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32nd INTERNATIONAL GEOLOGICAL CONGRESS

ADRIATIC-DINARIDIC MESOZOIC CARBONATE PLATFORM, ENVIRONMENTS AND FACIES FROM PERMIAN TO RECENT TIME

Leaders:
M. Juračić, Ladislav Palinkaš

Associate leaders:
Z. Barjaktarević, R. Buljan, S. Bergant, V. Jurak, I. Gušić, L. Marjanac, T. Marjanac, D. Matičec, A. Mezga, T. Paviša, S. Šestanović, S. Šoštarić-Borojević, S. Strmić, J. Sremac, J. Tišljar, I. Vlahović

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Front Cover:
Cliffs on DugiotokIisland (Central Dalmatia), made up of Senonian dolomitic limestones.

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Marco Polo

I have not told a half of what I saw since nobody would have believed me.
Marco Polo, world traveler, born on the island of Korčula

Introduction

The Mesozoic Adriati-Dinaridic carbonate platform, a unique geological formation developed along the passive continental margin of Gondwana, stands among other similar units in the world as a very representative example, owing to the size and diversity of its sedimentary facies. It stretches along the present Adriatic coast as the External Dinarides, known also as the High Karst Zone. It is a part of the Alpine-Himalayan orogenic belt, whose existence started in Permian times and terminated in the Paleogene, and then uplifted in Neogene times. Interesting phenomena related to karst geomorphology owe their names, used in international karst terminology, to local toponyms, such as "doline' and "polje". Even the term "karst" came after kras or krš. A great number of points of interest are situated on the pearl of the Adriatic islands, inhabited since prehistoric time by fishermen, peasants, and sailors, who dwelt in small villages with picturesque architecture. Fascinating scenery of the white rocky coast, with garlands of olives, vineyards, and a drapery of conifers around old stony villages, embraced by the emerald green-blue water of the Adriatic, gives a visual joy to the geological and cultural program. The trip is not focused on sedimentology exclusively. It will show some very special sites, including dinosaur tracks; carbonate platform foundations or distractions; recent carbonate deposition under temporal climate conditions; one of the huge karst springs feeding the sunlight green river, river delta, and marsh-lands in a young immature karst topography; civil engineering achievements; and national parks with unique variety of flora and fauna. The trip will involve travelling by boat along the coast and islands from Istria to Dubrovnik, primarily with short excursions on the mainland by bus.

Mladen Juračić and Ladislav Palinkaš

Introduction to the Adriatic Carbonate Platform

Ivo Velić, Josip Tišljar, Igor Vlahović, Dubravko Matičec and Stanislav Bergant

The ancient Adriatic Carbonate Platform, which represented a part of the so-called Mediterranean Seuill (Dercourt et al., 1993), was formed during the Mesozoic Tethyan realm.

Due to the complex geological history of the platform area, especially the significant post-depositional tectonics, there are different opinions among Croatian geologists concerning two important issues: its **name** and its **stratigraphic range**.

It is very important to discuss these questions sepa≠rately to avoid the confusion of hitherto discussions, i.e.:

(1) to try to find the best designation for the platform, and
(2) to determine its most appropriate stratigraphic range.

Name of the platform

The most important issue for the designation of the platform is enabling a clear differentiation between palaeogeographic relationships during the platform's existence in the Mesozoic, and the present structural pattern of the Dinarides mountain belt formed during the Tertiary tectonic cycle. The Dinarides, which link the Southern Alps with the Albanides, Hellenides, and Taurides, are composed of two genetically different parts: the Outer (External) Dinarides along the Adriatic Sea, composed mostly of relics of the carbonate platform and its foundation, and the Inner (Internal) Dinarides, situated between the Outer Dinarides and the Pannonian Basin, composed of passive and active continental margin rocks, including ophiolites.

Among numerous designations used for the carbonate platform deposits outcropping in the area of the Outer Dinarides studied over the last few decades, the most frequent in the recent geological literature are the Dinaric Carbonate Platform, Adriatic–Dinaric Carbonate Platform

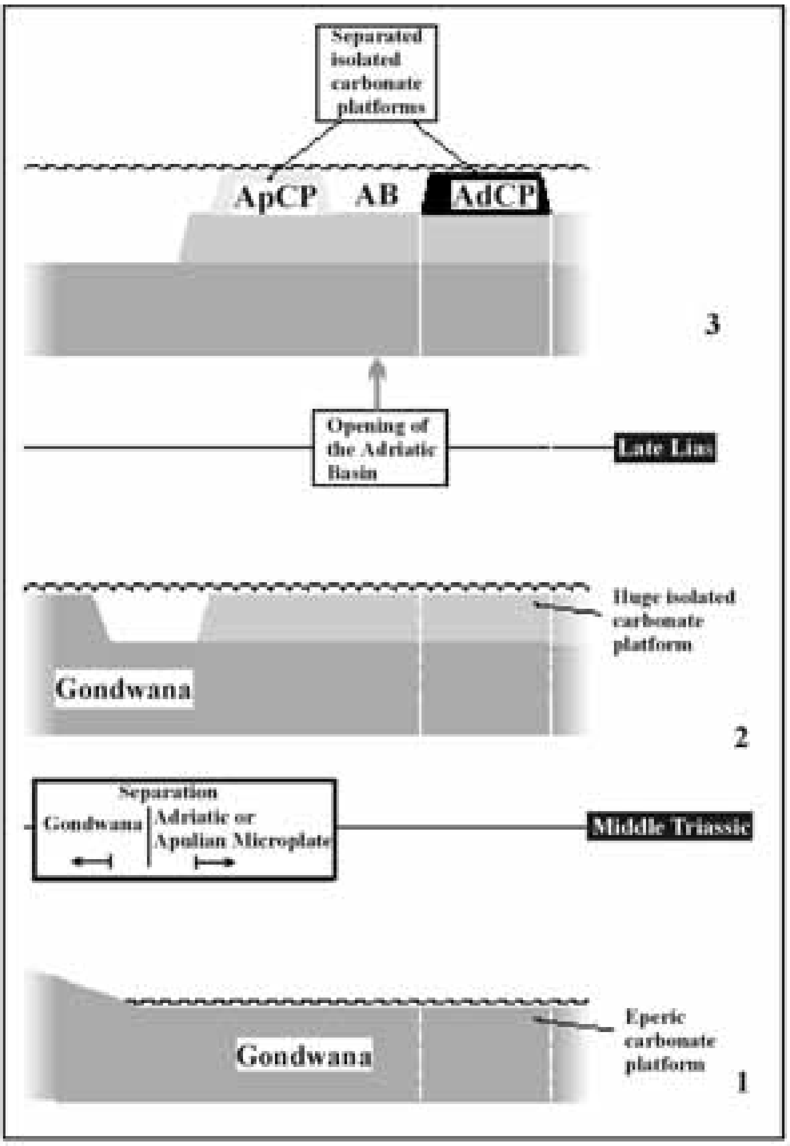


Figure 1.1 - Schematic illustration showing the main events before the separation of the Adriatic Carbonate Platform: (1) until the Middle Triassic rifting, the study area represented a part of the epeiric platform located along the northern Gondwana margin; during this event, the Adria Microplate or Apulian Promontory was separated, and a huge isolated platform was formed (2), which was partly disintegrated during the Late Lias, resulting in the formation of the Adriatic Basin (AB), and Molise–Lagonero Basin (not shown), and the final separation and isolation (3) of the Adriatic Carbonate Platform (AdCP), the Apulian Carbonate Platform (ApCP), and the Apenninic Carbonate Platform (not shown). After Velić et al. (2003).

(or Adriatic–Dinaridic Carbonate Platform) and the Adriatic Carbonate Platform.

The term "Dinaric" in the name of the platform geographically depicts the mountain belt formed by the platform's disintegration, but unavoidably incorporates several problematic issues:

– the Dinarides were uplifted in the events that took place several tens of Ma after the last carbonate deposition on the platform. In this way, the platform would be named after the mountain belt, which would be formed by its disintegration far in the future.

– as already mentioned, the Dinarides as a mountain belt comprises a large proportion of deposits which are not genetically connected with the platform, including almost all of the highest peaks, which are located within the Inner Dinarides area. Even in the Outer Dinarides, there are a significant amount of rocks which do not belong to the studied carbonate platform *sensu stricto*.: underlying rocks (Palaeozoic, Triassic, and earliest Jurassic sedimentary rocks and small occurrences of magmatic rocks), and overlying deposits (Tertiary limestones, flysch deposits, coarse-grained carbonate clastics – Jelar breccia and the Promina deposits, isolated Neogene fresh-water basins, and Quaternary cover).

– the term "Dinaric" primarily represents a structural and / or geomorphological term, and its usage for a palaeogeographical unit might cause confusion in communication.

A combined term Adriatic–Dinaric Carbonate Platform (or Adriatic–Dinaridic Carbonate Platform) introduces, in our opinion, besides the previously mentioned shortcomings of the term "Dinaric", an additional problem, since this name might be confused with a concept of Herak (1986), who proposed a hypothesis where two different platforms existed, separated by a deep-marine area from the Late Triassic to the Eocene (named the Adriatic and Dinaric Carbonate Platform).

Therefore, we consider that the best term is the Adriatic Carbonate Platform, since the term "Adriatic":

– fits well geographically; since the remains of the platform are situated in the belt stretching along the NE Adriatic coast, and a significant part of the former platform is covered by the present Adriatic Sea. The name "Adriatic" is "free" for use, because the platforms located along the SW Adriatic coast have their own names – the Apulian and Apenninic Carbonate Platforms.
– its temporal dimension fits perfectly; the disintegration of the Adria Microplate (Apulian Promontory) in the Late Lias caused the formation of the precursor of the present Adriatic Sea, the Adriatic Basin, and in this way, the separation of the newly formed carbonate platforms: Adriatic, Apulian, and Apenninic.
– it cannot cause confusion between the carbonate platform, and the result of its disintegration; the Mesozoic Adriatic Carbonate Platform finally disintegrated in the Tertiary, and incorporated as the SW part of the Dinarides mountain belt.

Considering the abbreviation of the platform name, the "AdCP" is proposed instead of the usually used "ACP", to avoid confusion with the same abbreviation commonly used for the Apenninic Carbonate Platform (Fig. 1.1).

The stratigraphic range of the platform

Concerning the second issue – that is, the stratigraphic range of the Adriatic Carbonate Platform as an autonomous entity – the most important point is to define this huge carbonate body and make it palaeogeographically recognizable. Although the Outer Dinarides comprise carbonate deposits of a wider stratigraphic range (from the Carboniferous to the Eocene), only a part of this succession belongs to the Adriatic Carbonate Platform *sensu stricto*, i.e. to the spatially-defined isolated shallow water platform.

In the wider sense, the entire sequence of Upper Palaeozoic, Mesozoic, and Palaeogene carbonates of the Karst Dinarides has been included into the Adriatic Carbonate Platform *sensu lato* (Tišljar et al., 1991; Velić, 2000) or Adriatic–Dinaric Carbonate Platform *sensu lato* (Pamić et al., 1998), since the entire sequence was deposited on carbonate platforms of different types (an epeiric carbonate platform during the Palaeozoic and Lower to Middle Triassic, an isolated carbonate platform during the Late Triassic to the end of the Cretaceous, and on carbonate ramps during the Palaeogene). However, if we define this platform *sensu stricto* (as a specific palaeogeographical entity, representing a completely isolated, intra-oceanic, carbonate platform, surrounded by other separated carbonate platforms formed on the same foundation), its stratigraphic range should be significantly reduced to include only a part of the Mesozoic deposits. In this way, the defined platform *sensu stricto* would, nevertheless, include the major part of the carbonate succession of the Outer Dinarides.

