NOVI VINODOLSKI

The tourist town of NOVI VINODOLSKI developed and grew along the seashore in the central part of the northern Croatian coast, on the Riviera of Novi Vinodolski from the ancient Frankopans' fortress NOVI GRAD.

In history, Novi Vinodolski affirmed itself as political and cultural centre of the Principality of Vinodol ("Vinodol" - "Vallis vinearia") and with "The Vinodol Code" in 1288. It was the craddle of a pleiad of writers of the family Mazuranic. In 1878, thanks to the evergreen vegetation and mild Mediterranean climate, clean sea and air it gained the position, after Opatija, of being tourist pioneer of the seaside region. The physiognomy of the town is characterized by the littoral architecture of white facades and red roofs which raise themselves in the old town core from the sea level up to the church and tower on the hill overtopping thus the town outline like they were protecting this stone town above the sea. For this specific panorama Novi Vinodolski was recognizable in the past, it is recognizable in the present and probably it will be in the tourist future. The soul of the town is represented by the rests of the cultural heritage: walls of the Roman fortress "Lopsica", rests of the Paulist friars' monastery, Frankopan citadel with stronghold, cathedral, chapel of the Holy Trinity and St. Marin on the homonymous islet, the house of the brothers Mazuranic, reading club and library from 1845, homeland museum and gallery, the old core of the town as well as the preserved authentic folklore of this town. The traditional hospitality of the population, crystal-clear sea, town and surroundings without industrial pollution, circulating of mountain air from high forests in the nearby hinterland suitable for hunting tourism grant to Novi Vinodolski inestimable ecologic advantages especially for the development of the tourist and hospitality industry. Classic hotels, modern tourist villages, camp sites, bungalows, flats and rooms in private houses represent lodging capacities for more than 10,000 tourists per day. In the hotel buildings and in the immediate surroundings of the hotels sports and recreation constructions, open air and indoor swimming pools with seawater, saunas and other facilities for tourists' personal needs have been built. The sea of the town port with moors for boats, petrol stations, a crane and a ramp for lifting up and floating the boats, parking grounds for cars, trailers and boats are intended for nautical tourists for whom the service of aid and rescue at sea is organized too. Via the Adriatic tourist road, railway station of Rijeka, airport of Krk-Rijeka and especially via the blue ways, the town is connected with Europe and the Mediterranean.

http://www.tz-novi-vinodolski.hr/encity_of_novi.html

OPATIJA

In 1844 Hignio Scarpa, a patrician from Rijeka built amidst the bay-tree and oak-tree vegetation the villa "Aangiolina" - that was the beginning of tourism in Opatija - a town where the royal families and man of distinction (Wilhelm II, Franz Joseph I, Gustav Mahler, Isadora Duncan, A.P.Chekhov... among others) used to winter. By the end of the 19th century, Opatija was the winter and the health resort of the worldly Central Europe.

Today when winter and summer display their charms, Opatija is the biggest pearl in the kvarner bay; among others there are: the pittoresque Volosko the old fishing places Icici and Ika, Lovran with its old center and modern hotels, Meveja and Moscenicka Draga with large sandy beaches, Kraj and Brsec high above the sea, and last but not least the medieval towns on the nearby hills - Kastav, Veprinac and Moscenice. The Opatija Riviera is unique combination of climatic, vegetative and cultural opposites. The average temperature in Opatija is some degrees higher then in neighboring places, thus allowing successful growth of camellias, magnolias, palms, bamboos, and other subtropic plants in its parks. Surrounded by this luxuriant evergreen vegetation there are hidden numerous hotels - classical historical and secessional buildings from the last century, of refined beauty but modern enough to keep up with the progress and satisfy all the exigencies the todays tourist demands.

The tourist tradition of Opatija is as old as the town itself. In numerous restaurants along the Riviera you can taste the European national dishes as well as Oriental dishes. The choice is up to you - either the livery waiters serving by candle lights or the rustic ambience of the littoral pub. Beside chattering in cafes and coffee-houses your entertainment can go on on dancing terraces , in disco clubs, in night clubs and you can try your chance in the Casino . Moreover you can attend numerous concerts, operas, folk shows, fils, theatre performances and exhibitions. Furthermore, Opatija is also a congress town and a sport town (boasting tennis and other sport grounds and swimming pools) and if you are traveling by boat you will be well satisfied when mooring your yacht in its marina. And last but not least it is possible also to ski or ride a horse on Ucka or on the nearby highlands. If you want to experience even more we suggest you to make an excursion by coach, by car or by boat to the famous places as Venice the islands, the marvellous Postojna caves, Pula and all those nice places in Istria and along the Adriatic coast..., then to return to bosom of Opatija.

The Opatija Riviera (25 km long) is spread along the eastern coast of Istria, at the foot of Ucka (1396 m), sheltered from winds. It is accessible all year by roads and in its vicinity there is also an airport.

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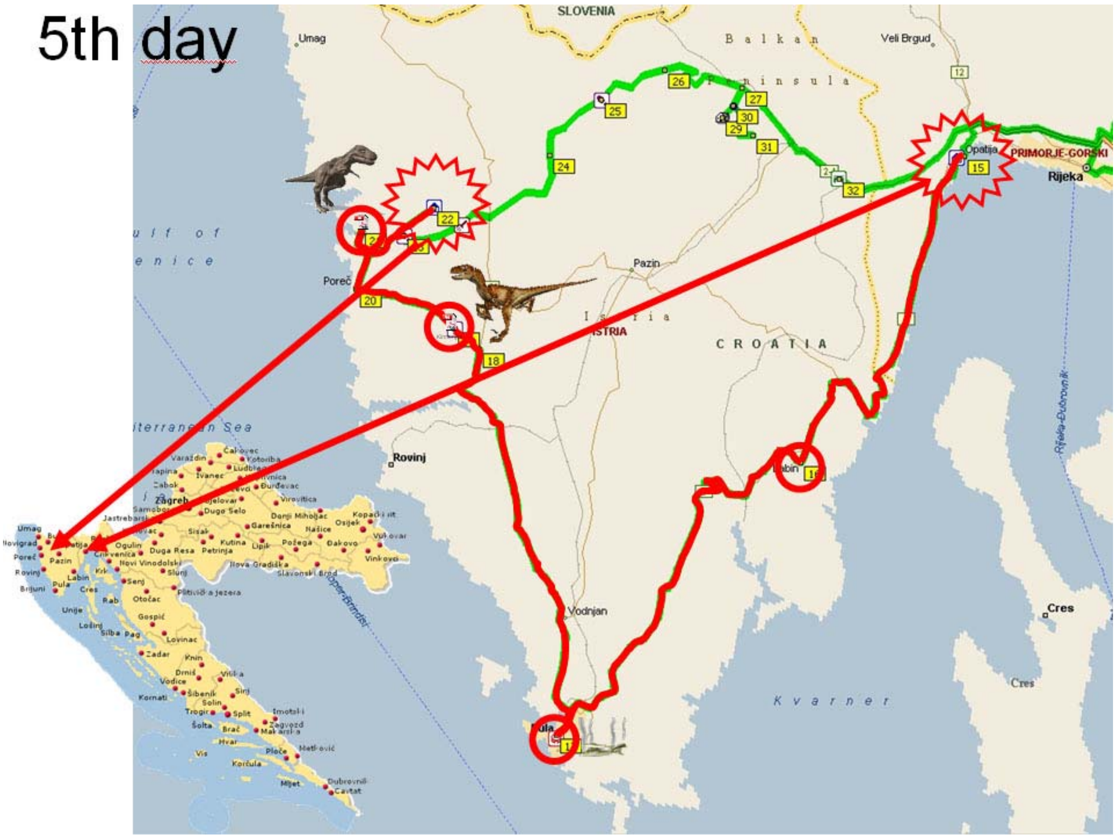
http://www.opatija.net/default.asp?l=en
http://www.travel.hr/opatija/eng/index.html

8. DAY 5



GEOLOGY OF ISTRIA

Karmen Fio

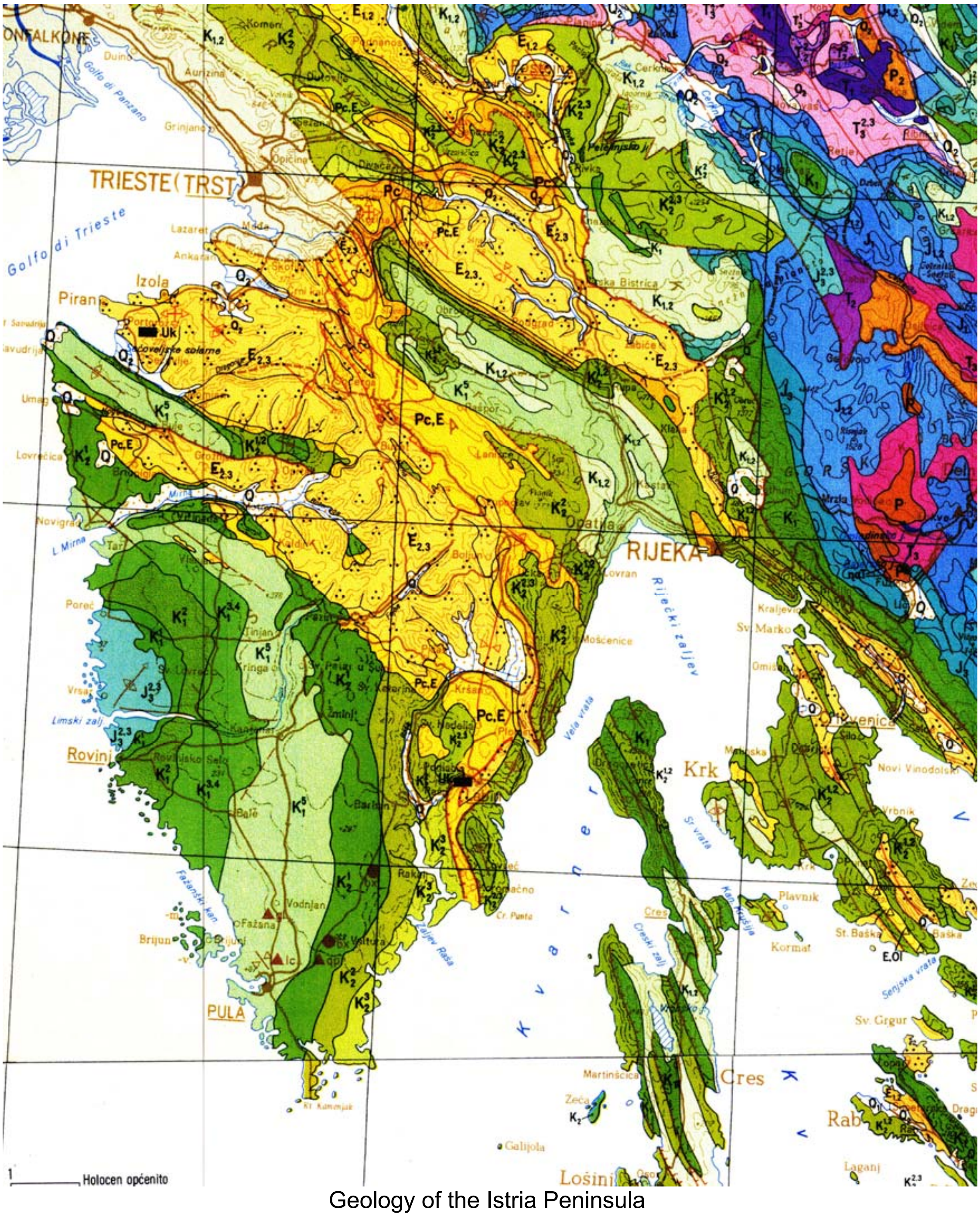
The Istria Peninsula (Fig. 2) and its wider area is built of carbonate sediments of the Middle and Upper Jurassic (the core of the so-called western Istria anticlinal structure), Lower- and Upper-Cretaceous limestones and dolomites in folds wings, middle Istrian flysh sincline structure and the Cretaceous-Paleogene overthrusts zones of the Ćićarija (Chicharia) area. With the pronounced reverse tectonics and relative motion of the structures towards the southeast, there are some overthtust zones in the middle and eastern part (Učka Mt.).

The western Istria is an anticlinal form with the Karst plateau (flat) on top made of dolomites and dolomite breccias of the Lower and Upper Cretaceous. From the geological point of view, Istria can be divided into three regions:

– the Jurassic–Cretaceous–Eocene carbonate plain of southern and western Istria,

– the Cretaceous–Eocene carbonate–clastic zone, characterised by overthrust structures in eastern and north-eastern Istria (from Plomin and Učka to Ćićarija), and

– the Eocene flysch basin in central Istria (Velić et al., 2003).