Until the Middle Triassic, the area of the future Adriatic Carbonate Platform represented a part of the northern Gondwana margin, which was characterized by the deposition of siliciclastics and carbonates on the carbonate platform of the epeiric type. During the Middle Triassic, disintegration of the foundation and eventual separation of the Adria Microplate (or Apulian Promontory) took place, resulting in the formation of a huge shallow water body within the Tethyan realm. However, although the thick Upper Triassic alter≠nation of early- and late-diagenetic dolomites (regionally known as the Main Dolomite – Hauptdolomit or Dolomia Principale), are present at several localities throughout the area of the Dinarides, and represent typical deposits of the iso≠lated carbonate platform, it should not be ascribed to the Adriatic Carbonate Platform *sensu stricto*. Namely, during that period the entire area of the Adria Microplate was still united (Fig. 1.1).

Disintegration of the huge platform, i.e. separation of the Adriatic Carbonate Platform from the Apenninic and Apulian platforms, took place in Late Lias (it started in Middle Lias), through the formation of a trough connecting the Ionian Basin with the Belluno Basin which existed to the north of the platform. In this way, the Adriatic Basin, chara≠cterized by deep-marine deposition, was formed as the first precursor of the present Adriatic Sea, and this event should define the lower boundary of the Adriatic Carbonate Platform s.s.. During the same period, some areas along the NE margin were also drowned, resulting in a further reduction of the former platform area.

The Middle and Late Jurassic and Cretaceous were characterized by the gradual movement of the Adria Microplate towards Laurasia, resulting in a gradual subduction, enabling deposition of a several km-thick sequence of almost pure shallow-water deposits on the Adriatic Carbonate Platform. Although this succession in general may be defined as deposits of the isolated carbonate platform, it should be mentioned that during some periods, other types of carbonate platforms existed in this area: during some events, small platforms of a rimmed type were established (around emerged parts when the depositional area was significantly reduced, e.g. around emerged areas in the Kimmeridgian, or the uplifted blocks in Late Cretaceous); environments of the drowned platform existed (e.g. near Cenomanian–Turonian boundary, Gušić and Jelaska, 1993); or carbonate ramps were formed (e.g. in Cenomanian, Tišljar et al., 1998; Korbar et al., 2001).

The position of the upper stratigraphic boundary of the Adriatic Carbonate Platform is quite arguable. In the Late Cretaceous, the platform was characterized by gradual disintegration as a result of collisional processes, causing significant differentiation of the sedimentary environments, culminating in the latest Cretaceous and Palaeogene with the formation of flysch troughs within the former platform area. Since the Early Cenomanian, the platform was characterized by the existence of different blocks, i.e. a subsequently more and more complex palaeogeo≠graphical pattern, including emerged areas, shallow water environments, carbonate ramps, and deeper intraplatform troughs (Tišljar et al., 1998; Korbar et al., 2001). By the end of the Cretaceous, large areas of the platform emerged, and the depositional area of the platform gradually became smaller and smaller. At the very end of the Cretaceous, a general emersion took place, and the Palaeogene transgression over an expressive palaeorelief took place, mostly in the Eocene (Palaeocene rocks have been documented only in some places, e.g. in the area of W Slovenia, and in restricted areas of S Dalmatia, where the hiatus was the shortest). However, deposition of the so-called Liburnian deposits and Foraminiferal Limestones in the Palaeogene was primarily influenced by intense tectonics, i.e. the formation of the foreland basin(s) within the former carbonate platform. Carbonate depositional environments represented irregular carbonate ramps, characterized by narrow belts, retreating contemporaneously with tectonic deformation. Resulting carbonate successions of a foramol type, mostly only several to 200 m thick, represented merely the introduction of flysch deposition, and the subsequent infilling of the basins with clastic–carbonate deposits (Promina deposits and the Jelar breccia). Therefore, con≠sidering the (1) restricted depositional area, (2) the principal role of synsedimentary tectonics, and the subordinate role of primary carbonate production, and (3), the resulting fairly small sequence of carbonate deposits, the Palaeogene deposits did not represent a massive shallow water carbonate factory covering a vast area. Consequently, these deposits, which are separated from the Cretaceous succession mostly by a relatively long hiatus, should not be considered as part of the Adriatic Carbonate Platform.

In conclusion, we would like to emphasize the importance of making a clear terminological distinction between the carbonate platform and the product of its disintegration. Therefore, disintegration of the Adriatic Carbonate Platform (AdCP) and of its neighbouring areas, which culminated in the Oligocene–Miocene, resulted in the formation of the Dinarides mountain belt. The stratigraphic range of the AdCP *sensu stricto*, i.e. a completely isolated carbonate platform, might be defined as being from the Late Liassic to the end of the Cretaceous.

DAY 1

Introduction to the geology of Istria

Ivo Velić, Josip Tišljar, Igor Vlahović, Dubravko Matičec and Stanislav Bergant

The geological literature on Istria is very abundant and heterogeneous, and extends over more than two centuries. Consequently, there is insufficient space here for a full account. We will therefore restrict ourselves to discussions on the geology of Istria, even omitting papers such as G. Stache's famous "Die Liburnische Stufe und deren Grenz-Horizonte" (Stache, 1889).

Most general data on the geology of Istria can be found in the sheets and explanatory notes to the 1:100,000 scale Basic Geological Maps, although they were published twenty-five to thirty years ago. The stratigraphy, tectonics, raw materials and geological history of Istria are described in six explanatory notes to the Basic Geological Map Sheets: Pula, Cres, Rovinj, Labin, Trieste, and Ilirska Bistrica. Here, one can also find detailed reviews of previous investigations and lists of references.

From the mid-1960s to the mid-eighties, there were no systematic geological investigations of regional significance in Istria. However, it should be noted that, in the seventies, detailed lithofacies and biofacies investigations of shallow water carbonates in Istria began. In addition, several important international and national geological meetings were held, presenting new knowledge on the geology of Istria:

-the 16th European Micropalaeontological Colloquium,

-the 4th Regional Meeting of IAS,

-the 5th Meeting of Sedimentologists of Yugoslavia, -International Symposium on the Evolution of the Karstic Carbonate Platform: Relations with other Periadriatic Carbonate Platforms,

-the 1st Croatian Geological Congress,

-the 80th Summer Meeting of the Italian Geological Society and

-the 6th International Congress on Rudists.

Recent investigations for the new Geological Map of the Republic of Croatia (lithostratigraphic map, scale 1:50,000), started in Istria in the mid-eighties. New data were obtained also by several specialised investigations. This review is predominantly based on the paper "A Review of the Geology of Istria" from the Excursion Guidebook of the First Croatian Geological Congress (Velić et al., 1995a). One can also find an extensive reference list of published works in the review of the geology of Istria in the paper of Velić et al. (2003).

The stratigraphic and palaeogeographic evolution of Istria

Although intense post-sedimentary, Tertiary tectonics have significantly affected the entire area of the former Adriatic Carbonate Platform, resulting in the very complex tectonic pattern of the area, there are localities with quite well-preserved stratigraphic records, enabling recognition of important events in the geological history of the Adriatic Carbonate Platform. One of them is Istria, a peninsula located on the NW part of the Croatian coast, with an area of some 3,000 square km.

From a geological point of view, Istria can be divided into three regions:

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

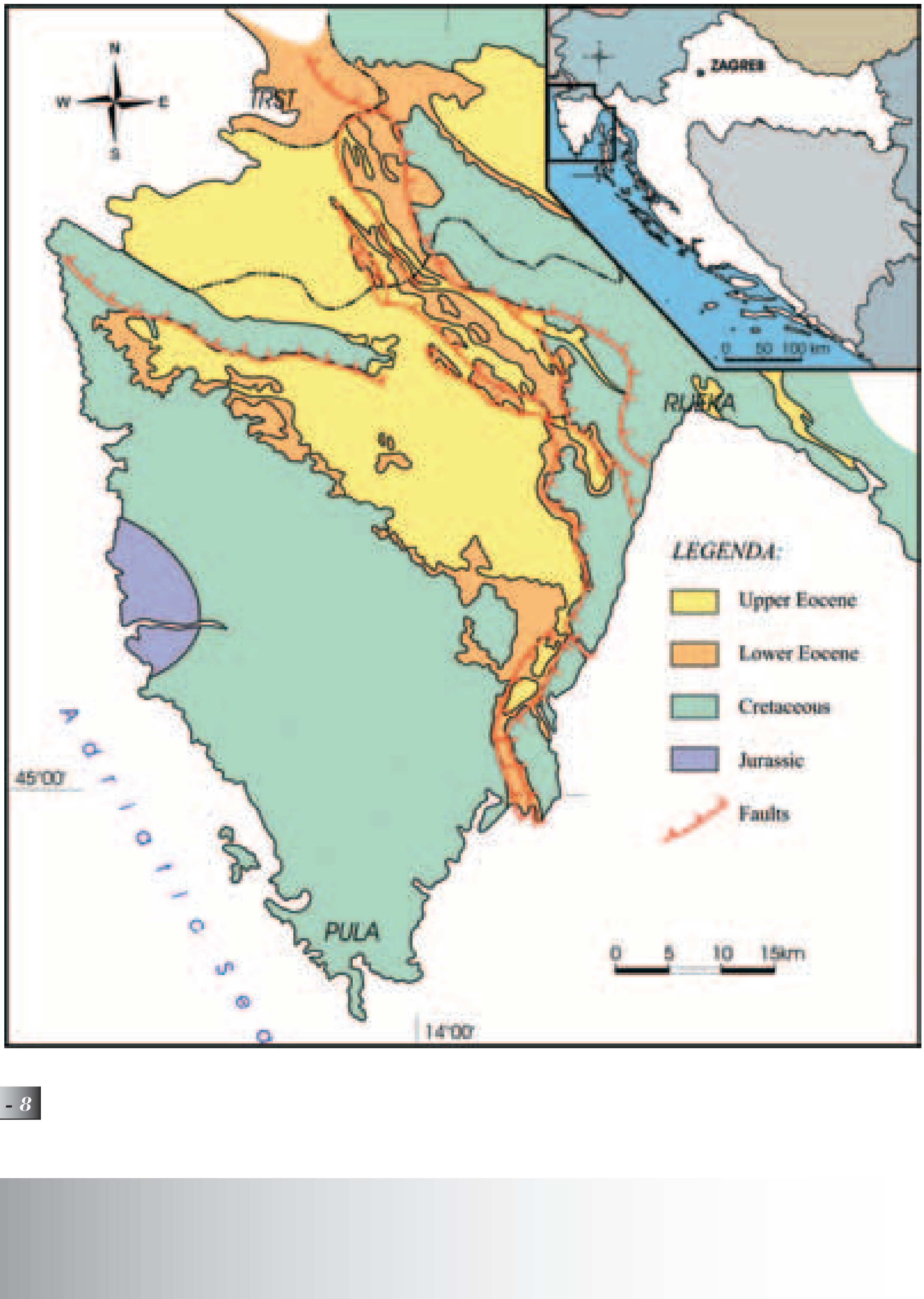
-the Cretaceous–Eocene carbonate–clastic zone, characterized by overthrust structures in eastern and northeastern Istria (from Plomin and Učka to Ćićarija), and

-the Eocene flysch basin in central Istria.