Geology of the Istria Peninsula

LABIN

The medieval town of Labin is situated on the hill above Rabac. Its old name of Albona was first mentioned in 285 AD. The birthplace of Matthias Flacius Illyricus, the reformer and collaborator of Martin Luther, it is a cultural and administrative center today. The rich cultural and architectural heritage of Labin is enlivened by number of art ateliers and by the bustling youth gathering in the coffee bars scattered around the old town. The Sculpture Park in nearby Dubrova features over 70 forma viva stone sculptures. After a walk through the narrow streets of the Old Town, pay a visit to the Town Museum with its archaeological and unique in this part of Europe, a miniature coal mine. Have a look at the Memorial collection of Matthias Flacius Illyricus, peek into the art ateliers, enjoy the view of Rabac and Cres island from the Fortica or pop into the small, elegant shops and take refreshments on one of the terraces of the local coffee bars. Whether to do business or just to have a chat, these are the places where everyone meets.

'RES PUBLICA ALBONESSIUM'

Labin, a picturesque town situated on a 320 meters high hill and only three kilometers from the seaside, was inhabited already two thousand years B.G. The remnants of Kunci, one of the settlements called the 'castellums', dating from the Bronze Age, can be found in the vicinity of Labin. Its old Illyrian-Celtic name is Albona or Alvona and it was probably founded by Celts in the 4th century B.C. on the ruins of the ancient city. Some historians say it was fortified by the Illyrians in the 11th century B.C. They also say that Albona in the Celtic language means 'a town on the hill' or 'an elevated settlement'. Titus Livius said that Labin inhabitants were pirates. After the conflicts between the local inhabitants and Romans, which had started in the 3rd century B.C., Istra came under the Romans in 177 B.C. The borderline was the river Rasa. Labin and its surroundings thus became an integral part of Illyrian, the Roman province with a high degree of independence and authority over the nearby settlements. The oldest written document about Labin is a relief from the 3rd century with the insertion 'RES PUBLICA ALBONESSIUM'.



http://www.rabaclabin.com/en,210,labin.aspx

PULA

Pula (italian: Pola, from the Roman name: Provincia Iulia Pola Polentia Herculanea) is the largest city in Istria and administrative centre of the region since Roman times.
Pula city has 67 000 inhabitants, together with satelite settlements more than 100 000 imhabitants, and is 5th largest city in Croatia.

LEGEND

The legend of the Argonauts describes the pursuit of the Colchidians after the ship Argo and the Golden Fleece. The subjects of the king of Colchis gave up further pursuit after the death of their king's son. Fearing that they would be punished for his death and the failure of the quest if they returned to Colchis, they decided to settle where the prince had died. Pula therefore became not only a harbor of refuge to the Colchidian fugitives, but also their place of exile. The most famous geographer of the antiquity - Strabo - claims that this is how Pula was founded and according to this legend, it was about three thousand years ago.

ILLYRIAN PERIOD

In the Illyrian period, until the arrival of Roman legions, Pula was no more than the surroundings of nearby Nesactium, the political, administrative, military and religious center. As a result of intensive colonization, good trade routes, as well as the importance of its military position, Pula took over the leading position.
Numerous trades developed in that period: stone cutting for the many buildings in Pula and its surroundings, agriculture, viticulture, olive-growing, fishing and pottery for the transport of olive-oil, wine, wheat and fish.

ROMAN PERIOD

In the Roman Imperial period (1st - 3rd centuries) the greatest classical monuments in Croatia were built in Pula. The most magnificent and surely central classical monument is the Amphitheater popularly called the Arena. This Amphitheater, used for fights and battles of men and animals, was built in the 1st century AD, during the rule of Emperor Vespasian. The ground plan is elliptical, its size being about 130 m x 105 m, and 32 m high, which ranks it as the sixth largest Roman amphitheater existing today. The Arena could once hold up to 23,000 spectators, whereas today it can seat some 5,000 people.
Classical Pula was supplied with all major achievements of Roman civilization, it had its water supply and sewage systems, Forum, which was the administrative, commercial and religious center, capitolium with temples (in the Forum), two theaters, large city cemetery (mentioned by Dante in his “Divine Comedy”), houses richly ornamented with mosaics and marble. The city was fortified by walls and was entered through some ten gates. The greater part was destroyed in the beginning of the 19th century, so that only

some of the gates have been preserved until today. The Triumphal Arch of the Sergi is situated at the end of the street (Via Sergia) leading eastwards from the Forum. This triumphal arch leaned against the city gate (Porta Aurea) so that only its western, visible side was richly decorated. This monument was erected at the end of the 1st century BC by Salvia Postuma Sergi with her own money in honor of three members of her family who held important positions in Pula at that time. According to the inscription on the arch, the monument was constructed between 29 and 27 BC. For centuries this impressive Roman monument has attracted the attention of famous artists, especially Italian ones, such as the great Michelangelo. Heading north there are two other remaining city gates: the Gate of Hercules and the Twin Gates. Outside the city gates lay the cemeteries called necropolises. Fragments from monuments found at these burial areas are today kept in the Archaeological Museum of Istria. Not far from the Twin Gates are the remains of a sepulchral structure, octagonal Mausoleum dating from the 1st – 2nd centuries AD. The Forum, the central city square of ancient and medieval Pula, was on three sides surrounded by arcades with statues and reliefs and on the northern side by temples. The Temple of Augustus, built between 2 BC and AD 14, has been completely preserved to the present day.
On the eastern slopes of the central hill of the city, present-day Kaštel, are remains of the Small Roman Theater with its scene, semi-circular orchestra and tiered section for the audience. The Large Roman Theater, situated outside the city, was completely destroyed; only a fragment of its relief on the exterior wall is kept in the Archaeological Museum of Istria. Close to the Small Roman Theater is the Archaeological Museum of Istria which today houses numerous monuments from the prehistoric, Roman and early medieval periods found in the area of Pula and Istria.

PULA BEFORE THE 5TH CENTURY
Owing to its geographical isolation Pula avoided migrations, plundering and invasions of the barbarians until the 5th century when it was conquered by the Visigoths and then Ostrogoths. Under the Eastern Roman Empire the town prospered and was given military importance in the conflicts between the Byzantine army and the Goths.

PERIOD OF FEUDALISM TO THE PRESENT DAY
In the second half of the 6th century the Slavs began their invasion of the Istrian peninsula, and after dreadful fights the population declined while trade and manufacture came to a standstill. The new rulers of Istria, the Franks, brought with them the new feudal system which enabled the settling of Slav, Croatian farmers, but brought about the resistance of Istrian towns. With the development of feudalism and the establishment of city-states on its territory, Istria faced the arrival of Venice. In 1150 Pula swore allegiance to the Republic of Venice and accepted all the obligations towards it - to pay tribute, to build and equip galleys, to support it in wars. Pula was thus bound to Venetian economical and political aims, which defined its development for the next few centuries. During the 14th, 15th and 16th centuries Pula was attacked and conquered by Genoese, Croatian-Hungarian and Habsburg armies, causing the devastation of numerous medieval settlements and villages. Besides the war calamity, the population of Pula and Istria was

decimated by numerous epidemics of plague, malaria, typhoid and small-pox. As a result of the dilapidation of monumental buildings, ruined economy and decimated population Pula fell into disrepute. Nevertheless, due to its geographical position and the importance of its harbor for trade routes, Pula simply could not disappear. The town was saved by organized Croatian and South-Slav settling. After the revolutionary year 1848, the Austro-Hungarian Empire realized the importance of Pula's harbor and started an intensive development of a huge naval port and shipyard. This resulted in the gradual settlement of Pula and within 50 years the population increased from 1,126 people to about 40,000. Pula was still described as a village cut off from the rest of the world, but later on vast sums were invested in the sewage system and infrastructure. Eventually the investments transformed rural Pula into a prosperous town. With the new railway Pula gradually took over the role of Trieste and Rijeka as the main port for Dalmatia. This enabled Pula to develop two functions at the same time - the military and trading one. Under the protectorate of Vienna the official language in Pula was German, but Italian remained the everyday language in use among numerous social classes, while the use of Croatian very soon completely disappeared. Such was the situation during World War II under the fascist rule, when Pula, as an antifascist town, organized its battle for the future under bomb raids and devastation, as well as reprisals over the historically defeated side. After the War and German occupation Pula came under the Anglo-American administration. In 1947 Pula finally turned to its natural hinterland - Croatia (according to the 1943 Resolution that defined Istria as a part of Croatia), and therefore Yugoslavia. This caused still another exodus of the malcontent domiciliary Italian citizens. It marked the beginning of a new period in the history of Pula that lasted until Croatia gained independence.

Amphitheater

The most famous and important monument, the starting and ending point of every sightseeing tour is the Amphitheater, popularly called the Arena of Pula, which was once the site of gladiator fights. It was built in the 1st century AD during the reign of Emperor Vespasian, at the same time as the magnificent Colosseum in Rome. The ground plan is elliptical, the longer axis measuring about 130 m and the shorter one about 100 m. Gladiator fights took place in the central flat area called the arena, while the spectators could sit on the stone tiers or stand in the gallery. It is believed that the Amphitheater could seat about 20,000 spectators. Local limestone was used for its construction. In the Middle Ages it was the site of knights tournaments and fairs. Today it is the venue for summer performances - the Film Festival, Opera Season, Equestrian Festival, concerts, ... which can seat about 5,000 spectators. The underground passages, once used by the gladiators, nowadays host a regular exhibition of viticulture and olive growing in Istria in ancient times. The exhibits include reconstructions of machines once used for the production of olive oil and wine (mills, presses, vessels) and amphorae used for storing and transporting olive oil and wine. The Amphitheater is situated outside the old city walls because of its size and geographical configuration. The road that leads to the center was constructed during

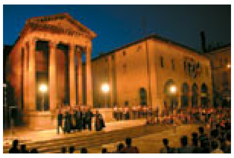
Emperor Vespasian, after whom it was named - Via Flavia. Even today it represents one of the main city roads.

Triumphal Arch of the Sergi – Golden Gate

The "Golden Gate" was erected between the years 29 and 27 BC by the Sergi

family, in honor of three members of the family who held important positions in Pula at that time. This triumphal arch leaned against the city gate Porta Aurea thus called because of its richly ornamented arch or gilded elements.

Temple of Augustus



The Temple, situated in the Forum, is dedicated to goddess Roma and Emperor Augustus. It was constructed between the year 2 BC and AD 14 when the Emperor died. According to its shape it follows the typical pattern of temples.

Floor mosaic "The Punishment of Dirce"

After the bombing of World War II remains of Roman houses with mosaics were found under the block of houses around the Chapel of St. Maria Formosa. The most impressive one is surely the floor mosaic with the central field presenting the mythological scene of the "Punishment of Dirce"(Amphion and Zethus are tying Dirce to an enraged bull, since out of envy Dirce had been cruel to their mother Antiope.) This figural scene presents the central field of a large floor mosaic composition (12 m x 6 m). The entire mosaic composition is divided into two equal sections with altogether 40 decorated areas dominated by geometrical patterns with animal details (fish and bird). The mosaic covered the floor of a central room of a Roman house, probably from the 3rd century. It has been preserved at the site where it was found, so that the level of house floors in the Roman times, which is 2 m below today's level, is clearly visible.

http://www.pulainfo.hr/en/

KIRMENJAK QUARRY

Aleksandar Mezga

All the dinosaur fossil remains on the Adriatic–Dinaridic carbonate platform, now outcropping along the eastern coast of the Adriatic Sea, have been described from Cretaceous deposits. There are numerous sites with dinosaur footprints and bones, the oldest find to date was found within Hauterivian layers. The new locality with the dinosaur footprints has been discovered recently. The age of the trackbearing deposit is Upper Tithonian and represents the oldest evidence of dinosaurs on the Adriatic–Dinaridic carbonate platform. The site is in an active quarry front near the village Kirmenjak in the central Istria (Fig. 1). The site is very rich in footprints, almost a thousand of them have been found on the outcrop (Fig. 2).

Figure 1: Exposed surface with the dinosaur footprints in Kirmenjak quarry.