The geological peculiarities of these regions had been noticed historically by the inhabitants of Istria, who coined specific names for them: *Red Istria* – the southern and western Istrian plain named after the *terra rossa* covering a large part of the younger Mesozoic and Eocene carbonates; *White Istria* – in eastern and northeastern Istria, characterised by karstified outcrops of "white" Cretaceous–Eocene limestones; and *Gray or Green Istria* – in central Istria, characterized by Eocene flysch.

The Istrian succession suffers from the same problem as the rest of the carbonate platform area in Croatia: marginal areas of the platform are missing, since they were drowned by the Adriatic Sea. Therefore, we are dealing with inner platform deposits, since the margins, defined by offshore wells and geophysical research, are in Istria, at least 20–30 km further away. The studied deposits are also characterised by generally thinner units than in penecontemporaneous deposits in other parts of the AdCP, probably as a consequence of the palaeogeographic position of Istria as an African promontory, i.e. its specific position along the margin of the *Adria Microplate*

Figure 1.2 - Map showing the schematic distribution of large-scale sequences in Istria, and the location of the Western Istrian anticline (partly modified after Velić et al., 1995a). Deposits of all largescale sequences of Istrian carbonates and flysch are for the most part irregularly covered by relatively thin Quaternary deposits (5th large-scale sequence).



(or *Apulian Promontory*).

The Istrian succession consists predominantly of carbonate rocks, ranging in age from Late Dogger to Eocene, with subordinate Eocene siliciclastic rocks, flysch and calcareous breccia, and Quaternary terra rossa and loess. According to the results of investigations, the Istrian Late Dogger to Eocene succession can be divided into four sedimentary units, or large-scale sequences of carbonate deposits, bounded by important discontinuities / emersion surfaces representing different durations, covered by Quaternary deposits. The following largescale sequences have been distinguished (Fig. 1.2):

1) Bathonian–lowermost Kimmeridgian;
2) Upper Tithonian–Lower/Upper Aptian;
3) Upper Albian–Upper Santonian;
4) Eocene;
5) Quaternary.

Tectonics

The tectonic pattern of the Croatian part of Istria is composed of three structural units (Fig. 1.2).

-The Western Istrian Anticlinorium comprises the largest part of western and southern Istria, being composed of carbonate deposits of the Middle and Upper Jurassic in its oldest part, and surrounded by Cretaceous and Eocene carbonates.

-The second unit, the Pazin Flysch Basin, is composed of relatively thin Eocene limestones and thick flysch deposits, cropping out in the central and NW parts of the peninsula.

-The third unit is composed of stacked thrusted structures of Ćićarija Mt. in the northern part; and of eastern Istria, as well as the Učka Nappe, which are composed of Upper Cretaceous and Eocene carbonates and Eocene flysch.

The oldest record of tectonic activity in Istria has been found in the Late Bathonian. The movements represent the oldest deformation in Istria, referred to as the D1 deformation. The effects of these movements were local emersion and a more intensified relief of the subtidal area. It has to be mentioned that we are dealing with recent orientations of structures, and that possible subsequent rotations of the area have not been taken into consideration.

After a brief emersion, subtidal sedimentation was reestablished, resulting in filling and leveling of the former relief. The continuity of sedimentation was not interrupted until the beginning of the Kimmeridgian, when the area of Istria was influenced by a regional emersion that lasted through the major part of the Kimmeridgian and Early Tithonian.

Tectonic activity during the Cretaceous (D2 deformation) can be traced as periodic syn-sedimentary movements occurring throughout the period. Namely, the West Istrian anticline (anticlinorium) had already been formed in the Early Cretaceous. The oldest evidence of its existence is from the Hauterivian. The hinge of this macrostructure remained emergent throughout the rest of the Cretaceous, i.e. until the Eocene transgression. There is a lot of evidence to support this theory, in principal:

–The exposed succession northeastward from the core of the anticlinorium to the Pazin flysch basin is more or less continuous from the Bathonian to various levels of the Upper Cretaceous.

–Eocene foraminiferal limestone has been found overlying the peneplained relief of Valanginian, Hauterivian, Barremian, Albian, and Cenomanian ages.

–Bauxites from the footwall of the Eocene limestones were deposited in the palaeorelief of the Cenomanian and Albian limestones. This fact, together with the transgressive nature of the Eocene foraminiferal limestones on deposits of different ages, excludes the possibility of continuous deposition of a complete Lower and Upper Cretaceous sequence, and its subsequent erosion prior to deposition of the foraminiferal limestones.

–The emerged area was inhabited by dinosaurs during the interval from (at least) the Hauterivian to the Late Cenomanian, as indicated by their footprints and bones. A large quantity of fresh potable water and terrestrial vegetation would have been necessary for their survival.

– An older succession than that exposed on the coast of Istria can be traced under the sea towards the SW, along the extension of the core of the Istrian Anticlinorium.

Deep wells in the sea-floor confirm this idea, and provide evidence for the dimensions of the macrostructure.

By the end of the Cretaceous, almost the entire Adriatic Carbonate Platform, including the area of Istria, was affected by regional emersion of a very variable duration. Emersion was the consequence of the final Cretaceous compression. The Late Cretaceous tectonic events initiated the disintegration of the former carbonate platform, and marked the end of the typical productive platform carbonate sedimentation, since renewed marine conditions in the Eocene had different characteristics.

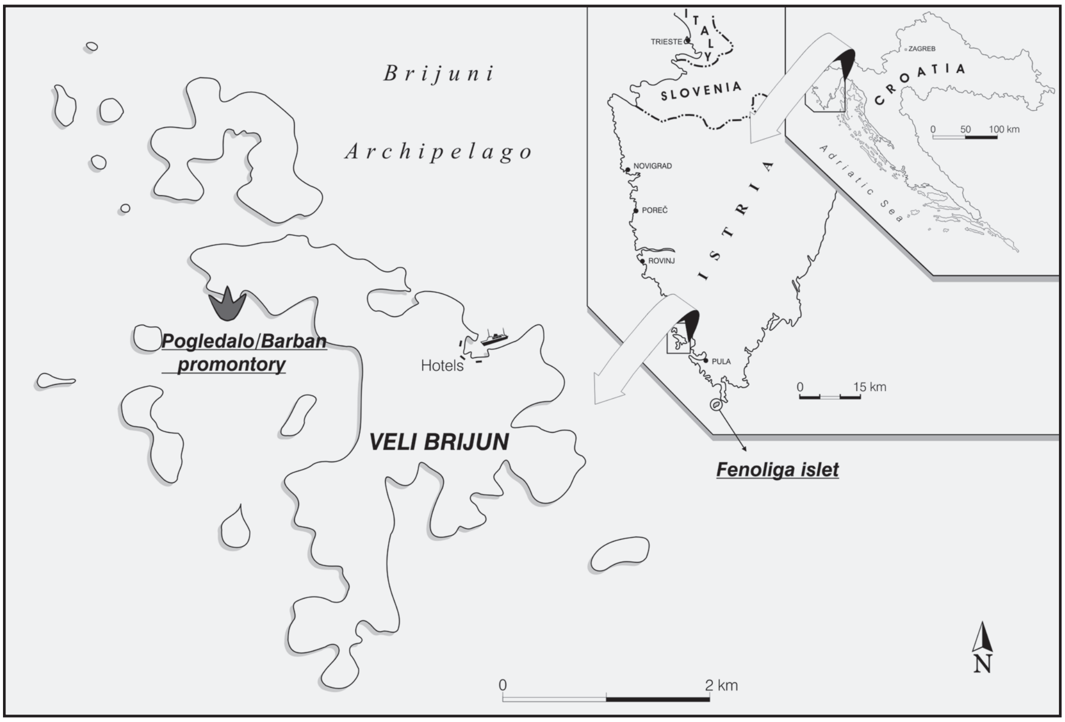
The Eocene transgression was a consequence of a new, D3 deformation. The intensity of these movements was witnessed by the formation of flysch basins, while their further increase resulted in a regional compression of the area. Hence D3 deformation became the decisive factor in the tectogenesis of the Dinarides. The result of this tectonic activity is obvious throughout the Adriatic coastline in the form of the so-called Dinaric strike of structures (approximately 315–135 degrees).

The duration of the D3 deformation, i.e. the question of its upper boundary is not definitely denoted, because of the problem with stratigraphic determination in poorly-developed terrestrial sediments. Anyway, these movements probably are partly Miocene in age.

Neotectonic deformation (D4) in the entire Dinarides is a consequence of the N–S oriented activity of the greatest regional stress. Neotectonic activity comprised either the formation of new, neotectonic structures, reactivation of old inherited brittle structures into the regional transcurrent faults, or rotation of already existing structures towards the new stress orientation.

Figure 1.3 - The Brijuni Islands archipelago.

Figure 1.4 - Location of the Pogledalo/Barban promontory and Fenoliga islet.



The Brijuni Islands National Park

Ladislav Palinkaš and Sibila Borojević-Šoštarić

The Brijuni Islands National Park has been compared to heaven on earth. According to legend, angels collected the remains of Eden and created a lasting symbol for mankind – an oasis of peace, and a wondrous gift of nature, protected by the waves.

The Brijuni National Park and Memorial Park is one of the brightest pearls of natural beauty in the Adriatic (Fig. 1.3, 1.4). It can be compared only with the well-known Kornati Archipelago Island group. What makes the Brijuni Islands so attractive, is the abundance and variety of flora and fauna in a splendid landscape of the indented island coastline in the emerald blue-green sea.

The Brijuni Islands were proclaimed a national park on 27th October 1983. The park covers an area of 3,635 hectars. It consists of 14 islands: Veliki Brijun, Mali Brijun, Sv.Marko, Gaz, Obljak, Supin, Supinić, Galija, Grunj, Vanga, Madona (Pusti), Vrsar, Jerolim, and Kotež, which together make up 734.6 hectares. The surrounding sea makes up for a larger portion of the park - 2,900 hectares.

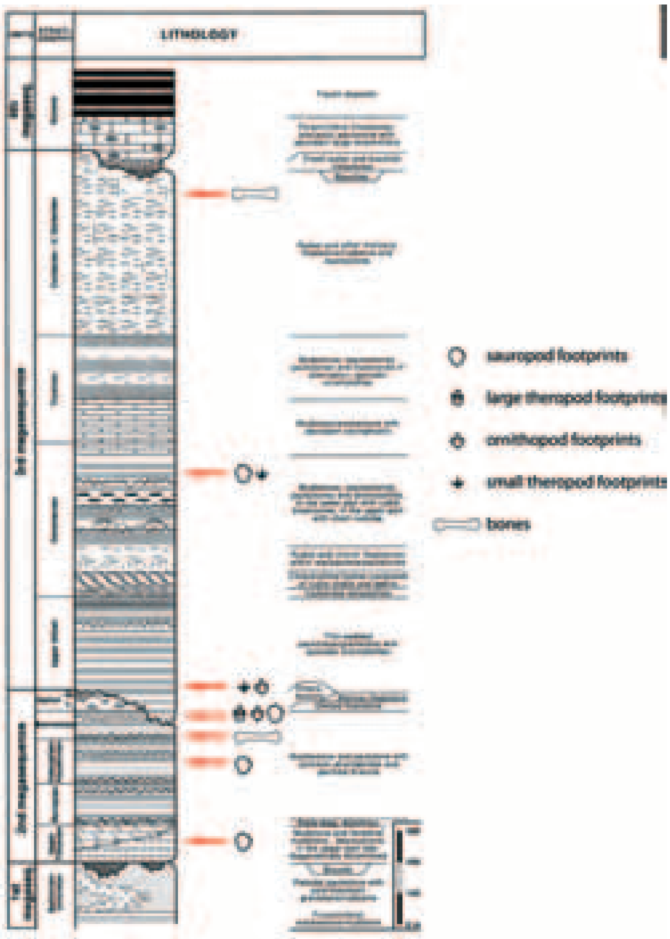


Figure 1.5 - Lithostratigraphical column of Istria, with dinosaur finds.

According to geological and geomorphologic make-up, the Brijuni Islands are a continuation of the Istrian mainland, and are made up of horizontal layers of Cretaceous limestone, covered by thick layers of brownish-red soil. The rise in sea level during the past tens of millennia, as a result of melting ice, gave the islands their final appearance and a highly indented coastline. The total length of the coastline of all the islands put together is 46.4 kilometres. The most indented islands are Veliki Brijun (26.6 km), Mali Brijun (8.2 km) and Vanga (3 km). The shores are mostly low and rocky; however, their horizontal stratification makes them easily accessible. Some bays have shingle and sand.

Climatically, the Brijuni Islands belong to the northern Mediterranean, and have all the features of the western Istrian coast. The mean temperature of the coldest month is 5.9 degrees Celsius, and 23.3 degrees for the warmest. Average annual precipitation is 817 mm. Low summer rainfall, and a relatively high humidity play a significant role in shaping the vegetation of the islands. The islands also have a rich cultural heritage dating from Roman and Byzantine times.

Amidst century-old olive trees and vegetation, originating from various climates, cultural and historic monuments emerge like pearls. Some

Figure 1.6 - Large theropod footprint left by allosaurid dinosaur from the Progledalo/Barban promontory.

of the most attractive are unique examples of Roman architecture, which offer an insight into the spirit and taste of an ancient culture.
The remains of Roman country manors dating from the 1st - 2nd century B.C. in Veriga Bay on Veliki Brijun are a must, as are the remains of the Roman thermal baths, Venus's temple. On the west coast of Veliki Brijun, one can see a Byzantine castrum (fort) dating from the 6th century, and the remains of the St. Mary basilica (5th - 6th century), which bears witness to the beauty of this edifice, which was razed to the ground, and then rebuilt. Not far from the hotels, one can visit the church erected in 1481 dedicated to St. Germain.
A zoo, a safari park, a museum, sculptures, a flower garden and numerous other attractions make the Brijuni Islands a natural resource, whose message and beauty support man's

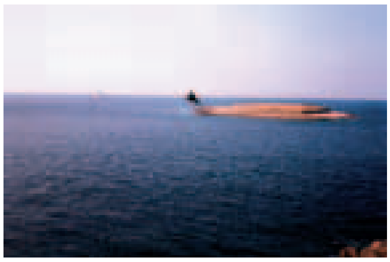


Figure 1.7 - Fenoliga islet, with the location of a trackbearing layer.

lasting efforts through the centuries to co-exist with nature.

Stop 1.1:

Dinosaur tracks on the Pogledalo/Barban promontory, Brijuni Islands and the Fenoliga islet

Mezga Aleksandar and Bajraktarević Zlatan

All fossil remains (mostly footprints) of dinosaurs on the Adriatic-Dinaric carbonate platform (which is now outcropping along the eastern coast of the Adriatic Sea) came from the Late Jurassic and Cretaceous (Valanginian - Cenomanian) sediments (Figs. 1.4). The oldest find is of Late Tithonian age.
Research on the dinosaur footprints of the Brijuni Archipelago began in 1925, with the work of the Austrian industrialist Bachofen-Echt, who has described two different types of footprints. Footprints on the Pogledalo/Barban promontory were discovered during later investigations by Velić and Tišljar (1987), and described recently by Dalla Vecchia (2002).
The Pogledalo/Barban site (Fig. 1.5) is characterized by intertidal/shallow subtidal deposits, represented by thin-bedded peloid packstone-grainstone. The sediment contains benthic foraminifers, green algae, ostracods, gastropods, and corals. (Dalla Vecchia, 2002). Dinosaur footprints occur on the upper bedding plane of a layer composed of fenestral micrite. The layer is sub-horizontal, with an exposed area of 43 x 5.5 m, and a thickness of 130 mm. The overlying bed is a thinly-bedded, stromatolitic-peletal limestone, with a thickness of 100-200 mm. Ripple marks indicate a shallow water to intertidal environment.
Sixty-one dinosaur footprints were discovered on the trackbearing surface, and 16 of them

Figure 1.8 - Circular footprints, assigned to the sauropods/

form four trackways. Other footprints do not make trackways, but occur individually. Among these, two types can be distinguished. The first type is a robust, stout, tridactyl form (Fig. 1.6), arranged in four trackways and with 34 isolated footprints. The second type is a gracile, slender, tridactyl form. These footprints belong to large theropod dinosaurs, similar to allosaurids (Fig. 1.6). The reconstructed lengths of these large theropods, ranges between 7.5 - 8 m, and average velocities were around 5 km/h.

Dinosaur tracks on the islet of Fenoliga (Fig. 1.5) were discovered by Gogala (1975). The islet is comprised of concordant, well-bedded, white-grey limestone layers, with bed-thicknesses varying between 0.1 and 1.5 m. The track-bearing outcrop comprises the upper bedding plane of a 12-cm thick limestone layer, exposed over an area of 45 x 16.5 m (Fig. 1.7) Two carbonate lithofacies can be discerned on the outcrop: white massive micritic limestones predominate on the western side, while the eastern side is characterized by a grey Rudist biostrome, between 2 - 2.5 m wide, and oriented N-S. The dinosaur footprints occur on the upper surface of the biostrome, suggesting that the biostrome was dead, and at least temporarily emergent during trackway formation. The foraminifer *Broeckina (Pastrikella)* cf. *balcanica* Cherchi, Radoičić and Schroeder was determined, and indicates a Middle to Late Cenomanian age (Mezga and Bajraktarević, 1999).

On the explored outcrop, 146 dinosaur footprints arranged in six trackways, and six footprint groups have been recorded. Two basic types of footprints were differentiated: large (23-40 cm) circular–elliptical footprints, assigned to the sauropods (Fig. 1.8), and smaller (15-20 cm), slender tridactyl footprints that were assigned to the theropods (Fig. 1.9). The footprints from Fenoliga serve as a basis for determining the size and speed of these dinosaurs. The length of sauropods was estimated to be between 8,5 - 11 m. The length of theropods range from 3 - 3,5 m. Their speeds were about 1 - 3 km/h for the sauropods, and 4 - 7 km/h for the theropods (Mezga and Bajraktarević, 1999).

Footprints of three theropod and at least six

Figure 1.9 - Theropod footprints from the Fenoliga islet.

DAY 2

Disintegration of the Adriatic carbonate platform

Ladislav Palinkaš

Foundation of the carbonate platform as an autonomous entity of the epeiric type on the future northern Gondwana margin, can be traced in places by the deposition of carbonates already in the Middle Permian time, as on the Velebit Mt.. Fragmentation of Pangea in the Middle Triassic time gave rise to the formation of an ensialic block, Adria Microplate or Apulian promontory, as a vast shallow water body inside the Tethyan realm. It enabled the foundation of a huge carbonate platform, comprising Adriatic, Apenninic and Apulian platforms, which existed as an isolated carbonate platform far into the Late Lias. Separation of the platforms was along a trough connecting the Ionian Basin and the Belluno Basin, and the precursor of the present Adriatic sea, the Adriatic Basin. This event represents the lower boundary of the Adriatic carbonate platform (AdCP) *sensu stricto.* Afterwards, the AdCP became a site of long-lasting shallow water deposition up to the Late Cretaceous. This tectonic quiescence, disturbed only by the epeiric drowning of peripheral parts, and the creation of carbonate ramps and deeper intra-platform troughs, was interrupted by incipient collisional processes, progressively intensified, which gave rise to the diversification of sedimentary environments. The tectonic paroxysm in the latest Cretaceous and Paleogene led to the formation of the flysch trough within the former platform region. Large areas of the AdCP emerged, with the reduction of the carbonate depositional sites. The Paleogene transgression, mostly in the Eocene, obliterated the diversified palaeorelief morphology and marked the beginning of the AdCP disintegration. Promina deposits and Jelar breccia, clastic carbonate infillings of the flysch basin, are tectogenic products deposited in the basin, shelf, coastal environments, alluvial fans, and braided-river systems. The Oligocene-Miocene time gave birth to the Dinaric mountain belt.

The Island of Rab

Rab is separated from the mainland by Podvelebitski Kanal (the Velebit Channel) with the shortest distance from the land being 1,800 m. With an area of 91 sq. km, a greatest transverse length of 22 km, and its total coastal length of 103.2 km, it reaches a maximum altitude of 408 m at Mt. Kamenjak, and comprises three ridges of limestone.

Rab and all the Dalmatian islands were originally connected with the mainland; about 20.000 - 30.000 years ago, the lowering and elevating of the land, and the penetration of the sea water into the basins, resulted in the current island chain. The origin of the islands can be gleaned from their karst topography, which is identical to that found in the craggy Dinaric Alps, which stretch from the eastern Adriatic and down to Greece.

Figure 2.1 - At the south end is a 13th-century Romanesque cathedral, whose campanile (bell tower) is considered to be the finest example of Romanesque architecture on the Adriatic littoral. It is the first in a line of four bell towers on a ridge dominating the old town.

Rab Island is one of the most densely-wooded islands in the Adriatic, and is a veritable botanical exhibition, with plants not native to the island. The Komrcar Park, with its laurel, poplar, cypress, Indian fig-tree, rosemary, pine, and hundred-year-old agave, is now the pride of Rab. Its more than 300 freshwater springs provide a valuable water supply for the population of the island – which, in contrast to most of the Adriatic islands, is increasing, in part because of good communications with the mainland. Because of these numerous springs, Rab is considered to be the greenest island in the Adriatic.