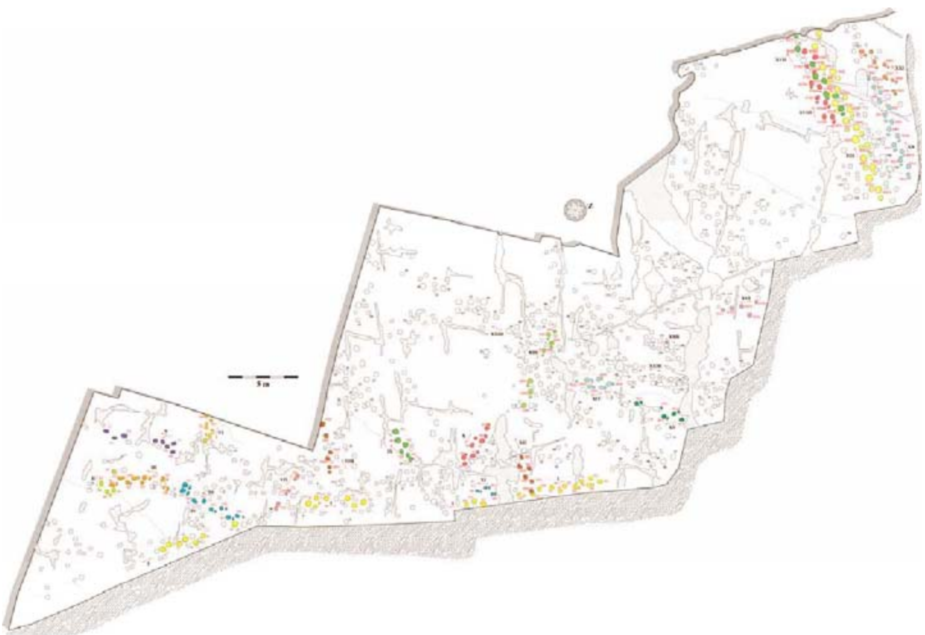


Figure 2: Detailed ichnological map of the Kirmenjak site.

Most of the footprints have an oval or horseshoe shape without clearly visible digit impressions and are relatively shallow (1–2 cm). Although the state of preservation is far from ideal, the prints belong to sauropod dinosaurs based on their morphology (Fig. 3). The oval-shaped prints represent pes prints and the horseshoe-shaped prints the manus prints (Fig. 4). The footprints are of various dimensions, manus prints having the length range between 5.5–26.5 cm, pes prints between 23–52 cm.

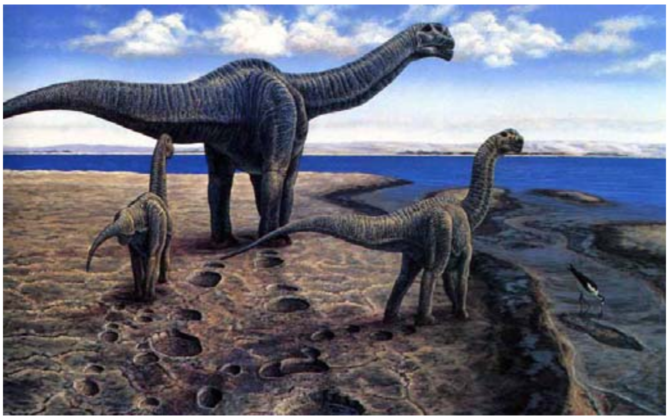


Figure 3: Sauropod dinosaurs like these, left the footprints in Kirmenjak (drawing by M. Skrepnick).

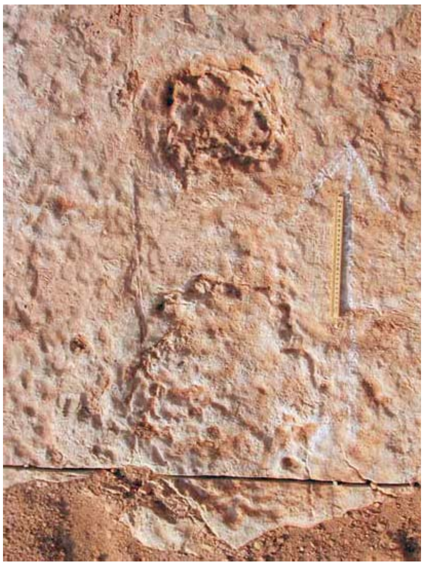


Figure 4: A couple of sauropod footprints from Kirmenjak quarry. Larger, circular print, represent the pes print and the smaller semicircular, the manus print.

The calculated height at the hip ranged between 153–306 cm. There are 23 trackways on the outcrop and they overlap frequently. There are also some areas which are heavily trampled by sauropod feet. The main direction of dinosaur movement is towards NE and because there are a number of parallel trackways it may be concluded that some of the individuals were moving together (indication of gregarious behavior). A large number of the trackways disappeared below the quarry surface and probably extends further. The trackways show characteristics of a narrow-gauge type. The pace and stride lengths indicate a slow walk of the individuals. The footprints could be assigned to *Parabrontopodus* ichnogenus and the ichnocoenosis could be assigned to the *Brontopodus* ichnofacies which is characterized by sauropod footprints in the carbonate platform environment. The presence of the large sauropod dinosaurs on the Adriatic–Dinaridic carbonate platform during the Upper Jurassic could be explained by its connection with the African continent via its southern margins. The sauropods could have migrated in the area during the emersion phase when the platform was going through a land stage. There had to exist a widespread continental area in order to support a survival of such a large terrestrial herbivores as the sauropod dinosaurs.

REFERENCE

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Grad Poreč
Cittá di Parenzo

POREČ


Mosaic in Euphrasius Basilica


Panoramic view of Porec


Gothic house

Poreč is one of the most famous Croatian tourist places. The number of residents exceeds the number of tourists during the summer months. Poreč tourism is more than sun, sea and perfect tourist image. The summer visitors know how to recognize the city that is still keeping its historical values, which can be seen in the historical city center. You can find museums, galleries in the most valuable city palaces, many of them are the homes for people as they have been centuries ago. Many of our guests probably do not know that they are walking on the streets, built during the Roman times. One part of the city ramparts and towers is still preserved, in the Pentagonal tower there is a restaurant and in the Round tower a pub. Besides Basilica, now it is possible to visit Euphrasius' bishopric, opened in the year 2000 as an architectural monument and the curch museum.

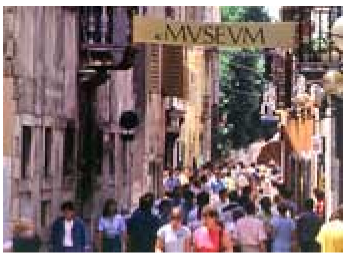

Porec sea strand


Panoramic view of Porec


Porec by night

The capital of the Croatian tourism has one more face - sports. Many individuals, teams and selections of different sports choose Poreč for traning. The sports offer satisfies even those most demanding tourist amateurs.


Euphrasius Basilica



Decumanus street


The remains of thetemple of Neptune

All of the old city of Porec is a tourist stage; this is a place where you can learn from the historical monuments, read from the facades and stone paved streets from the Roman era. The most unique monument is Euphrasius' Basilica, an early Christian cathedral, but there are many other symbols of 2000 years of history of the city. The old heart of the city of Poreč is also a great place to have fun. Ancient Decamanus, the main street of the old city, is a perfect promenade during the summer. Even if you haven't planned anything, something will draw your attention: jazz in the ancient stone collection garden or classical music concert in the Basilica, summer cocktails on the ancient Marafor Square, or simply watch the streams of people passing by. Wherever you go in the old city, everything has a distinctive charm because it pulsates both with ancient and modern times. Some of the streets and squares are the stage of the summer Street art.

http://www.istra.com/porec/

‘SOLARIS’ AUTO CAMP

Aleksandar Mezga

Numerous footprints belonging to bipedal theropod and quadrupedal sauropod dinosaurs has been found on the site inside the ‘Solaris’ auto camp northern of Poreč. The outcrop stretch itself on the area 33 meters long and 13 meters wide (Fig. 1). Over 500 individual prints and numerous trackways are registered on the outcrop (Fig. 2). The age of the trackbearing horizon is determined as the Late Albian regarding the microfossil assemblage found within.

Figure 1: The site with dinosaur footprints inside the Solaris auto camp.

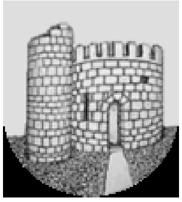
Figure 2: Detailed ichnological map of the Solaris site (drawn by Dalla Vecchia et al., 2000).

Theropod footprints are tridactyl, mesaxonic with slender digits and sometimes visible claw marks (Fig. 3). Beside as numerous isolated prints, theropod footprints occur on the outcrop in numerous trackways what is important for the estimation of speeds and gaits of dinosaurs. Non-tridactyl sauropod footprints occur as oval-circular and horseshoe-shaped. It is the result of different hind and forefoot morphology in sauropod dinosaurs. One clearly distinguishable trackway of sauropod dinosaurs and several isolated footprints are found on the outcrop. Their prints belong to a new sauropod ichnotaxon *Titanosaurimanus nana* (Fig. 4).

Figure 3: Well preserved theropod footprints from the Solaris site with visible claw marks.

Figure 4: Footprint of the front foot of sauropod dinosaur; belonging to the new ichnotaxon *Titanosaurimanus nana*.

The Late Albian is the period during which dinosaurs left the most conspicuous evidence of their presence along the Istrian part of the Adriatic-Dinaridic carbonate platform. The Solaris site is particularly important for the presence of hundreds of footprints and trackways of mid-sized bipedal dinosaurs and dozens of sauropod footprints. Bipedal dinosaurs were moving in straight lines or a slightly undulating fashion with a relatively fast walk gait. Sauropods of the Solaris site are small-sized, and the trackways indicate a very slow gait for the trackmaker. The directions of the trackways and footprints show a probable topographic constraint on the movement of the trackmakers, both theropods and sauropods. The Late Albian ichnoassociation of Istria is similar to that of the Albian of Texas but is peculiar for its miniaturization. The unusual small size of the sauropod trackmaker, together with extreme rarity of large predators (theropods) and the paleogeographic context, suggest it could be an insular ichnoassociation.



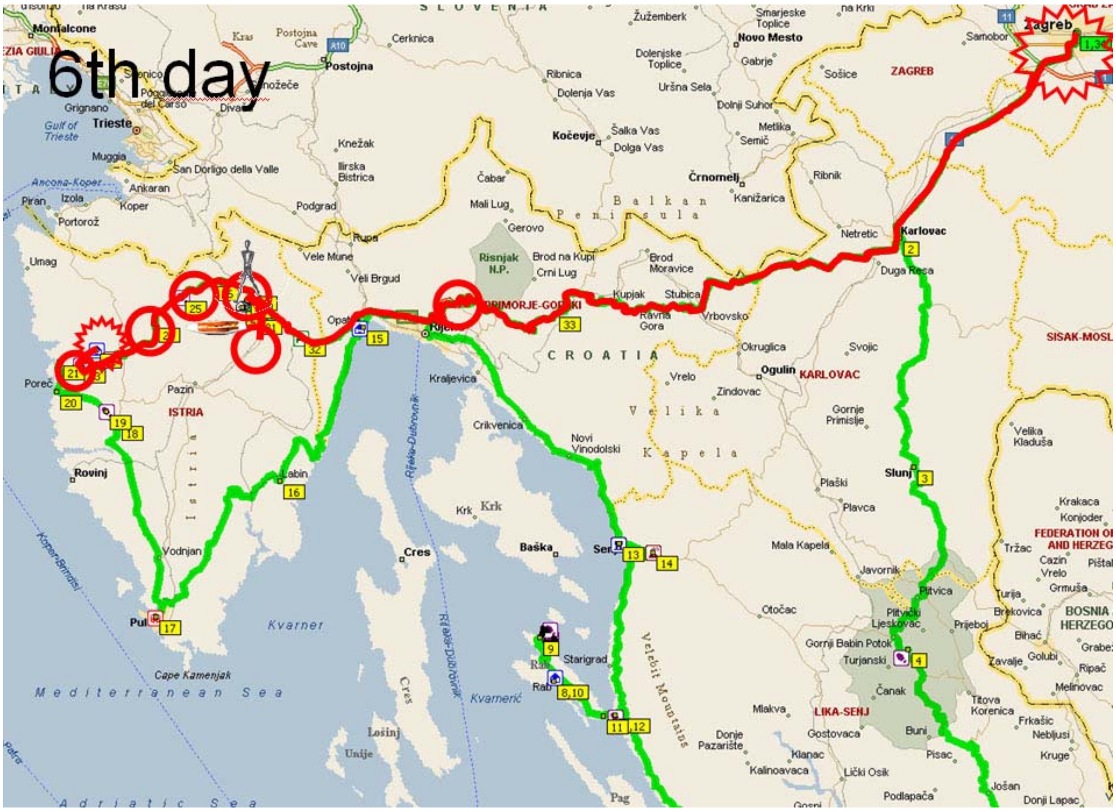
KAŠTELIR – LABINCI

District Kaštelir-Labinci is situated 13 km from Poreč, in West Istrian vine province.
Roman military road (Via Flavia), connecting Trieste and Pula, was passing through this province. During the reign of Venice, refugees from Bosnia and Dalmatia, running away from Turks, inhabited this district. The oldest preserved sacral object in the settlement is from 13th century. A medieval fortress, Nigrinjan, situated above the Mirna river valley, is today a symbol of the district.

Today 1600 inhabitants live in the settlements, mostly dealing with agriculture (producing vine, olive oil, potatoes and honey). Sport tourism is very important in this region, including the biking and paragliding. Due to the lack of night-light pollution, a famous observatory is situated in Višnjan.

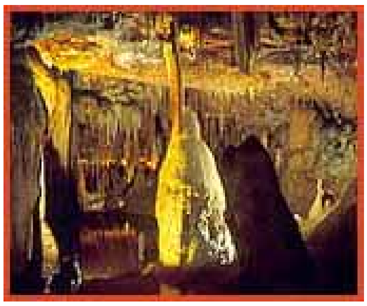
http://www.kastelir-labinci.hr/kastelir_labinci.htm

9. DAY 6



BAREDINE CAVE

Jasenka Sremac



Meet the mystical world of nature which has been developing for thousand of years, far away from the light of the day and the human eye. Visit the underworld the **BAREDINE CAVE**. This cave is a treasure chest of stalagmites and stalactites, underworld sculptures created through time by the patient work of water. Such shapes have been created, some of which are exceptional, such as the 10 meter long and high curtains, a very realistic sculpture of Our Lady, the body of a milkmaid called Milka, the leaning tower of Pizza and snowman the torchbearer-who has become the trade mark of our cave. In one of the atriums you will pass a crater that is 4m wide and 66 m deep which goes down to the underground lakes. And so through five halls, five galleries of abstract and realistic sculptures, a pleasant 40 minute walk, accompanied by our guide and custodian. The excitement of this adventure is also meeting the animals of the underworld. You will see the human fish and endemic animals that live only in this environment, miniature see-through crabs and insects. We aren't the only ones that have visited this kingdom of the God Had. At the cave's entrance there is a museum showcase where pottery of prehistoric man has been exhibited. Our far ancestors would probably leave the pots during the hot, dry, summer day to collect the precious water, drop by drop. This cave, the **BAREDINE** cave, even has its own love story from the 13th century. If one should believe a legend, a Poreč nobleman named Gabriel fell in love with a beautiful milkmaid from Nova Vas called Milka. Gabriel's mother tried, in every way, to diminish his love for her, but she couldn't, so she gave 3 gold pieces to highway robbers to secretly kill Milka. The robbers didn't kill the milkmaid but instead threw her into the cave. When Gabriel found out of his love's ill fortune, he got on a horse and disappeared. Only his horse was found but near another cave. The story has it that the stone body of the milkmaid is slowly skidding, from century to century, down to the bottom of the cave where we can see it now as it is seeking her lover. Today's cavers claim that one could pass through to the next cave by digging. So as our legend has it, we can assume that one day the bodies of our Romeo and Juliet will meet in the underworld and stay together forever.

http://www.istra.com/baredine/eng/index.html

MOTOVUN

Jasenka Sremac

An old legend states that long ago giants lived in the valley of the River Mirna. They were so big that they could, looking at the towns on the hillsides above Mirna, hand each other tools and big rocks. One of the towns that were built by the giants during this legendary time was Motovun. Many years later, when Istria was inhabited by ordinary people, the giants began to disappear. However according to legends and the stories of Vladimir Nazor the noted Motovun giant Veli Jože was so big and strong that he could shake the bell tower of the Motovun church with his bare hands.
Motovun is a town-monument, an ancient Istrian acropolis town located atop a 277 metre high hill, whose present appearance dates back to the Middle Ages, from the 12th and 13th century. Leading to the top of the hill and its Venetian town square is the longest Istrian staircase, with 1052 steps.
From the rich architectural heritage of Motovun especially noteworthy are the city gates with tower, renaissance town palace, town lodge, parish church Saint Stephan, the smaller churches of Madonna dei Servi and Madonna delle porte, the medieval lay outof the streets, town cisterns and many coats of arms on the building facades. The position and vistas of Motovun make it one of the most beautiful towns on the Mediterranean.
Around Motovun lie vineyards from which come the renowned Istrian wines, teran and malvasia, while the Motovun forest, which extends for kilometres along the Mirna valley, is the dwelling place of the famed underground mushrooms, truffles that are extracted in this region with the help of specially trained dogs. Summer and early autumn is the period when black truffles come to fruition, whereas the Istrian white truffles are gathered in late autumn and winter. In the month of October, in numerous places in the Mirna Valley, festivities of "The days of truffles" are held. Dishes made with these truffles are the pride of the Hotel "Kaštel" in Motovun.
Motovun has historically been the most significant inhabited locality in the surrounding area according to recent research by "New Age" scientists. The significance of this town is due to its positioning on the crossroads of the Earth's energetic meridians that is on the so called "Dragon's furrow". These meridians emanate positive Earth life energy into their surroundings and in places where these "furrows" intersect, as in the case of Motovun, strong sources of positive energy appear, they are the "breathing orifices" of the planet Earth. Such energy fields have a relaxing and calming effect on man, increasing his concentration and spirituality, offering rest and rejuvenation, are conducive to meditation and generate creativity and tolerance. This may be the reason why there are so many gatherings and social events attended by people from all over the world in Motovun.
Motovun film festival - The international Motovun film festival which was founded in the year 1999, at the beginning of August gathers here up to twenty thousand film lovers. The Hotel "Kaštel" regularly plays host to festival activities, from accommodation of contestants and guests of the festival to

evening festivities and night film showings on the hotel terrace.

http://www.histrica.com/hr/istra/zelena/motovun/
http://www.istra.com/pazin/eng/pov01.html

ISTARSKE TOPLICE – St. STEPHEN QUARRY

Jasenka Sremac

Abandoned quarry Sv. Stjepan (St. Stephen) is situated in the Mirna river valley at Istarske toplice spa (Fig.1).

Fig. 1. Abandoned quarry Sv. Stjepan (St. Stephen)

Gallery was excavated in rudist limestone of Cenomanian age (Fig. 2).
Limestone is light coloured, compact, decorative, with rudist cross-sections. It is highly resistant and therefore suitable for external and internal use.
Packstone to floatstone rock types can be recognized.
Commercial name of the limestone was „Ornamented rock St. Stephen of Istria". Excavation was stopped in 1965 g., because the quantity of limestone was too small for commercial exploitation.

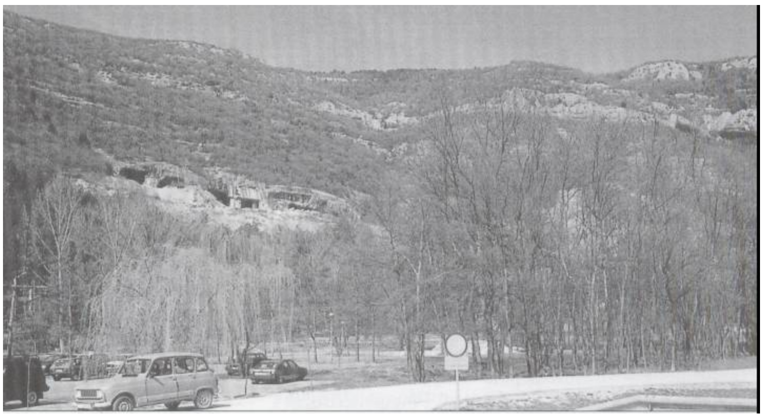


Fig.2. Abandoned quarry Sv. Stjepan. Excavated zone is 150 x 150 m wide, and 5-7 m high. (Šparica et al., 2000).

Eocene Carbonates and Flysch Deposits of the Pazin Basin

Stanislav Bergant, Josip Tišljar & Marko Šparica

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1. Istrian flysch and its relationship with flysch from NE Italy, W, SW Slovenia and the Adriatic coastal region in Croatia (Ravni Kotari area and Dalmatia)

The Istrian flysch according to MARINČIĆ (1981) represents only a small part of the elongated Dinaric coastal clastic zone (Fig. 1), which besides the Istrian part comprises the flysch basins of NE Italy and W Slovenia (Julian Basin), SW Slovenia (Vipava, Brkini), Ravni Kotari, Central Dalmatia (Kaštela–Split) and Southern Dalmatia (Konavli).

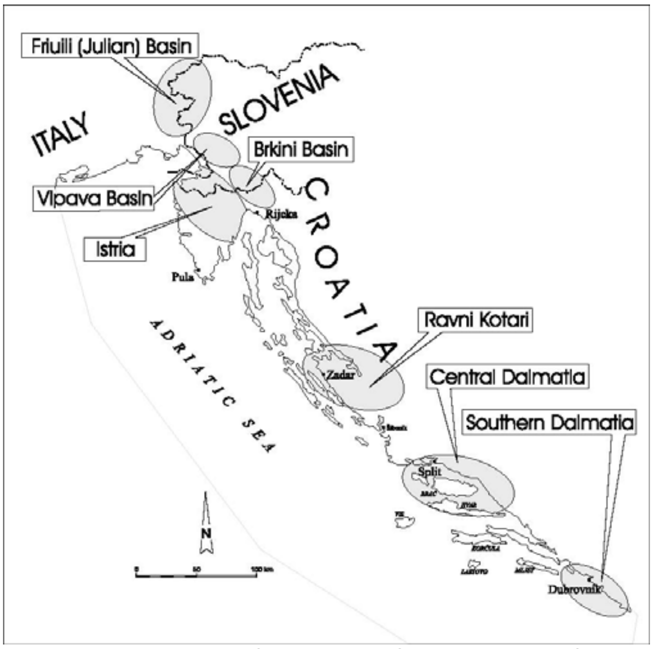

Fig. 1 Simplified map showing the position of the Tertiary flysch deposits of the Eastern Adriatic region.

A flysch trough started to form by the Pyrenean compressional tectonic phase from the Eocene to the Oli-gocene, and thus flysch represents syntectonic deposits. Generally, clastic deposition migrated southeastward from the Julian Prealps (Friuli) where it is of Maastrichtian to Early Eocene age (BUSER & PAVŠIČ, 1978; SKABERNE, 1987, 1989; TUNIS & VENTURINI, 1992) and continued over the Vipava syncline in the Palaeocene (DROBNE & PAVŠIČ, 1991), while Istrian clastics were deposited from the Middle Lutetian to the Bartonian (BENIĆ, 1991). Later stages of this migration were recorded from the Late Eocene (KOMATINA, 1967) to Miocene deposits in Central Dalmatia (Split Basin – MARJANAC, 1993), and still further to the southeast, over time spans ranging from the Bartonian (MARINČIĆ, 1981) to the Late Oligocene–Early Miocene, recorded in the deposits on Hvar island (PUŠKARIĆ, 1987).

This simplified Eocene palaeogeographical situation of a unique deep trough

(ŠIKIĆ, 1965; MAGDALENIĆ, 1972; MARINČIĆ, 1981; HERAK, 1986) seems much more complex when the existence of Mesozoic and Tertiary carbonates, shallow-marine clastics (ZUPANIČ & BABIĆ, 1991; MARJANAC & MARJANAC, 1991; BABIĆ et al., 1993) and palaeotransport patterns bordering flysch domains are taken into account.

Istrian flysch deposits are characterized by the alterna-tion of hemipelagical marls and gravity-flow deposits. The predominant deposits are 5–40 cm thick beds of turbidites, the bases of which are missing, developed mostly as laminated and cross-rippled sandstone beds (Tb–e, Tc–e and Td–e Bouma sequences). Complete Ta–e Bouma sequences up to 100 cm thick are rare. Sandstones are of mixed carbonate–siliciclastic composition. According to the low ratio of arenite to marl thickness it could be concluded that the flysch deposits are of a distal character. Turbidites were deposited from low-density turbidity currents (sensu LOWE, 1982).

The monotonous succession of marls and mixed carbo-nate–siliciclastic sandstones is intercalated with several thick carbonate beds composed of breccias, conglomerates, bioclastic arenites/siltites and marls. They show significant thicknesses of 0.5 to 5 m, sometimes over 10 m. These carbonate beds (megabeds) are interpreted as complex sequences of debris and turbidite origin and characterise the lower part of the basin fill. Some of them thin out and pinch out laterally, but the thicker ones are continuous over distances of more than 10 km. The base of these large beds is often flat, but sometimes shows shallow, wide erosional depressions.