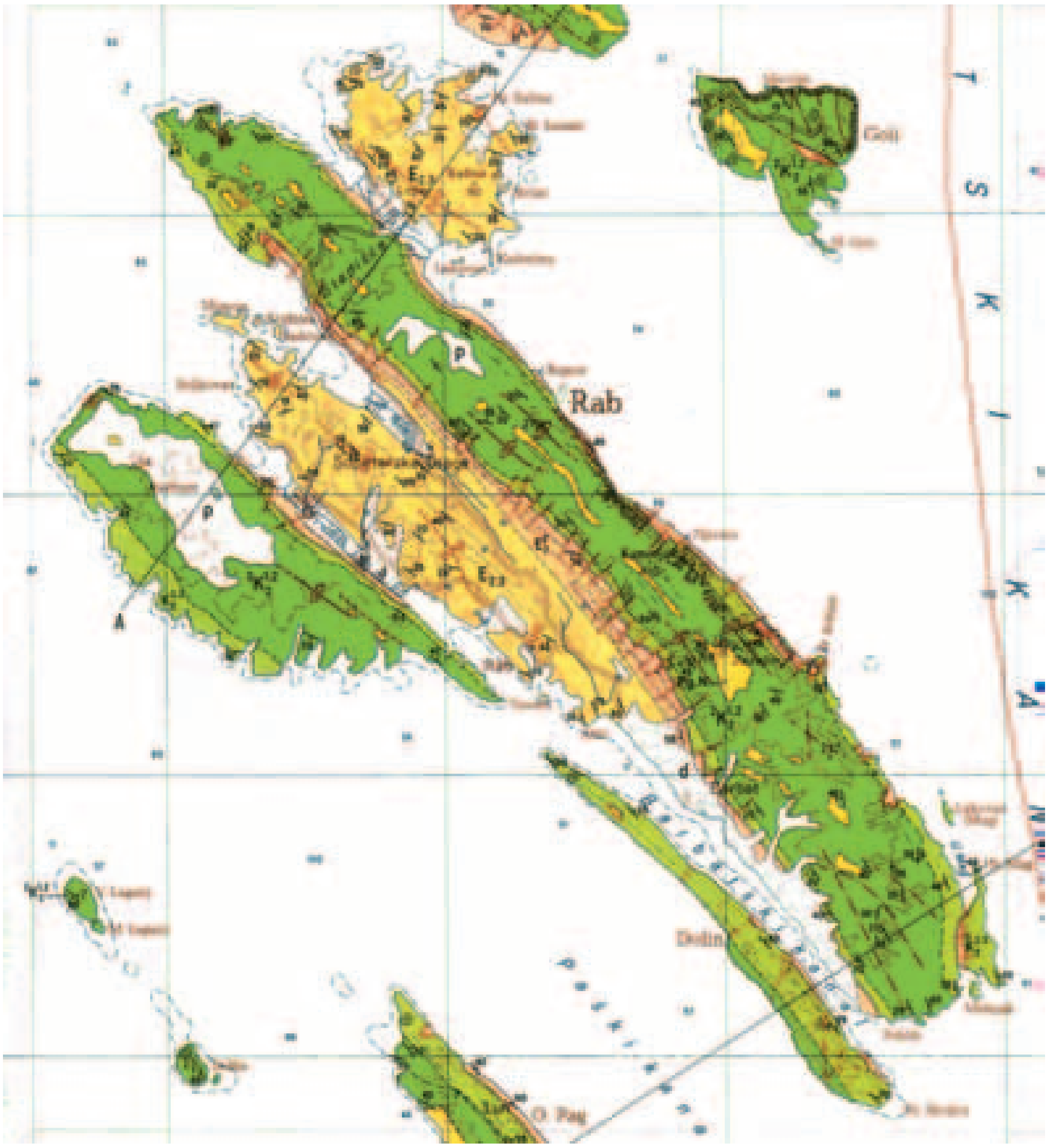


Figure 2.2 - Geological map of the Rab island. After Mamužić at al. (1969)

The ancient name *Arba*, *Arva*, *Arbia* (mentioned by Ptolemy and Pliny the Elder, and in *Tabula Peutingeriana*), derives probably from the Illyrian Arb, meaning dark, green, forested, which is a chief feature of the island even today. In the 10th century, the emperor Constantine Porphyrogenitus calls it *Arbe*, the form later taken over by the Italian language. The Croatian name Rab was first mentioned in 1446, in a document on the establishment of the Franciscan monastery of St. Euphemia in Kampor. Under the rule of Emperor August, Rab became a Roman municipality. Already in the 5th century, Rab was the seat of the diocese. Croats inhabited Rab some time later than the other islands, because they had to conquer a well-organised local Roman community. At the beginning of the 11th century, Rab fell under the rule of Venice for a short period, and then joined Croatia. At the time, a free urban commune was established, a political form which enabled the town and the island to enjoy peace and economic boom till 1409, after which the almost 400-year long rule of Venice followed. Fragments of the Venetian statutes from the 14th century contain interesting political, communal, and economic regulations. The diocese was abolished in 1828. Rab started to recover economically not before the first decades of the 20th century, when it became a climatic and summer resort.

The principal town, Rab, is a walled town, with three parallel main streets built on a steep promontory along the west coast (Fig. 2.1). At the south end presides a 13th-century Romanesque cathedral, whose campanile (bell tower) is considered to be the finest example of Romanesque architecture in the Adriatic coastal region. It is the first in a line of four bell towers, on a ridge dominating the old town. The town with its typical, twisting, and narrow Mediterranean streets, preserves many monuments of art: medieval churches, the Loggia, Venetian patrician palaces with beautiful doorways, etc.

Stop 2.1:

Eocene incised valley fill clastics of the Island of Rab

Tihomir Marjanac and Ljerka Marjanac

Introduction

The Lopar Sandstones are unique in the Eastern Adriatic realm owing to their silicic composition and shallow-marine origin. 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 traction currents, and we interpret them as sandwaves or complex dunes which have been deposited in an outer estuary or incised valley 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 truncated by the base of sandstone bodies. The shoreface sandstones document facies progradation by showing a gradual increase of thickness of individual beds, and a reduction in the number of marl interbeds. Where thick sharp-based shoreface sandstones overlie offshore marls, and the contact is marked by thick tempestites, we have interpreted this as a 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- and the overlying shoreface sediments, 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 sequence(s).

Frequent oscillations in sea level forced basinward and landward shifts of facies, so we can interpret the depositional environments as a paralic sea and incised valley(s), formed during relative sea-level falls.

Geology of the Island of Rab

The structural framework of the Island of Rab consists of two anticlines and two synclines (Fig. 2.2). The oldest rocks are Cretaceous carbonates, represented by Cenomanian - Turonian and Turonian - Senonian Rudist-bearing limestones (Mamužić et al., 1969), which are disconformably overlain by Paleogene carbonates. Paleogene deposits on the Island of Rab are composed of Foraminiferal Limestones (below), and "marls and sandstones" (Mamužić et al., 1969; Mamužić and Milan 1973) (above). The contact between Cretaceous and Paleogene limestones is characterized by gentle angular unconformity, and rare bauxite occurrences. The Foraminiferal Limestones are composed of three units, from the base upward: Miliolida Limestones, Alveolina Limestones, and Nummulite Limestones. They contain abundant foraminiferal fauna and accompanying taxa (bivalves, echinoderms, gastropods), which indicate Lower to Middle (Mamužić, 1962) or Late Eocene age (Mamužić and Milan 1973). Foraminiferal Limestones are overlain by glauconitic marly limestones, usually referred to as Transitional Beds (Fig. 2.3). Their thickness is very variable, and here it reaches only ca.10 m. The quality of exposures of Transitional Beds is quite poor, so direct

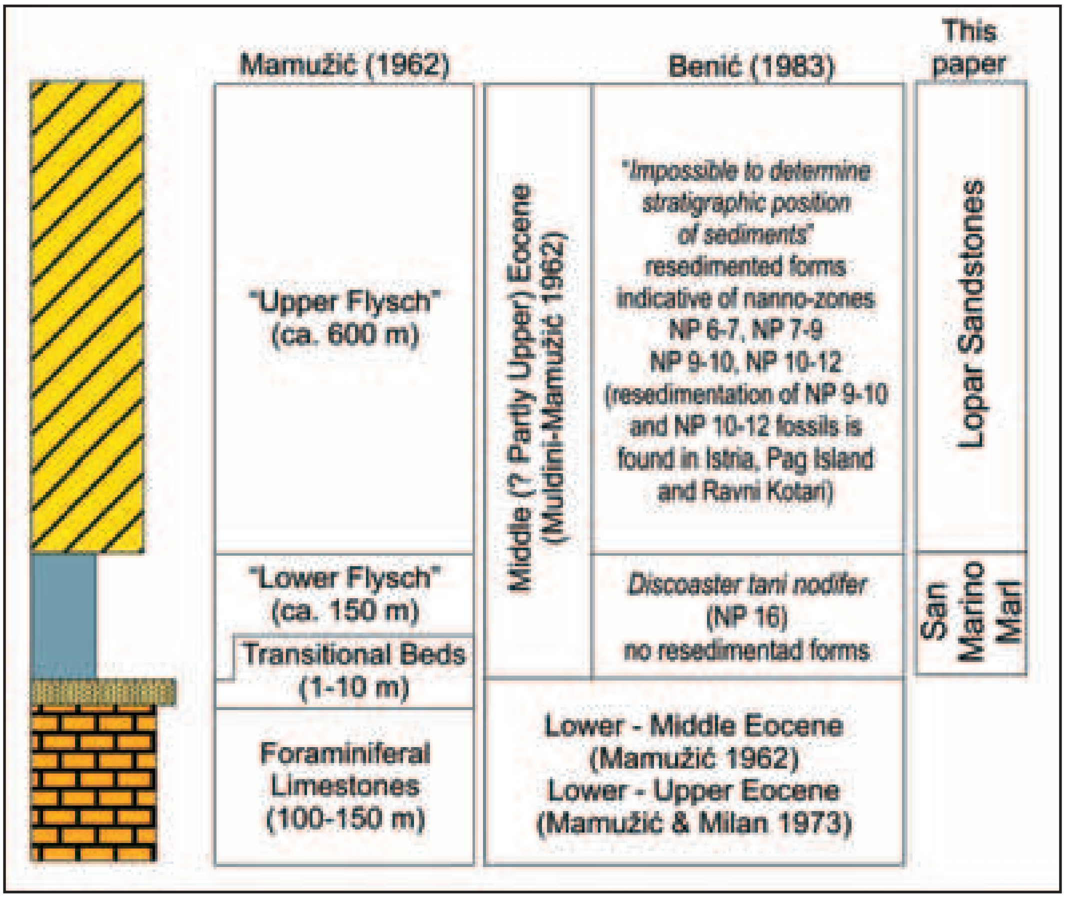


Figure 2.3 - Schematic stratigraphic column of the Rab island Paleogene sequence, and age attribution by various authors.

contact with overlying clastics is not visible. The Rab Island Eocene clastics were previously recognized as flysch (Marinčić, 1981), but their origin was reinterpreted in terms of tidal shallow marine deposits (Marjanac and Marjanac, 1991, Zupanič and Babić, 1991). The youngest are Quaternary deposits, which are partly of Eolian origin, and partly fluvial, and alluvial.

Eocene Clastics

In spite of the folded structure of the island, the Eocene clastics on the Lopar peninsula are tectonically almost undisturbed, and the quality of their exposures is excellent, because it allows the almost 3-D study of sedimentary bodies.
The Eocene clastics of the Island of Rab have been, until present, variously interpreted (Fig. 2.3): a) Mamužić (1962) divided the Eocene clastics into two units: "Lower" and "Upper Flysch", respectively (the "Lower Flysch" are marls with sandstone interlayers, while the "Upper Flysch" is an alternation of marls and sandstones); b) Muldini-Mamužić (1962) interpreted the "Lower Flysch" as deep-marine, based on microfossils, and the "Upper Flysch" as of a shallow-marine, even coastal environment; c) Marinčić (1981) held that the Eocene clastics of the Island of Rab are proximal facies of the flysch basin, which he reconstructed as extending from Italy to Albania; d) Marjanac and Marjanac (1991) reinterpreted the "Upper Flysch" sandstones as tidal sand waves that migrated towards the southwest; e) Zupanič and Babić (1991) interpreted the cross-bedded sandstones as complex dunes built under the influence of tidal flows, and concluded that the major part of the outer Dinaric clastic area was covered with a

Figure 2.4 - Tidal bundles.

shallow tidal sea in Eocene times.
Previous researchers have already recognized that the Lopar clastics comprise two distinct sedimentary units; the older unit, which is marly with only thin sand interbeds, and the younger one, which is predominantly sandy. For the benefit of simplicity, and to avoid genetic co-notations, we propose to call the older unit the **San Marino Marls** (instead of an informal, but specific name "Lower Flysch"), and the younger unit the **Lopar Sandstones** (instead of "Upper Flysch").

San Marino Marls

San Marino Marls are poorly exposed due to the large content of marl. Muldini-Mamužić (1962) reported poorly-preserved macrofauna composed of rare echinoderms and crinoid stems, but very rich microfauna, indicative of a deepwater environment. According to Mamužić (1962) San Marino Marls are about 150 m thick.