Beside the megabeds of the Istrian (Pazin) Basin (e.g. 40 m thick megabed near Gračišće), occurences of megabeds of exceptional thickness are known from the Julian (Friuli) Basin (SKABERNE, 1987, 1989; TUNIS & VENTURINI, 1992) and the Central Dalmatian Basin (MARJANAC, 1991, 1993).

There are two distinctive types of contact between the flysch and underlying deposits in the Istrian basin: a) continuous, and b) with erosional discordance between the flysch and carbonate ramp deposits.

Continuous deposition in the areas of Boljun, Ko-tli, Buzet, Šterna, etc., was characterised by gradual deepening from shallow-marine Foraminiferal Limestones to transitional beds with the first influence of a terrigenous contribution (“*Marls with crabs*”). Still further increases in the clay content led to the deposition of homogeneous hemipelagic marls (“*Globigerina marls*”). Flysch deposits begin with the occurences of alternating sandstone and marl beds.

On the southern border of the flysch area (Motovun, Pićan…), flysch deposits discordantly overlie different stratigraphic horizons of platform carbonates, i.e. Ceno-manian limestones and Middle Eocene Foraminiferal Limestones.

A model of the palaeotransport for the Istrian flysch basins was discussed by numerous authors. As the flysch domain represents an elongated trough with Dinaric strike (NW–SE), MAGDALENIĆ (1972) proposed a longitudinal component toward the ESE, which derived material from the Alps, and a transversal component toward the SW where the source area was the rising Dinarides. A similar pattern was given by MARINČIĆ (1981), anticipating the entire supply from the rising Dinarides, i.e. according to him all flows have a primary transverse direction toward the SW, while longitudinal palaeocurrents resulted from the deflection of transversal flows to the ESE. Occurrences of longitudinal palaeotransport, but of opposing north-westward directions was

proposed for the area south of Buzet after ŠIKIĆ & PLENIČAR (1975) and OREHEK (1991). BABIĆ & ZUPANIČ (1996) confirmed a longitudinal direction to the ESE. Generally, palaeotransport data for the longitudinal direction were collected from flute casts occurring on the lower bedding planes of mixed carbonate–siliciclastic sandstones. Alterna-tively, palaeocurrent measurements in carbonate megabeds of the Pazin Basin indicate a direction to the NNE for debris transport (BABIĆ & ZUPANIČ, 1996) assuming a supply from the outer (Adriatic) area.
A similar pattern of longitudinal palaeotransport of mixed carbonate–siliciclastic turbidites supplied from the N, NW and transversal palaeotransport for thick carbonate beds supplied from the S was proposed by TUNIS & VENTURINI (1992) for the Julian Basin. OREHEK (1991) declared a longitudinal (E and SE) transport for the Vipava Basin and an opposite NW direction for the Brkini Basin. MARJANAC (1993) described a complex, almost centripetal palaeotransport pattern for the Central Dalmatian Basin.

2. Nummulitic limestones and flysch profile near Kotli village (easternmost part of the Pazin Basin)

Kotli is a picturesque village situated in the vicinity of the Roč–Hum road in the valley of the upper reaches of the Mirna river in the easternmost part of the Pazin Basin. The strata crop out along the road from Kotli to the village of Krusvari. The section represents a typical continuous development of the Palaeogene deposits in Istria. The youngest part of the Foraminiferal Limestones, transitional beds and flysch deposits are presented. The thickness of the section is about 140 m.

Foraminiferal Limestones

This section begins with the uppermost part of the *Nummulitic limestones* characterised by massive, weakly expressed bedding, often with a well developed, typical, nodular-shaped upper surface, in some places with bioturbation. An abundant fossil assemblage has been found in the samples. These limestones were not biostratigraphically determined in detail. In the absence of orientated sections, large foraminifera are defined only at the generic level: *Nummulites* sp., *Discocyclina* sp., *Assilina* sp., *Rotalia* sp., *Operculina* sp., rarely *Alveolina* sp. and species *Sphaerogypsina globula*. Corallinacean red algae and the planktonic foraminifera *Turborotalia* and *Globigerinoides* are abundant. The limestones are skeletal wackestone/packstones to floatstones with weak sorting and sometimes mechanically destroyed bioclasts. Grain size ranges from less than 1 mm for bioclasts to more than 15 mm for foraminiferal tests. Bioclasts are suspended in a fine-grained micritic matrix which is sporadically recrystallised. Planktonic foraminiferal tests are often filled with sparitic calcite or authigenic glauconite. Terrigenous clasts are absent.
A change of depositional environment caused changes in the faunal assemblages. Representatives of the genus *Nummulites* became scarcer and *Discocyclina* and *Opercu-lina* genera became predominant in the upper part of the Foraminiferal Limestones.
Deposition of Foraminiferal Limestones mark the re-newal of carbonate sedimentation after the Late Cretace-ous emergence phase. According to

their fossil content, the Foraminiferal Limestones are of Lutetian age. The deposits correspond to sedimentation in shallower and deeper parts of shoreface environments with warm oxygenated conditions (*Nummulites*-limestones), and a transition to the deeper parts of the outer edge of relatively open carbonate ramps ("*Discocyclina*"-limestones). The frequent occur-rence of planktonic organisms and fine carbonate matrix leads to the conclusion of a pelagic influence.

Transitional beds

The Foraminiferal Limestones gradually pass upwards into a narrow zone of limestones of similar structural characteristics to those previous described. The sediments show characteristic wavy bedding planes. Benthic and planktonic foraminifera are dominant, but there is a greater influence of a terrigenus component, i.e. the appearance of clay intercalations and siliciclastic grains, which are more frequent in the upper part of deposits, where the limestones pass into clayey and silty limestones. The limestones are skeletal wackestone/packstone with rare grains of chert, quartz, feldspar and authigenic glauconite. Fossil fragments are poorly sorted, between 0.1–3 mm in size, in a recrystallised matrix.

Planktonic foraminifera occur which are typical for the biostratigraphic zone (P-11) of Middle Lutetian age: *Globi-gerinatheka mexicana* (CUSHMAN), *Morozovella arago-nensis* (NUTTALL), *Globigerina inaequispira* SUBBO-TINA, *Acarinina bullbrooki* (BOLLI), *Turborotalia fronto-sa* (SUBBOTINA), *T. passagnoensis* (TOUMARKINE & BOLLI) etc., accompanied by bioclasts of *Discocyclinae*, *Nummulites*, *Assilina* and *Operculinae*, corallinacean red algae, crabs and irregular echinoids.

These sediments were deposited in a quiet open marine environment with a significant pelagic influence, but shallow enough for large foraminifera. The presence of glauconite indicates deeper water (outer shelf) and less oxygenated (reducing) conditions with a low sedimentation rate (ODIN & MATTER, 1981).

Clayey limestones with crabs pass into greenish homogeneous massive hemipelagic marls approximately 40 m thick, which are rich in planktonic foraminifera (globigerina). These marls consist of variable amounts of carbonate and siliciclastic components. The carbonate component is predominantly of crypto- and microcrystal-line calcite of detrital and partly chemogenic origin. A siliciclastic component of quartz grains and clay particles originated from terrigenous sources.

The marls are of Upper Lutetian age, as shown by the planktonic foraminiferal assemblage of *Turborotalia fron-tosa* (SUBBOTINA), *T. possagnoensis* (TOUMARKINE & BOLLI), *T. premoli* PROTODECIMA & BOLLI, *Globi-gerina linaperta* GÜMBEL, *G. hagni* GOHRBANDT and *G. eocaena* GÜMBEL determined as the P-12 zone. Simi-lar deposits in the adjacent Buzet area, are according to nannofossil species: *Discoaster barbadiensis* TAN, *Dictyo-coccites bisectus* (HAY, MOHLER & WADE) and *Corono-cyclus nitescens* (KAMPTNER) determined as belonging to the NP-15–16 zone (BENIĆ, 1995).

Based on the microfaunal associations, the marls were deposited in a deep water environment of a few hundred metres to 1000 m in depth (GOHRBANDT, 1962; JURA-ČIĆ, 1980).

Flysch

Flysch deposition began with the first occurrences of the alternation of sandstone and marl beds above the homogenous "*Globigerina Marls*". This section comprises an aproximately 90–100 m thick succession of flysch deposits. The lower part of the flysch unit contains carbonate and marl beds ranging in thickness from 0.3 to about 7 m, while the upper part is composed of an alternation of thin hybrid carbonate–siliciclastic beds and marls. The carbonate beds comprise conglomerates, foraminiferal breccias, arenites and siltites. Some thick beds (megabeds) are of dual origin, i.e. debrite and turbidite. Lower parts of the megabeds of debrite origin are composed of lithic debris up to 20–30 cm in diameter (clasts up to few metres in size are known from some thick megabeds). Clasts of Late Cretaceous deposits, various types of Palaeogene limestones (the most often limestones with nummulites, glauconitic clayey limestones and rarely "Liburnian" limestones, limestones with miliolids and limestones with alveolinas) and marl chips are abundant. Skeletal particles are common: large foraminifera (ortho-phragminas, nummulites), corrallinaceans and rarely gas-tropods, corals etc. Debrites are normally graded, clast supported with often well rounded clasts.

Upwards, the megabeds gradually change character from debrite to turbidite, and this transition lead to the conclusion that the megabeds are the result of a single sedimentation event. Apart from debrites, carbonate turbidites are predominantly sandy with pebble-sized particles in their lower parts. They consist of similar particles as those described for the debrites, but of smaller dimensions, plus abundant particles of smaller benthic and planktonic foraminifera, bryozoans, echinoderms, etc. Carbonate turbidites are normally graded and can be described as complete Bouma Ta–e sequences. Megabeds always terminate with a thick pelite bed (Bouma Te inter-val) which was partly derived from a turbidite current (Tet) and partly from hemipelagic sedimentation (Teh).

Coarse-grained clasts (debrites) are interpreted as the products of cohesive debris flows and high-density turbidite currents, while the origin of carbonate turbidites is attributed to low density turbidite currents (LOWE, 1982). The increasing intensity of clastic deposition seems to be driven by the instability of shelves and seismotectonic activity (MUTTI et al., 1984), i.e. in Istria from the uplift of tectonised carbonate deposits. Large bed thicknesses indicate the high initial volume of redeposited debris (RICCI LUCCHI & VALMORI, 1980) and its proximal character. Thick massive marls in the upper part of the megabeds were deposited from the ponded turbidity current tails (KUENEN, 1968; MARJANAC, 1993).

According to the composition of the carbonate megabeds, the existence of emerged land and a shelf environment in the vicinity of the flysch basin could be assumed. Exposed land contributed lithoclasts of Late Cretaceous limestones, different types of Palaeogene limestones and probably "*Globigerina Marls*", while the abundant fossil content, primarily large foraminifera and their bioclasts, was derived from a shallow-marine environment, which existed on the upper margin of the flysch trough. On the basis of palaeocurrent data collected from carbonate beds in the southern part of the Pazin Basin, the existence of a foreland high situated on the southern parts of the present-day Istrian peninsula is proposed (BABIĆ & ZUPANIČ, 1996).

In the uppermost part of the flysch unit mixed carbonate–siliciclastic turbidite beds were deposited. They consist of thin, partial Bouma turbidite sequences with parallel and current-ripple lamination (Tb–e, Tc–e, Td–e), but beds without obvious internal structures typical for turbidites are common. The thickness of sand beds varies from 1–10 cm while marl beds range from 5–100 cm. Lower bedding planes are mostly flat, sometimes with small scale V-shaped flute casts and groove marks.
Sands are determined as lithic arenites and calcarenaceous sandstones (after the classification of PETTIJOHN et al., 1972). They are composed of siliciclastic and carbo-nate grains with minor amounts of fossil debris which is well sorted and ranges in grain size from silt to sand. Among the siliciclastic component subangular quartz grains, lithoclasts of chert and quartzite predominate, whi-le grains of feldspar, micas, garnets, zircon, routile and turmaline are less frequent. Resistant minerals are often well rounded, indicating relatively long transport. The carbonate component is present as fragments of micritic limestones, crystalline calcite and as fine-grained matrix. Fossil fragments are composed of redeposited comminuted faunal debris (planktonic foraminifera, corallinaceans, gas-tropods, corals, bryozoans, echinoderms, etc.). According to the SSE palaeotransport direction and abundant siliciclastic debris, an Alpine provenance could be assumed for the source material (MAGDALENIĆ, 1972).
The turbidites are mudstone-dominated and according to the low sand to marl ratio these sequences exhibit the characteristics of distal turbidites. The low thickness of mixed turbidites leads to the conclusion that the turbidite currents were low in bulk. The sequences where the basal units are absent belong to classes C and D of the turbidite facies (MUTTI & RICCI LUCCHI, 1972) and were deposited from diluted, low-density turbidity currents (LOWE, 1982) under a lower flow regime.

3. Megabeds within the distal flysch deposits near Hum, the smallest town in the World

The picturesque town of Hum is situated on the megabed, which is bedrock resistant to physical weathering unlike the distal flysch of central Istria.
The thickness of the Hum megabeds is 7 m. There is an intense erosion surface between the lower bedding surface and the underlying marls. The lower part of the megabed of debrite origin, is composed of poorly sorted clasts from 10–30 cm up to several metres in diameter. Clasts of Cretaceous limestone prevail, while various types of Palaeogene limestones are rare. The matrix is comprised of fine-grained clasts and bioclasts of large foraminifera (orthophragminas, nummulites), corallinaceans and rare corals.
Upwards, the megabeds gradually change character from debrites to carbonate turbidites, predominantly com-posed of sand with pebble-sized particles in their lower parts and a large amount of fine-grained bioclasts of large foraminifera, rare corallinaceans, and clasts of limestones, in their upper part. The Hum Megabeds are terminated by a thick pelite bed (Bouma Td–Te interval), containing clay and fine-grained particles of smaller foraminifera, planktonic foraminifera, bryozoans and echinoderms. This part of the

megabeds is derived partly from turbidite currents and partly from hemipelagic sedimentation.

In contrast to the distal flysch deposits within which the Hum megabeds occur, the gravitational flow from which the megabeds were deposited moved along the basin edge, i.e. approximately perpendicular to the axis of the flysch basin. It was initiated by synsedimentary tectonics – tectonic shocks – during the formation of one, or a series of several, deeper-marine troughs. During the tectonic lowering of the carbonate platform, gradually a deeper trough(s) formed which were accompanied by concurrent rising of trough margins where intense erosion of the uplifted parts of the Upper Cretaceous carbonate platform took place.

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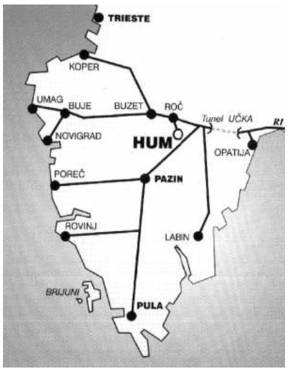
HUM

The smallest city in the world according to the Guinness Book of World Records .



In the central part of Istria, 14 km southeast of Buzet is Hum, the smallest city in the world with a population of only 23 citizens. The small town was first mentioned in 1102 under the name Cholm, and as such is still known as Colmo in Italy to this day. Although it was established in the Middle Ages, Hum has preserved all of the distinctive features of urban architecture that are characteristic of acropolis settlements and although small it was the center of Glagolitic literacy during the Middle Ages.

On one side it is closed off by urban defensive towers and a system of walls, while the other side is enclosed by the outer walls of houses. The bell-tower dates back to 1552 while St. Jerome's Parish Church guards a rich collection of a late Gothic chalice, a ciborium and other liturgical objects. Frescoes dating back to the 12th century that were created under the strong Byzantine influence are particularly valuable to the parish church which is not surprising when one learns that Hum was the residence of one of the richest patriarchal servants. What is remarkable about Hum is that along with nearby Roc, it was the center of Glagolitic literacy during the Middle Ages. In the church today is a Glagolitic graphite dating back to the 12th century which is among the oldest monuments of Glagolitic script in Istria. In memory of this valuable heritage, in 1977 the **Glagolitic Lane** was opened, a monumental complex that consist of 11 landmarks set up along a 7 km long walking path from Hum to Roc.

http://www.hum.hr/

ROAD RIJEKA-DELNICE-DUGA RESA-KARLOVAC

Karmen Fio

Going from **Rijeka** towards east to the inland, we pass from Lower Cretaceous sinclinal structure of the Grobnik field and go through anticlinal structure made of Upper, Middle and Lower Jurassic, Upper Triassic and Permian sediments on the way to **Lokve** and on to **Delnice** which are situated in the Upper Triassic dolomites with clastites in the base and Middle Permian mostly clastites (Savić et al., 1985). On the way towards Duga Resa we pass first through Upper Triassic limestones and dolomites and Upper Jurassic limestones, dolomites and breccias, and enter the Cretaceous area with clastites, limestones and dolomites (Bukovac et al., 1984). On the way to **Karlovac** we pass through an Upper Triassic part with limestones and dolomites, and some Pliocene unconsolidatet sediment areas.

LOKVE LOCALITY, GORSKI KOTAR

Ladislav ***Palinkaš*** *& Sibila* ***Borojević-Šoštarić***

(*Stratabound Barite Deposit, Sabkha Depositional Environment, Permian–Triassic Boundary (Lokve Locality in the Gorski Kotar, Central Croatia*),reprint from Field-Trip Guide Book, 22nd IAS Meeting of Sedimentology, Opatija, Croatia, September 17–19, 2003).

Barite mineralization in Lokve is a stratabound ore deposit conformably situated at the Permian–Triassic boundary. It is composed exclusively of pyrite and barite, separated into two distinct, juxtaposed horizons, stretching for tens of kilometres (Fig. 4.1).

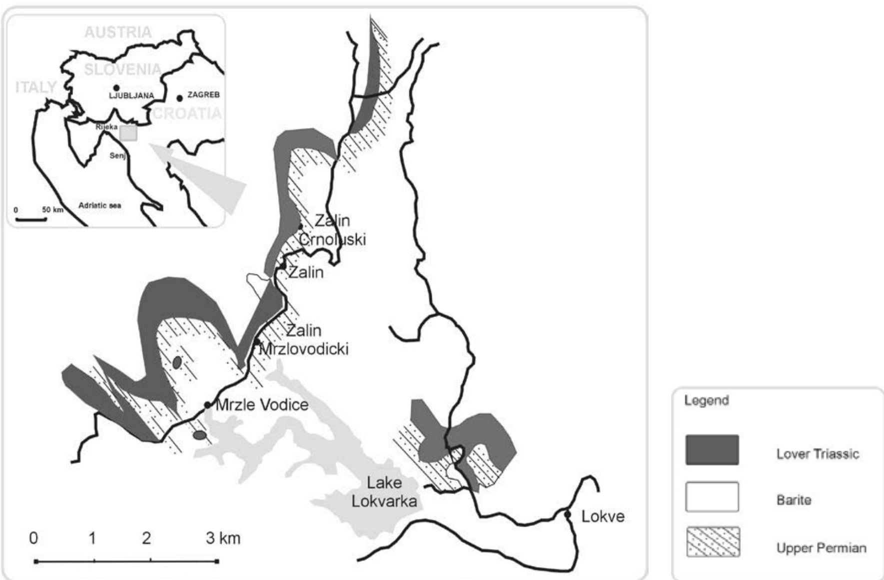


Fig. 4.1 Geological map of the Lokve village area (after ŠUŠNJARA & ŠINKOVEC 1973).

Discovery of cryptalgal fabrics and other conspicuous sedimentary features in underlying siliciclastics with massive pyrite passing upwards into barite-bearing dolo-mites supports their affiliation to a tidal flat facies, and sabkha environment1. Barite and pyrite accumulation were formed by early, diagenetic, bacteriogenic sulphate reduction in peritidal muddy environs, concomitant to the widespread process of evaporatic dolomitization. The early diagenetic model is supported by analyses of the sedimentary facies, trace element geochemistry and sulphur isotope distribution along two vertical profiles across the stratabound pyrite ore body.

GEOLOGY, DEPOSITIONAL ENVIRONMENT, MINERALIZATION

Middle and Upper Permian siliciclastic sediments occuring near Lokve village originate from newly exposed dry land areas, uplifted during an early continental rifting phase in the Dinarides. The progressive denudation created expressive relief and sedimentary spaces were infilled by persistant mature clastics. The final members of the Upper Permian clastic rocks are green-grey and grey-violet fine-grained siltstones and pelites. Extensive low-lying coastal areas in the Dinarides became sites of evaporite deposition in lagoons and coastal sabkhas. Smoothing of the relief halted clastic deposition, which together with a concurrent change in climate from humid–arid to moderate–warm, triggered carbonate deposition and formation of the basal dolomite. All the Lower Triassic carbonate lithotypes with stratabound mineralization in the Gorski Kotar area, adjacent to the conformable contact with the Permian clastics, originated in a sedimentary environment near mean sea level (BABIĆ, 1968; ŠČAVNIČAR, 1973).

The Lokve barite deposits are situated along the edges of the Upper Permian terrain, adjacent to the contact with the Lower Triassic dolomites. The largest deposits occur in the vicinity of the villages of Homer and Mrzle vodice.The barite ore is inter-stratified in the Lower Triassic dolomites, always lying directly over the Permian clastics impregnated with pyrite cement. The ore bodies are equilateral layers, ranging in length from several metres to 300 m, and 1 to 5 m thick . The richest ore grade yields 70 to 90% barite, but on average it varies between 20 to 70% (Fig. 4.2).

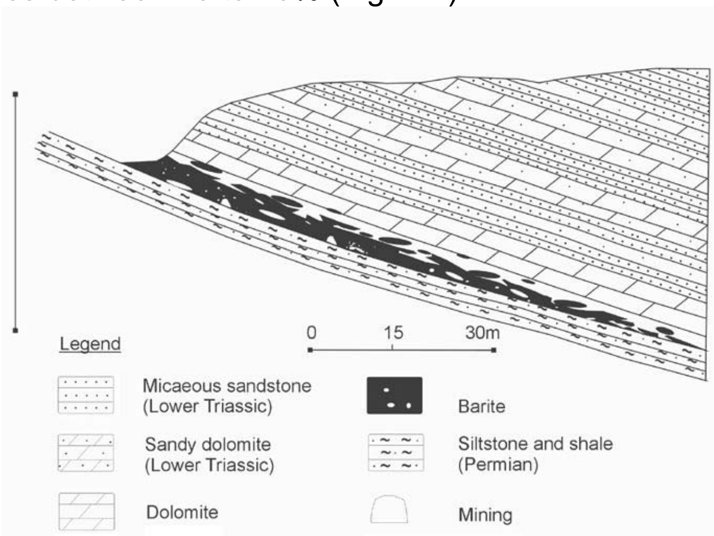


Fig. 4.2 Cross-section through the ore body at Lokve village, Homer locality (after ŠUŠNJARA & ŠINKOVEC 1973).

Barite has been mined for decades from clayey limonite, formed by the oxidation of pyrite in a transitional barite–pyrite zone. It was easily separated from the clay and limonite simply by washing. Rich ore in the dolomite has never been mined due to the lack of appropriate technology.

Homer locality, at the Lokve village in the central Gorski Kotar

The Homer locality is situated near Lokve village in the Central Gorski Kotar. The basal dolomite, at the contact with the clastics bears stromatolithic bioherms and biostromes, which gradu-ally pass into high-energy, peritidal, sedimentary features including oolitic deposits, cross-, oblique-, parallel- and ribbon-lamination.

Early barite pervaded all sedimentary structures in the dolomite, making them distinctly observable due to its higher weathering resistance (Fig. 4.5a–d, 4.6b, d; PALINKAŠ & ŠINKOVEC, 1986).

The schematic column of the Homer locality repre-sents a characteristic stratigraphic sequence at the Lokve village (Fig. 4.3).

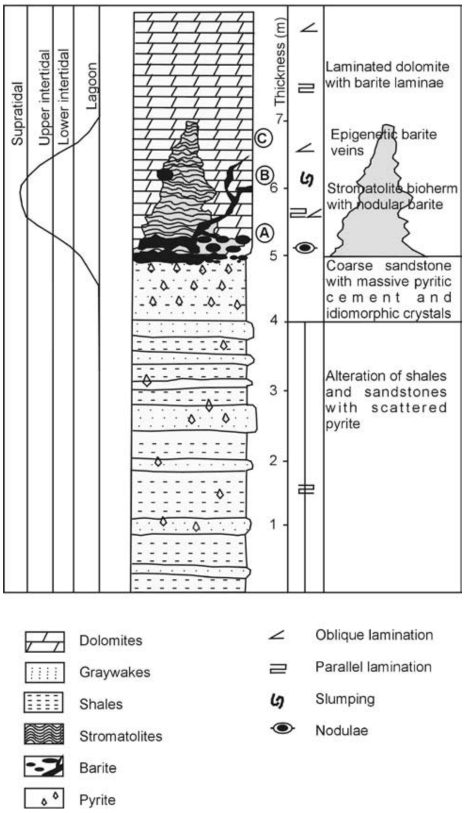


Fig. 4.3 Schematic stratigraphic column at the Homer locality, near the village of Lokve (after PALINKAŠ & SREMAC, 1989).