Lopar Sandstones

Lopar Sandstones consist of a few meters thick sandstone packages, which are divided by bioturbated sandy marls. The sandstones are more resistant to weathering, so they usually stand out in relief.
Muldini-Mamužić (1962) stated that these deposits contain abundant macrofauna (although poorly preserved) and poor microfauna, and that small forams disappear topwards and large nummulites start to predominate, which 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*.

Age of Rab clastics

The San Marino Marls are more fossiliferous compared to the Lopar Sandstones, which contain basically large foraminifers. Based on these large foraminifers, Muldini-Mamužić (1962) attributed the Rab clastics to the uppermost Middle Eocene, and possibly to a part of the Upper Eocene. Benić (1983) found nannofossils of the *Discoaster tani nodifer* nanno-zone (NP16, Upper Lutetian-Lowermost Bartonian) in the San Marino Marls, and found no resedimented forms in the studied samples. However, in samples of the Lopar Sandstones, more resedimented than autochtonous species were found. According to superposition, he assumed that the Lopar Sandstones 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. The last two allochthonous assemblages have also been determined in Istria, on the Pag Island, and in Ravni Kotari. Benić believed that these resedimented nannofossils originate from flysch which was contemporaneous with the Foraminiferal Limestones.

The Lopar sandstones

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

Sandy marls

Bioturbated sandy marls were deposited on a relatively shallow shelf, which is indicated by macro- and microfossil assemblages with associated *Skolithos* and *Cruziana* ichnofacies. Intensive bioturbation indicates a good aeration of the environment, a slow deposition rate, and a minor terrigenous input. The depositional environment was probably deeper lower shore-face, as indicated by the intensity of bioturbation, the large size of boring organisms, and the episodic input of sand, probably during storms (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 destroyed by intensive bioturbation. Thus, the sand grains originated from sand beds, although some may be Aeolian in origin.

A poorly bioturbated sandy marl, with smaller ichnofossils, and no sand interbeds was deposited during periods of poor aeration of the bottom water, as indicated by a lower bioturbation rate and the smaller size of ichnofossils. The depositional environment was probably an open shelf (offshore).

Heterolithic packages (Sandstone-marl alternation)

Heterolithic sediments were deposited above the storm wave base, as indicated by HCS and SCS structures in sandstones. Storms alternated with relatively long fair-weather periods with only suspension sedimentation, when benthic

Figure 2.5 - Double mud drapes are locally well-developed, also note rippled bottomset which pinches out downdip.

organisms recolonised the sea bottom. The depositional environment was probably a proximal part of the open shelf, namely an upper part of the lower shoreface, as indicated by a large number and the overall thickness of the storm-beds.

Sandstones

Migration of dunes produced large-scale cross-bedded sandstones, whereas variation in migration intensity and periodical erosions formed large complex sedimentary bodies that are usually referred to as sand waves, and can be recognized as Allen's (1984) type 2 and 3 bodies, or complex dunes of Ashley (1990).

Tidal bundles (grouping of laminae in packages that are divided with finergrained or thinner sandstone, Fig. 2.4) are considered diagnostic for tidal processes (Visser, 1980; Roep, 1991), as well as double mud drapes (Fig. 2.5) and herring-bone structures. Thicker packages of cross-laminae are interpreted as the 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.

Tide amplitudes are low on the open sea, but they increase in funnel-shaped straits, large bays and estuaries. High tide amplitudes are a prerequisite for the generation of tidal sandstone bodies such as dunes, sand waves, and bars. However, the topography of the depositional realm controls the tide amplitudes. What the Kvarner Bay Eocene palaeo-topography looked like, we do not know yet. Zupanič and Babić (1991) interpreted a shallow marine realm, which they referred to as 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 funnel-shaped bay or incised valley.

Figure 2.6 - Slumping affected offshore sandy marls and the overlying shoreface sandstones.

Biocalcarenites

Biocalcarenites were interpreted as skeletal tempestites (Marjanac and Marjanac 1991), which occurred during exceptionally strong storms. However, they may also have been a consequence of ravinement erosion, which affected the underlying lithified sands. Storm origin is indicated by gutter-casts, which were formed by local vortices in a storm surge. It is unlikely that the storm will create erosional relief deeper than a few decimetres to a metre 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 meters, and up to tens of meter,s. Lithoclasts, which are identical to the underlying sandstones document relatively deep erosion, down to the level where the sand was already cemented, and support 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 the erosion of poorly lithified sediments. However, it seems that skeletal debris did not originate from the underlying sediments, because there we do not see identical fossils in living positions, nor do the fossil assemblages look natural, because abundant *Nummulites* tests occur together 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 a very shallow depositional setting in any case.

Conglomerates

Conglomerates occur only at the bases of the units A, B and C1, in the lower part of the Lopar section. Gravel does not form individual beds, but occurs within cross-bedded sandstones in the form of thin lenses and interbeds, and sometimes they line the foresets. Gravel interbeds are sometimes 10 cm thick, with erosional bases, and 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 up to 10 cm, and rounding as well as sphericity are generally good. Clast lithologies are odd with regards to the External Dinarides setting, because they are mostly represented by various cherts and silicified arenites, and no carbonates (!), so their provenance is still unknown.

The grain size of gravel indicates considerably high fluid velocity, and good rounding (despite resistant lithologies) document their long tractional 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 deposited 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.

Slumps

Slumps frequently occur within Lopar Sandstones, and are characterized by lensoid geometry and slump folds (Fig 2.6). Their thickness reaches up to 6 m, and they occur within marly intervals, as well as within sandstones. Slump folds are commonly made up 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 slump base is clearly erosional, whereas its upper surface is generally flat. The sediments overlying the slump are found to onlap its top surface.

Slumps indicate slope instabilities, regardless of its gentle dip. Marls must have facilitated slumping and got remoulded in the “matrix” which surrounds the slump folds. Slump failures may have been initiated by slope oversteepening, slope overloading, liquefaction, hydraulic shocks, or earthquakes. It seems that overloading due to a 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.

DAY 3

Foundation of the carbonate platform in the Middle Permian time
Ladislav Palinkaš

The Adriatic carbonate platform (AdCP), as a unique entity, existed from the Middle Triassic to the Late Cretaceous, when the process of disintegration gradually stopped carbonate deposition. Diversified sedimentary environments, producer of clastic sediments predominantly and orogenic uplift, finally created the mountain chain of Dinarides. The death of the AdCP raises a question of its birth. Was it an instantaneous event along the margins of the southern Pangea? Diversification of sedimentary environments in Permian time from the NW Dinarides in Slovenia to the Central Dinarides, does not offer the only answer. Carbonate deposition, as the foundation of the carbonate platform on the Permian clastics, was not a concurrent process experienced at the full extension of the southern Pangaea in the region of the present Dinarides. In Žirovski Vrh area (NW Slovenia), carbonate deposition started in the latest Permian over the fluvial Val Gardena sandstones, in Gorski Kotar (NW Croatia), marine sandstones of the latest Permian age are succeeded by the Lower Triassic dolomites, while on the Velebit Mt., carbonate deposition and the establishment of the first carbonate ramp evidently started in Middle Permian time and continued without break as a part of the Mesozoic megacycle.

The National Park Velebit-Paklenica

The protection of the wide territory of Velebit, as well as its major and minor parts, has a long tradition. In 1978, Velebit received "The Charter of UNESCO" as a part of the international net of the biosphere reservations (MAB – Man and Biosphere), and in 1981 almost the whole mountain with an area of nearly 2000 km^2 became a nature park. The North part, with a total area of 109 km^2, is, along with the National Park "Paklenica", the second national park of this mountain massive .

The entry to the canyons of Mala and Velika Paklenica (Small and Large Paklenica), are truly a phenomenon, due to their geological and hydrological particularities, the abundant karst, and the wealth of flora and fauna. The creeks Mala and Velika Paklenica give great value to the entire region, enriching it, and in the spring and autumn, the sheer power of the creeks erodes the limestone walls of the canyons, thus deepening them further every year. Both the Velika Paklenica Canyon, 14 km long, and the Mala Paklenica Canyon, 12 km long, are deeply cut into the massive south face of the Velebit mountains.

The geological particularities of the National Park are seen in the sharp karst formations in the regions of Bojinac, Vidakov Kuk, and on the plateau between both canyons. Here, many varying karst formations are visible, from cracks in the limestone, channels, basins, fissures, and caves, which arose from the intensive activity of flowing water, and from the large temperature differences during individual seasons.

Basins with cracks and channels are particularly well-developed in the Bojinac region, where the karst formations were created during glaciations, evident in the numerous moraine deposits. The park boasts some 70 caves, among which the most spectacular are the Manita Peć cave, and the Vodarica pit. Only the Manita Peć cave is open for viewing.

The water impermeable sediments are located under the porous, and layers of carbonate rocks, in the extended regions of Velika Paklenica, Brezimenjača and the source regions of Mala Paklenica, and in the temporary flow of the Orljača River.

As such, there are several constant and temporary rivers in the Paklenica National Park, and many constant water sources. Sources of drinking water, renowned for their excellent quality, are Stražbenica, Kontinovo Vrilo, Crno Vrilo, Velika Močila and Pećica.

Stop 3.1:

Carbonate platform environment from the Middle to Late Permian time: Palaeozoic sediments of the central Velebit Mt.
Jasenka Sremac and Tihomir Marjanac

Introduction

The Upper Palaeozoic tectonic belt of the Mt. Velebit and Lika region represents the best known and most completely developed Palaeozoic area