Underlying rocks are Permian clastics, sub-parallel alternation of shales and sandstones on a centimetre-scale. The rocks are dark, almost black, often with macrofloral remains. The coarser members are impregnated with pyritic cement, which amounts to a few percent, but increases significantly approaching the clastic–carbonate boundary (to a few tens, at places almost massive pyrite). In the uppermost part of the clastics, the first scattered masses of barite appear intermingled with massive pyrite. This barite–pyrite boundary is overlain by barite-bearing dolomite.

At places stromatolithic bioherms distinctly emerge as prominent masses surmounted and surrounded by cross-laminated dolomite, with numerous high-energy water structures (PALINKAŠ & SREMAC, 1989).

At the lowermost part of the basal dolomites, a nodular, pyrite–barite ore, with chicken-wire structure occurs (Fig. 4.6a). Stromatolitic fabric in the dolomite is clearly demarcated by chemically resistant barite, but thin sections and acetate peels revealed conspicuous lamination with acicular barite. Crudely developed barite lamination and coarse fenestrae suggest an intertidal stromatolitic fabric formed from pustular mats in fairly agitated water of an unprotected environment.

Školski brijeg locality, near Mrzle vodice village (Central Gorski Kotar)

Discrete stromatolitic morphotypes pervaded by barite have been observed at Školski Brijeg near Mrzle vodice village after PALINKAŠ & SREMAC (1989; Fig. 4.4c). The stromatolitic series starts with low relief species having almost biostromal characteristics (Fig. 4.4c, point A). Coarse fenestrae, cavities, crude lamination and low relief indicate a subtidal, but low energy environment. The conditions gradually changed into more agitated water causing formation of columnar SH-stromatolites of different shapes. Conical and domal forms prevail (Fig. 4.4c, point B). The outer surface of the stromatolites is covered by a pyritic crust approximately 5 cm thick at the crest of the columns. It was a former soft, colloform mat, ideal food for sulphate-reducing bacteria, digested during later anoxic conditions within sediments, after burial. The burial must have been fast, perhaps even immediate, since algal growth ceased instantaneously, and organic matter was preserved from disintegration in otherwise oxidizing waters.

On the left side of Fig. 4.4c, point C, one may observe a 0.5 metre-tall, club-shaped column with coarse, irregular fenestrae, formed from a pustular mat. The pyrite crown is missing, since the mucilage, or organic layer, was destroyed during emergence and subaerial exposure, a common occurrence in the disintegration process on living stromatolites in the upper intertidal regime.

The uppermost pyritic, irregular layer (Fig. 4.4c, point D) is a cross-section through a ridge-and-rill pseudo-columnar stromatolite shaped by wave action and tidal scouring in sub-littoral but again lower energy water.

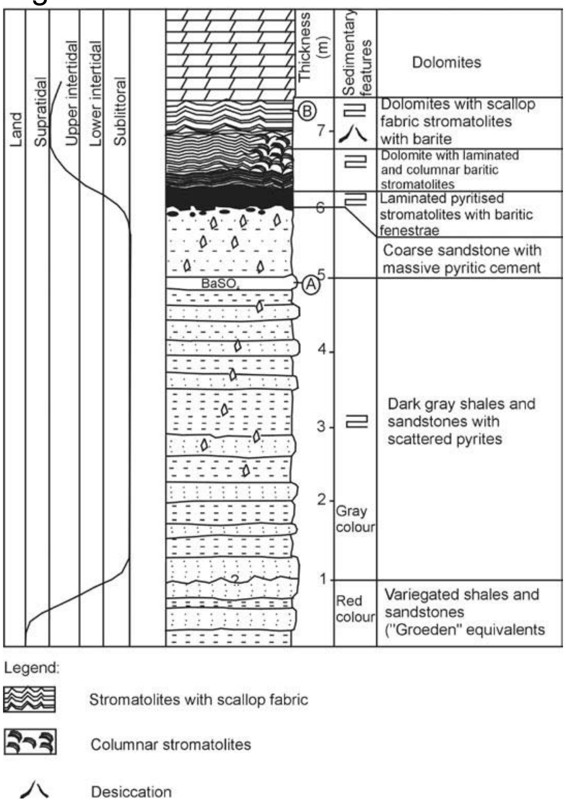


Fig. 4.4 Schematic stratigraphic column at the Mrzle Vodice locality (after PALINKAŠ & SREMAC, 1989).

Mrzle vodice locality (Mrzle Vodice village, Central Gorski Kotar)

The situation at the village of Mrzle Vodice in central Gorski Kotar is markedly different (Fig. 4.3). The Permian clastics are red with green and grey intercalations, named “Groeden equivalent” (SALOPEK, 1960). A layer of grey siltstones and sandstones, rich in pyritic cement overlies “the red clastic series”. The upper surface of the clastics is impregnated by a large quantity of pyrite, even massive in places, with delicate lamination and barite fenestrae. It was a former organic-rich, stromatolitic layer, pyritized completely during early diagenesis. It carpeted muddy shoals with stagnant, hypersaline water, as deduced by the absence of trapped detrital particles and grazing metazoans.

Fine, undulate lamination on a millimetre-scale at the contact of the clastics and dolomites changes to slightly coarser laminae in the overlying dolomites, with the first sign of domal forms, laterally passing into flat laminated fabric, suggesting an increase in water energy. Stromatolitic fabrics succeeding upwards are upper inter-tidal to supratidal formations, and curling of algal mats is due to desiccation processes (Fig. 4.5d).

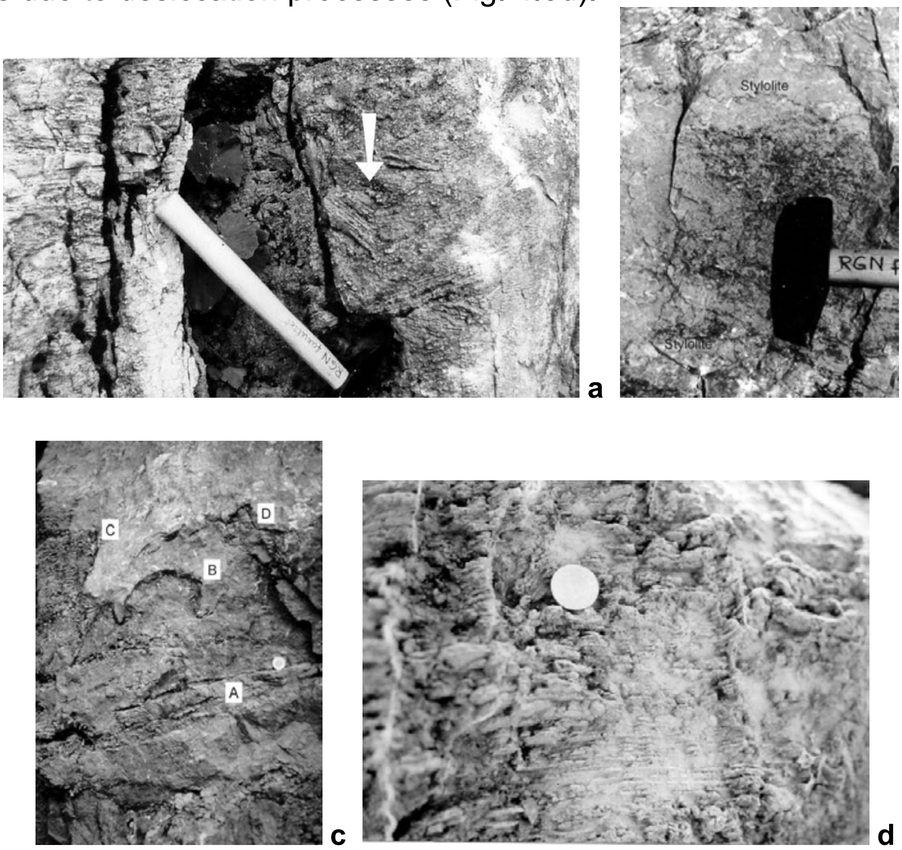


Fig. 4.5 a) Early diagenetic dolomitization of lime sediment, caused by evaporative transpiration in tidal flats, induced partial stiffening of newly formed dolomite laminae, and sedimentary features were afterwards baritized. The heavy load of the overlying carbonate rocks on the soft, water-rich mud layer deformed primary ore structures and brought about intraformational collapse and cracking of the laminae (original sediment was probably of tidal channel origin). b) Stylolites as a late diagenetic feature, passing through patches of dolomite and barite in mottled ores (upper part of the basal dolomites), represent evidence of the early diagenetic origin of mineralization. c) Školski Brijeg locality different morphotypes (diameter of a coin – 2.5 cm): A) Low relief biostromal formation with pyrite crust. B) Discrete columnar stromatolites with prevailing conical and domal forms. The outer crust is composed of an approximately 5 cm thick pyrite crown at the top of the column. C) Club-shaped columnar stromatolites with missing pyrite crust and crudely developed baritic, fenestral fabric. Internal structure minutely baritized. D) Ridge-and-rill stromatolites formed in lower water energy. d) The Mrzle Vodice locality, flat-laminated barite stromatolites with scallop fabric due to desiccation process in the upper intertidal (diameter of coin 2.5 cm) (after PALINKAŠ & SREMAC, 1989).

Comparing the localities, there is an obvious difference in water energy. Školski Brijeg might be referred to as a headland, while Homer belongs to a bight coastal type. Mrzle Vodice, with fine, laminated organics-rich stromatolites (transformed completely into pyrite, and limo-nitized by ongoing weathering) and no trapped particles, might have been a muddy embayment with sabkha envi-ronment characteristics1 (PLAYFORD & COCKBAIN, 1976).

GENESIS, ORE FORMING MODEL, SULPHUR ISOTOPES AND TRACE ELEMENTS

There were several propositions for the genesis of the Lokve deposits. JURKOVIĆ (1959, 1962) considered the deposit to be of submarine exhalative origin, and some veinlets cutting sedimentary features as secondary-hydrothermal remobilization. ŠUŠNJARA & ŠINKOVEC (1973) attributed the deposits to syn-sedimentary ore forming processes in shallow, partly or completely land-locked basins, during regressive conditions. ALJINOVIĆ (1997) considers the deposit as late diagenetic, epigenetic, hydrothermal, connected with the intrusion of the Middle Triassic hornblende andesite near the village of Fužine.

The authors propose the following ore depositional model, supported by sulphur isotopes, trace elements and sedimentary features of the host rocks and mineralization (PALINKAŠ et al., 1993).

The first stage of the ore forming process began with clastic deposition in the Late Permian (Fig. 4.7a). The dark grey and black colour, abundant plant debris and ubiquitous pyritization indicate reducing diagenetic conditions, but not necessarily euxinic bottom waters. In contrast, some textural elements, grain size and flora remnants are indirect signs of shoreline proximity and high-energy water. Red, green and grey Groeden clastics, underlying a few-metre-thick, pyrite-bearing reducing horizon at Mrzle Vodice (Fig. 4.4) were exposed subaerially as country rocks during an earlier regression cycle.

The second stage of the model (Fig. 4.7b) requires an abrupt change in the depositional style, introducing carbonate sedimentation. Structural features of the basal dolomites and other lithotypes indicate a peritidal environ-ment and represent a preferable site for future oncoming baritization. At that time the first carbonate sediments were calcareous, preferentially aragonitic in composition.

The third or "Mineralization stage" is closely related to dolomitization processes (Fig. 4.7c). The lime sediments deposited in near-shore shallow waters were soon subjected to subaerial evaporative pumping in a tidal flat environment, during a regressive phase of fluctuating sea level cycles. Early diagenetic dolomitization, as a replacement process caused by hypersaline brines with high Mg^{2+}/Ca^{2+} ratios, is followed by concurrent manifestations including:

– a significant increase in the porosity of dolomite in comparison to the aragonite precursor, due to the remarkable difference in specific volume between ara-gonite and dolomite. It facilitated any subsequent infiltra-tion process, e.g. baritization;

– early diagenetic lithification, making dolomitized lay-ers rigid, has a characteristic geomechanical effect on the underlying soft water-rich sediments. This is noticeable by intra-formational brecciation and collapse structures (Fig. 4.5a). Subsequent upward dewatering of the underlying soft

deposits may be important in the transport of barium to its final depositional place;
– the upper surface of the tidal flat sediments, exposed to intensive drying, shows desiccation cracks and curling of the algal mat;
– release of high strontium concentrations during dolomiti-zation of aragonite mud may have been sufficient for the formation of celestobarite evaporitic deposits.

Celestite may replace an older generation of evaporite minerals, or be an isomorphic substitute in barite minerals. Barite from Lokve is enriched in strontium. ŠIFTAR & ŠINKOVEC (1973) reported authigenic celestite as an accessory mineral in the deposits.

The source of barium should be sought in the empha-tically reducing environments of the underlying organic-rich siliciclastic layer, former stromatolitic algal mat and clayey sediment. The thriving of sulphate-reducing bacteria upon burial enables high production of dissimilatory H2S, which lowers the Eh of connate water. The prolific H2S production is accompanied by two effects: formation of early diagenetic iron monosulphide and a drastic decrease in sulphate concentration. It dissolves, aided by the high salinity, disseminated authigenic barite minerals in the siliciclastic sediment. An additional quantity of barium ions might have been delivered from surrounding brackish, marshy areas by groundwater feeding coastal plains.

The brines were being expelled from soft, sulphate depleted, underlying mud by the heavy load of the rigid carbonate layer and evaporative pumping, along all inter-stices, and solution cavities. They were expelled through porous laminated dolomites, which served as conduits and in-filling space nourished by the Ba-rich solution.

Reprecipitation and encrustation of the basal dolomites by barium sulphate was the early diagenetic process as proved by intra-formational collapsing and cracking of partly stiffened laminae (Fig. 4.5a). The same holds true for nodular and macro-cellular barite structures grown like concretions in the tidal flat sediments (Fig. 4.6a, c).

The last, but not the least important contribution to the model are the geochemical data. Sulphur isotope values, along two vertical profiles in the pyritous clastics at the Homer and Mrzle Vodice localities attest to an increasing downward tendency. At the Homer locality the isotope $\delta^{34}S$ values range between -15.47 and +10.44‰, and at the Mrzle Vodice locality from -15.00 to +20.15‰ (Fig. 4.8a, b). This is confirmatory evidence of a closed to semi-closed system regarding sulphate supply.

Nodular barite at Homer has $\delta^{34}S$ value +17.06‰, stromatolitic laminar barite +15.37‰, veinlets in biostromes +15.90‰.

At Mrzle Vodice barite intercalation is even at +17.40‰ and stromatolitic lamina +17.40‰. All these values might be related to the Lower Triassic seawater, with a slight increase due to microbial fractionation (PALINKAŠ & PEZDIČ, 1989).

The trace element geochemistry is similar in some details to the Kupferschiefer. The Mrzle Vodice ore bearing sequence, starting with “red beds”, shows a characteristic zoning of Cu, Pb and Zn, Zn/Cu>>1, and Co/Ni<0.1. The maximum concentration is in the massive pyrite, Hg – 33.4 ppm, Zn – 320 ppm, Cu – 17 ppm, Pb – 720 ppm, Mn – 284 ppm. Manganese has the same fate as barium in a hydrogen sulphide reducing environment. Its high mobility as Mn2+ gives rise to upward migration and encrustation at the clastic–dolomite boundary, i.e. Eh–pH barrier (Fig. 4.6a).

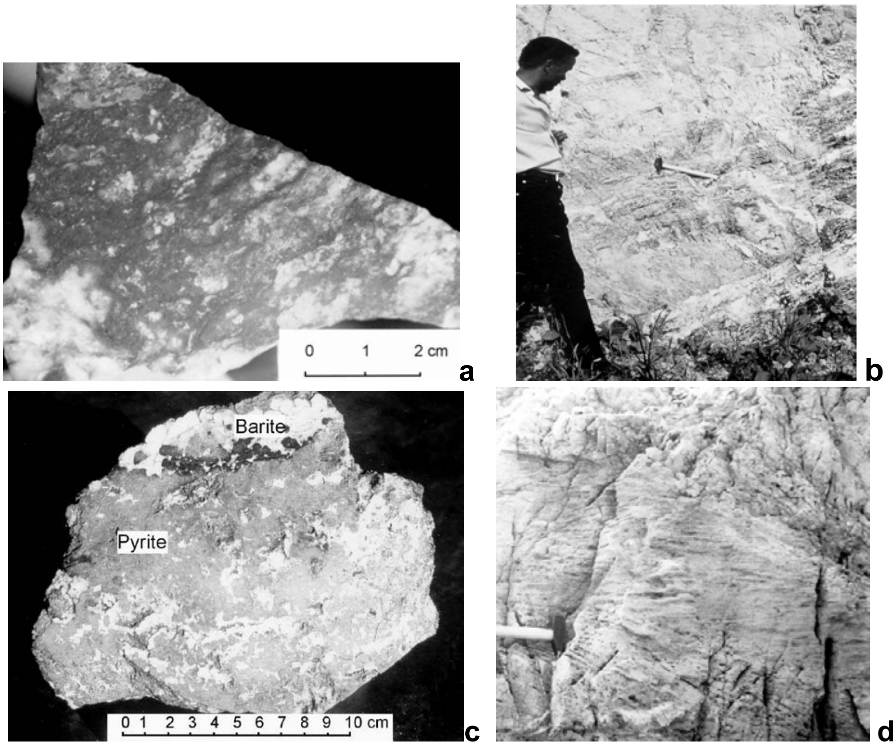


Fig. 4.6 a) Macrocellular and nodular structures (chicken-wire) typical of evaporites, in this case barite (white and pinkish masses in dolomitic laminae), growing in tidal flat sediments. Homer locality. b) Barite biostromes in the basal dolomites. c) Massive pyrite and barite ore with macrocellular structure, at the clastic–dolomite contact, usually weathered into manganiferous gossan, Mrzle Vodice locality. d) High-energy water sedimentary structures (cross-bedding) in the basal early diagenetic dolomites, cemented by barite, easily noticeable due to the weathering resistance of barite in comparison to dolomite (after PALINKAŠ & SREMAC, 1989).

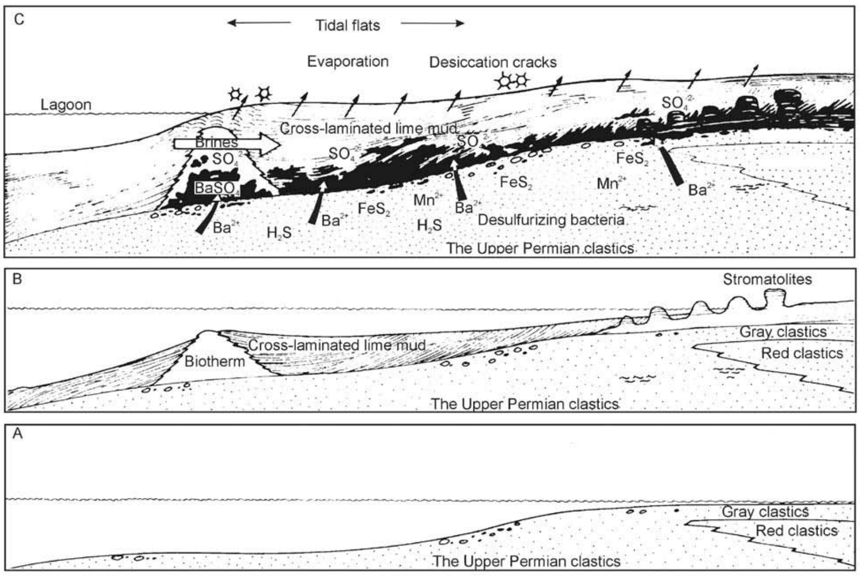


Fig. 4.7 Three stages of ore deposit development: a) deposition of Upper Permian clastics; b) regression and sedimentation of laminated lime mud, and c) evaporitic dolomitization accompanied by barite ore forming processes (after PALINKAŠ et al., 1993).

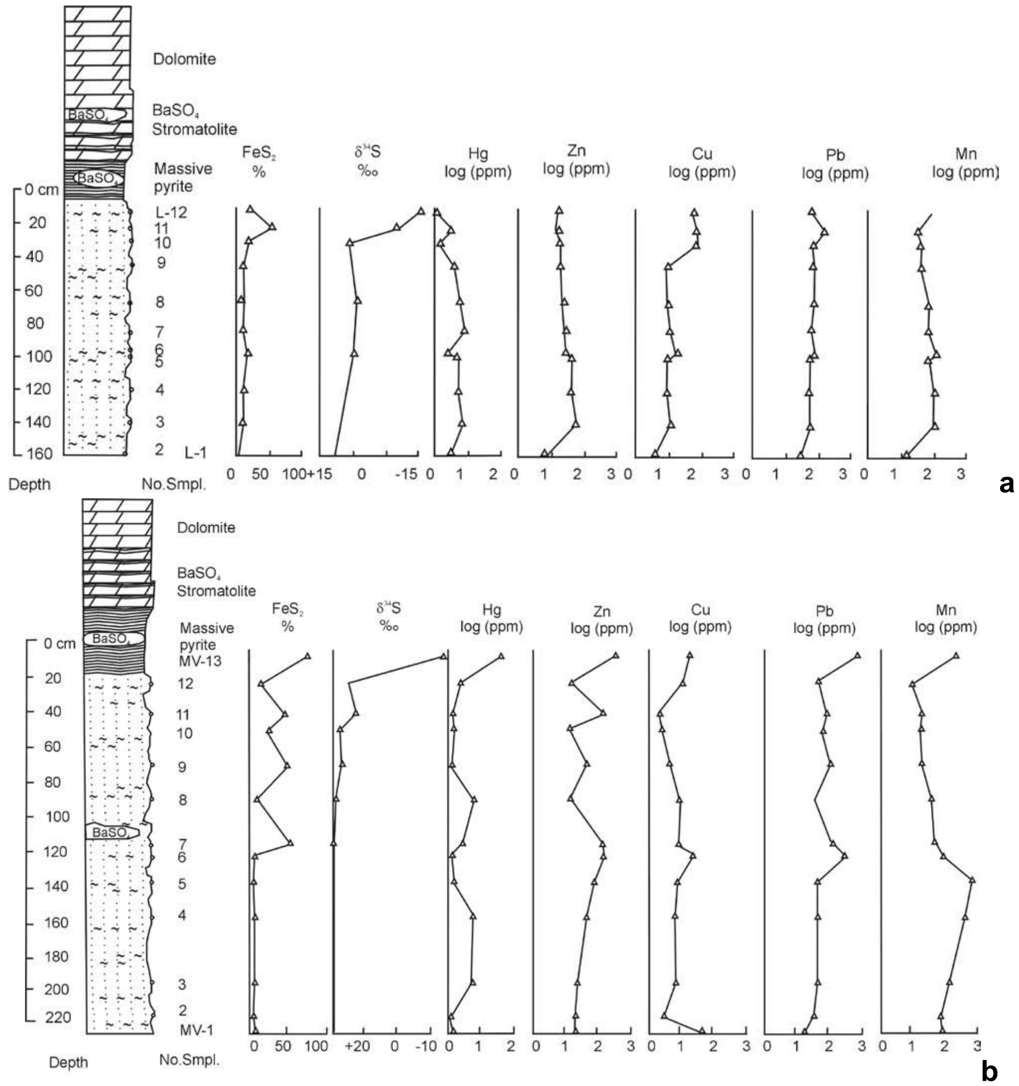


Fig. 4.8 a) Distribution of heavy metals and $\delta^{34}S$ values on the profile of the pyritous clastics at the Homer locality, and b) at the Mrzle Vodice locality (after PALINKAŠ & PEZDIČ, 1989).

Short scenario of the ore forming process

In order to summarize the presented ideas on the sedimentary and ore forming model, a short review of the important events in successive order is given:

1) deposition of the Upper Permian clastics;
2) regression and carbonate deposition;
3) lowering of the mean sea level by evaporative draw-down and exposure of lime mud to intensive evaporation;
4) dolomitization and early diagenetic lithification;
5) loading of the rigid dolomitized horizon over a soft, organic-rich, water-logged, clayey reductive sediment, where reduction of barium sulphate caused precipitation of iron monosulphides, and release of barium took place;
6) expulsion and diffusion of Ba-rich, sulphate deficient brines into overlying porous dolomites, saturated with landward moving hyper-saline lagoonal brines carrying sulphate, promoted by evaporative pumping;
7) barite precipitation in porous dolomite, possible re-placement of former evaporites, and concretionary growth.

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