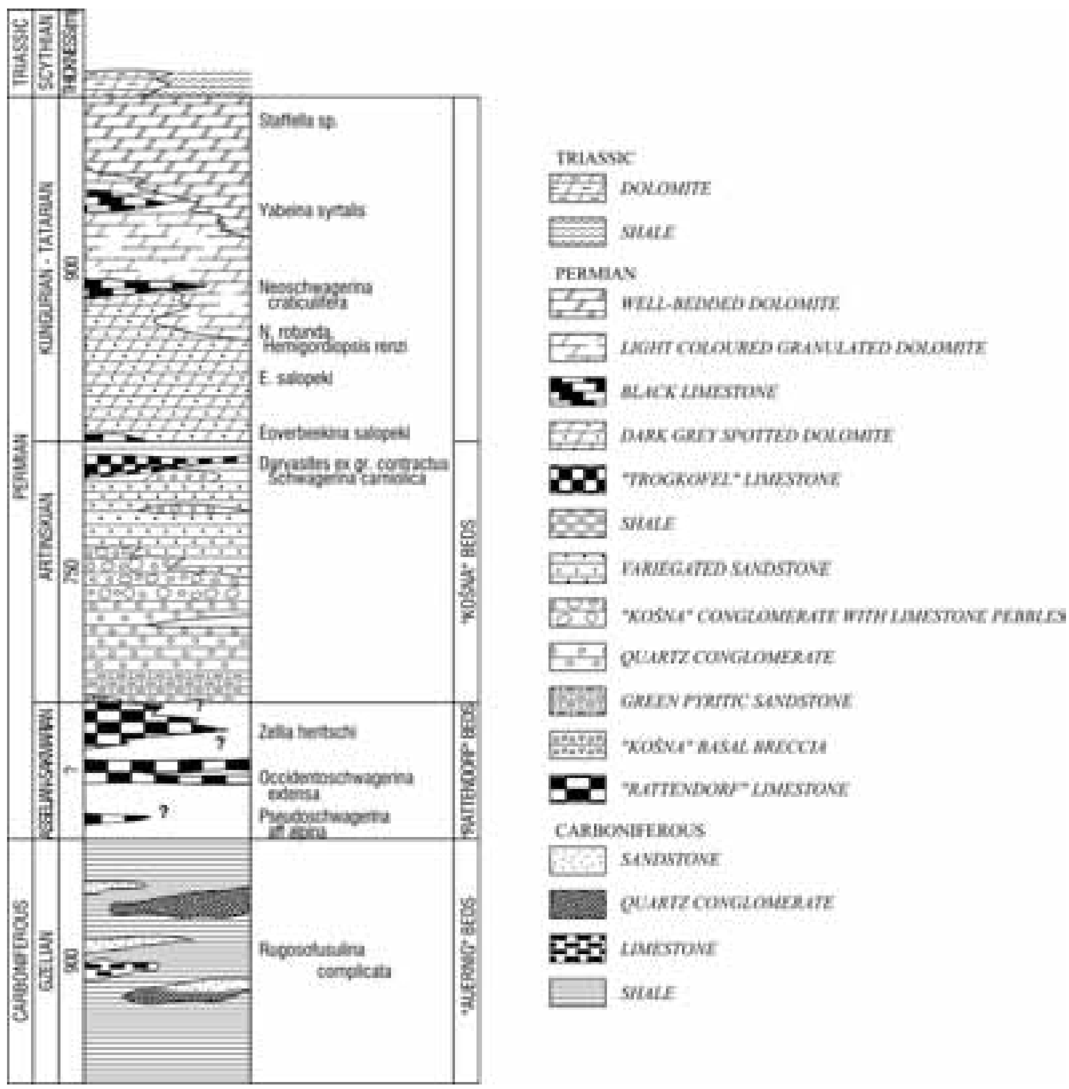


Figure 3.1 - Geological column of the Velebit Mt. Permian deposits (after Ramovš et al., 1990).

in Croatia. Sediments exposed here range from the Pennsylvanian (Moscovian) to the Late Permian in age. Carbonate sedimentation took part sporadically during the Carboniferous and Early Permian. Intensive tectonic uplift at the beginning of the Middle Permian caused the formation of prominent relief and its rapid erosion, followed by sedimentation of terrigenous molasse sediments.

After the phase of instability, the lowering of the relief enabled the stabilization of the area, and the formation of a carbonate platform environment that existed until the end of the Permian. Rapid production of carbonate material resulted in more than 900 m of carbonate sediments, dolomites, and limestones, rich in diverse and numerous fossils from Middle to Late Permian age (Salopek, 1942; Kochansky-Devidé, 1965; Ramovš et al., 1989)

Lengthy carbonate sedimentation began after the deposition of the red sandstones, with the black limestone of the *Eoverbeekina salopeki* zone, which can be observed west of Brušane village (near Gospić, central Croatia - Fig. 3.1.

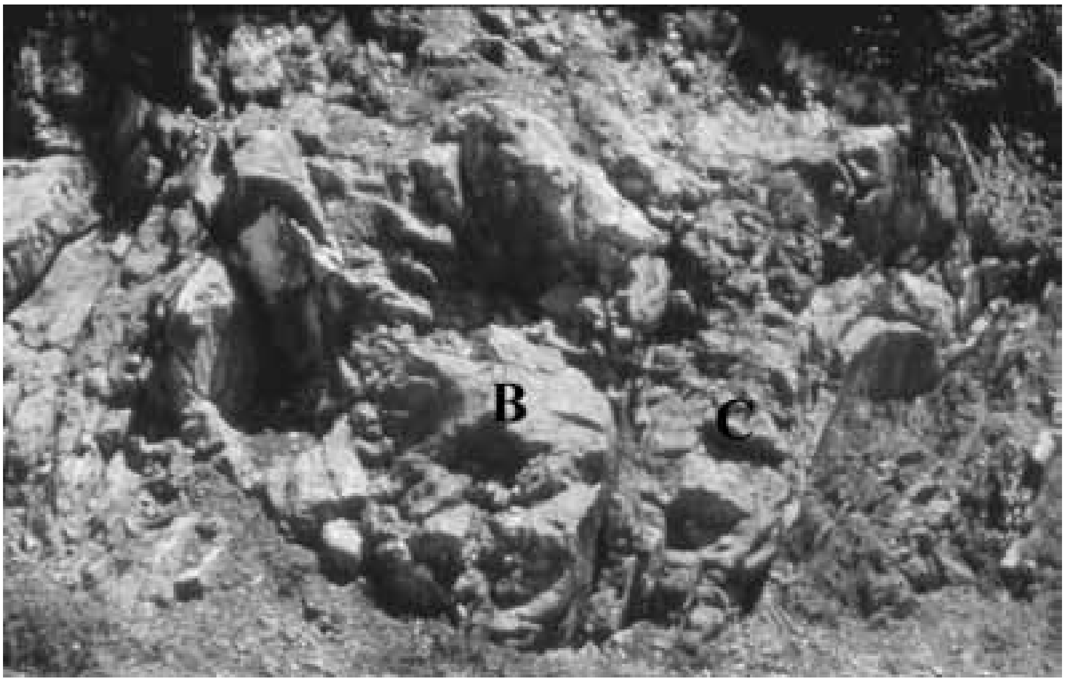


Figure 3.2 - Patch reef in the Paripov jarak, near the Baške Oštarije village, along the Gospić - Karlobag road (after Sremac, 1991).

Limestones contain large gastropods (*Platystoma, Bellerophon*), cephalopods (*Orthoceras*), and a typical microfauna (*Eovrebeekina, Sphaerulina, Staffella*). Limestones are overlain by an approximately 300 m thick sequence of grey "spotted" dolomites. White spots represent recrystallized algal, foraminiferal and microfossil skeletons, predominantly of dasycladacean *Mizzia*, accompanied by *Eovebeekina, Staffella, Neoschwagerina, Waagenophyllum, Bellerophon, Pleurotomaria, Orthoceras,* and *Edmondia.*

The second limestone belt, the *Neoschwagerina craticulifera* zone, is extremely rich in macrofossils. Numerous brachiopods (45 taxa), predominantly spiriferids, enteletids, productids, and oldhaminoids, including several endemic species, the aberrant bivalve *Tanchintongia*, calcisponges, bryozoans, and gastropods, have been collected from the area of Brušane and Baške Oštarije. Foraminifera: (*Neoschwagerina, Dunbarula, Nankinella, Schubertella, Glomospira, Globivalvulina*, etc.), and calcareous algae: (*Mizzia, Vermiporella, Gymnocodium, Permocalculus*, and many other taxa), are extremely abundant. Small patch-reefs produced by calcisponges, bryozoans, cyanobacteria, and/or *Tubiphytes,* have been found in this horizon (Sremac, 1991).

The middle and uppermost limestone zones are separated, or in some places, replaced, with light grey crystalline dolomite ("Schwagerina"-dolomite *sensu* Salopek, 1942), with *Mizzia, Likanella, Salopekiella, Goniolinopsis, Neschwagerina, Kahlerina, Dunbarula,* and gastropods. Fauna from the lowermost limestone zone also occurs sporadically (*Stafella, Eoverbeekina*). In some parts of the basin, sedimentation of the so-called "transitional dolomites" (*sensu* Salopek, 1942), or "early diagenetic supratidal dolomites" (Tišljar et al., 1991), with scarce fossils, had already begun in this period.

The uppermost limestone zone, the Yabeina syrtalis Zone, was named after the dominant fusulinid species - Yabeina syrtalis, although specimens of *Yabeina* also occur in the middle limestone horizon. Differences in microfossil assemblages are not very distinct from the middle zone, but some new macrofossils occur in the Yabeina-zone, such as brachiopods (*Derbya, Streptorhynchus, Orthotetes*), and gastropods (*Temnocheilus*). Dense "transitional" dolomites

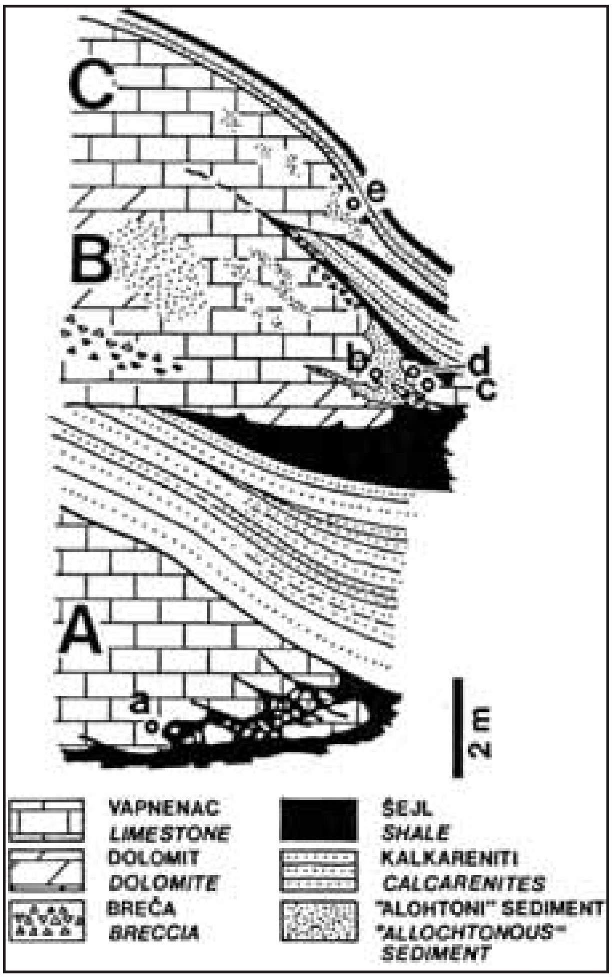


Figure 3.3 - Vertical section through the patch-reef complex in the Paripov , near the Baške Oštarije village, along the Gospić-Karlobag road (after Sremac, 1991). Bold letters indicate individual reef units, as referred to in the text.

(*sensu* Salopek), or "early diagenetic supratidal dolomites" (Tišljar et al., 1991), are well-bedded and rather poor in microfossils. In the lower portion of this sequence, Permian microfossils, predominantly gymnocodiaceans, have been found. The uppermost portion contains small foraminifera typical for stressed environments. A continuous transition from the Upper Permian to the Lower Triassic, followed by an increase in the clastic component in dolomites, has been indicated by previous authors (Salopek, 1942; Ramovš and Kochansky-Devidé, 1981). Nevertheless, a lack of index species in the uppermost dolomite beds leaves the question of the position of the Permian-Triassic boundary open.

Observation stop: Paripov Jarak near Baške Oštarije village

(central Velebit Mt.)

In the area of the Brušane and Baške Oštarije villages, in the central part of the Velebit Mt., dolomite-limestone sediments of the Middle and Upper Permian are well developed. Three zones of black limestones can be clearly distinguished, containing numerous well-preserved micro- and macrofossils. The observation point is located near Baške Oštarije on Velebit Mt., also known as "Salopek's second zone of black limestones, pv2". These black limestones have attracted researchers due to their rich fossil content, and interesting sedimentological features (Kochansky-Devidé, 1965; Sremac, 1991; Marjanac and Sremac, 2000). During sedimentation of these limestones (Neoschwagerina craticulifera zone), the dominant environments were algal meadows of dasycladaceans and gymnocodiaceans. At several places on the platform mound, structures were formed. Among them, there is an interesting patch-reef which is today well-exposed along the Gospić-Karlobag road.

Three phases of reef formation can be distinguished (A-C), and lentoid carbonate bodies were divided by clastic sediments-calcarenites (reef debris) and shales (Figs. 3.2 and 3.3).

Description of the reef complex

The bluish-black limestones are bituminous biomicrites (framestones), which overlie some 10 m thick black shales with thin calcarenite interbeds. The dolomitized parts are light grey in colour (Figs. 3.2 and 3.3).

The sub-stratum, composed of skeletal debris and a muddy matrix, was first colonized by tabular calcisponges, fenestellid bryozoans, and

Figure 3.4 - Martinia velebitica in the sponge cavity. The reef framework made of encrusted frame-builders hosted numerous reef-dwellers, such as foraminifera, calcareous algae, gastropods, and brachiopods (after Sremac, 1991).

algae. Debris composed of calcareous algae such as *Mizzia* and *Permocalculus,* rare gastropods and crinoids are also present. Thick oncoidal (cyanobacterial) crusts coat the organisms.

The first reef frame builders were tabular calcisponges, fenestellid bryozoans, and algae. Two types of oncoidal crusts can be recognised: micrite crusts with poorly visible laminae, and crusts with well-developed chamberlets, which are filled with dolomite. Sometimes sessile organisms colonized oncoid crusts, but were later overgrown by cyanobacteria.

The reef framework composed of incrusted frame-builders hosted numerous reef-dwellers, such as foraminifera, calcareous algae, gastropods, and brachiopods (Fig. 3.4). The primary porosity was reduced by this process. The remaining inter-space is filled with micrite, and fine-grained skeletal debris. Some voids in the reef framework are geopetally filled with internal sediment, composed of carbonate silt, fine-grained calcarenite, and sparry calcite.

The reef limestones locally contain large solution cavities (some more than 30 cm in diameter), filled with laminated fine-grained debris (carbonate silt and calcarenite), scattered skeletal debris and lithoclasts.

The genesis of the reef cavities is twofold; the "growth cavities" are remnants of primary reef framework porosity, and "solution cavities" developed within the vadose zone during episodic exposures, and atmospheric water flushing.

The reef top surface of individual sedimentary bodies is characterized by breccias, composed of clasts of early lithified limestones and skeletal debris. Large bivalves *Tanchintongia ogulineci* are also present. The reef top relief consists, in places, of protruding incrusted organisms, filled with silt and mud.

Laterally, the role of the skeletal debris in the fine-grained matrix increases, and the body **C** laterally turns into a thin calcarenite bed (Fig. 3.3). The body **A,** however, ends laterally, bounded by shale, rich in scattered cobble-sized lithoclasts and incrusted organisms. Locally, the breccia forms channelized beds (eg. laterally to the body **B**) as a substrate for subsequent colonization by pioneering organisms, and their encrustants. The reef bodies are onlapped by calcarenites (floatstones, Fig. 3.5), with more-or-less well-developed normal grading, sometimes cross-laminated, and sharp tops. The calcarenites are interbedded with thin black shales, interpreted as storm-beds (tempestites).

The reef growth was finally aborted, and the reefs buried beneath thick black shales. This was probably a result of rapid relative sea-level rise.

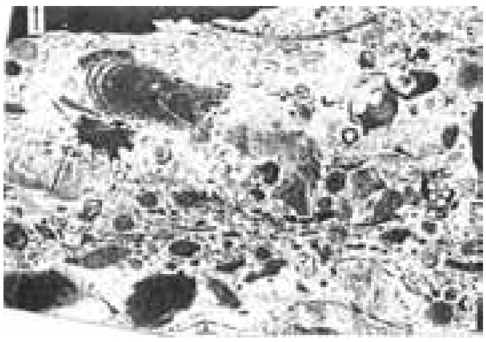


Figure 3.5 - Floatstone with unsorted reef debris (after Sremac, 1991).

Figure 3.6 - Rujno medial moraine ridge in the seaward direction.

Short Scenario of reef-building events

The reef evolution can be summarized in 7 phases:
1) substrate colonization;
2) the formation of primary reef framework with dwellers;
3) reef framework encrustation;
4) early lithification;
5) shallowing (relative sea-level fall), followed by weathering and erosion;
6) infilling of secondary reef porosity;
7) deepening (relative sea-level rise), followed by recolonization (or final burial as after reef body C).

The Palaeozoic sediments of the Velebit Mt. can be considered as a foundation of the later carbonate platform environment, subsequently developed, here and elsewhere in the External Dinarides in the course of Mesozoic time.

Quaternary glacial and associated deposits of Velika Paklenica and Rujno

Ljerka Marjanac and Tihomir Marjanac

Case history

The earliest idea about the Mediterranean being influenced by glaciations, and so the Adriatic as being the northeast epicontinental sea, was introduced just as a hypothesis by Luis Agassiz (1840) in his discussion about glaciations. The idea that at least the highest peaks of the Croatian External Dinarides were glaciated, dates back to 1899, and Albrecht Penck's journey to the Dinarides. Hranilović (1901), Gavazzi (1903a,b), and Schubert (1909) also promoted the idea of glaciation on the Velebit Mountain, but it was not accepted by other researchers (i.e. Gorjanović, 1902). Later on, geomorphologist Milojević (1922) described what he interpreted as glacial deposits in the Paklenica canyon on the Velebit Mountain, and so also did Bauer (1934/35), and Degen (1936). Malez (1968) made a general statement that the mountain tops of the coastal Dinarides, including the Velebit Mountain, were glaciated during Pleistocene, but provided no documentation. It is interesting to mention that J. Cvijić (1917) already described the glaciation of the southern Dinarides at the beginning of the 20th century, but only in areas over 1000 m a.s.l.. Poljak (1947), Leon Nikler (1973), Belij (1985), and Bognar et al. (1999) contributed greatly to the understanding of the phenomena. Recently, studied deposits along the Adriatic coast, interpreted as of glacial origin, yielded evidence in favour of the glacial origin of these Quaternary deposits (Marjanac et al. 1990, Marjanac and Marjanac, 1991).

Geology of the area

The study area is part of an extensive karst region of the Velebit Mountain. Rather poor vegetation cover allows a fairly good insight

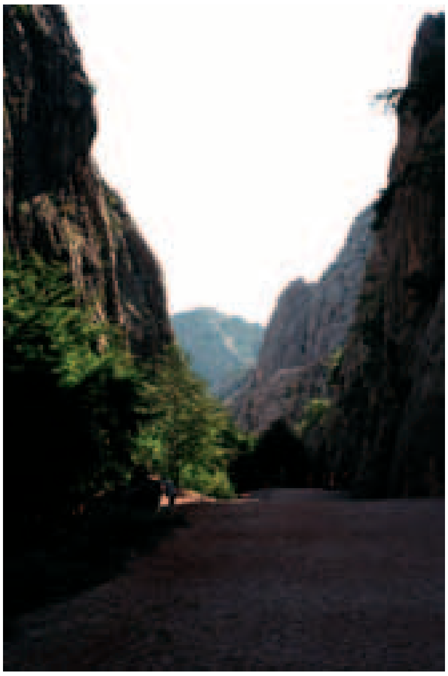


Figure 3.7 - The Velika Paklenica Canyon (looking in a downstream-seaward direction).

into the geological framework. The canyon of Velika Paklenica has been deeply incised into predominantly carbonate rocks of the Triassic, Jurassic, and Tertiary ages, nearly perpendicular to the main NW-SE strike of the bedding and the tectonical structures. Triassic is here represented by Lower Triassic clastics (micaceous sandstones, siltstones, and shales, sandy oolithic calcarenites; commonly red coloured), Middle Triassic limestones and sandstones, with the occurrence of volcanoclastics, and the Upper Triassic complex of transgressive conglomerates, dolomites, and pyroclastics. The youngest are carbonate Jelar breccias and conglomerates, massive to poorly bedded, of supposed Paleogene age. They transgresively overlay various older deposits. The Rujno area is a large valley developed within a complex of Upper Triassic and Jurassic well-bedded dolomites and limestones. The valley is divided into two parts, Malo Rujno and Veliko Rujno, by a glacial moraine ridge. The whole valley is covered with fluvioglacial sediment, according to the basic geological map of the area (Sheet Gospić). In the vicinity of Rujno also Lower Permian clastics (conglomerates and sandstones), and Upper Permian dolomites, are present. During our recent studies of Quaternary deposits in V. Paklenica and Rujno, we recognized all the stated lithologies in Quaternary clastics of glacigenic origin which are first described as such in the following text.

Figure 3.8 - Trench showing glacially-derived, unsorted debris - Rujno medial moraine. Clasts with glacial striae were found there.

Sediments and their origin

Quaternary deposits can be found within the broader surroundings of Rujno and V. Paklenica, but regarding the present state of exploration, we will refer strictly to Rujno valley (Fig. 3.6), and the V. Paklenica canyon (Fig. 3.7).

Rujno moraine is an elongated composite sedimentary body (ridge) composed of glacially-derived material (Fig. 3.8). It consists of three "amalgamated" smaller bodies (debris accumulation), each representing a different phase of glacial advance. The sediment is an unconsolidated, matrix-supported conglomerate (ca. 30% clay-silt matrix). 70% of unsorted rounded debris, with an average maximum diameter of 25 cm, is represented by a predominantly dark grey limestone (probably Jurassic), and small red-coloured particles (Lower Triassic). The ridge is covered with grass and shrub vegetation. Scattered large boulders - erratics - are visible on the surface. Their size range is 60 to 250 cm in diameter.

The Rujno moraine (NW from Velika Paklenica canyon), which lies between 830 and 950 m a.s.l., was interpreted as terminal by Nikler (1973) and Belij (1985). However, it shows all the characteristics of a medial moraine, and is considered as such in this paper. Consequently, the corresponding glacial tongue proceeded further downslope towards lower altitudes, leaving behind an extensive lag of coarse debris which was later resedimented and sorted by meltwaters.

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

Velika Paklenica moraines occur almost along the whole length of the canyon. They change in composition from the proximal to distal part of the canyon, depending on the source area from which the ice was coming from. This regards the various lithologies of Permian, Triassic, or Jurassic eroded by ice advance and meltwaters during the ice retreat. Thus the moraine in the proximal canyon is a typical diamictite, and matrix-supported, with a high clay content, and derived from Lower Triassic clastics. Towards the distal canyon part (seawards), diamicts become 90% carbonate in composition, with little matrix, or they turn to openwork conglomerates (matrix washed out). Clasts of Lower Triassic rocks become very rare, because they are softer and easily weathered during transport. Jurassic limestones and dolomites predominate, and clasts are much larger, commonly rounded boulders over 1 m in diameter. Sediments are more or less cemented. Distally downstream, moraine is commonly reworked, redeposited and sorted, so it becomes clearly bedded. In several places, an alternation of diamicts with boulders and intervals of reworked moraine are visible, which probably represents several phases of ice advance and retreat. An excellent section of the road cut shows two such intervals, a glaciofluvial conglomerate beneath an unsorted diamict with large rounded boulders, here interpreted as basal moraine. A sediment wedge in the glaciofluvial conglomerate was recognized and interpreted as a possible ice wedge filled with coarse debris during ice advance.

The most impressive remnant of an end moraine in the V. Paklenica canyon (Marjanac and Marjanac, 1999), is visible below Anića Kuk (a well-known rock-climbers' wall) at the forehead of Anića Luka. It is about 250 m a.s.l., and probably represents Early or Middle Würmian glaciation. This one is composed of cobbles and boulders 1 to 10 m in diameter (the largest one being 22 m) "floating" in a gravel/arenite size "matrix", which is well-cemented. Boulders and cobbles are subrounded to rounded, commonly spherical to oval, and poorly-sorted. At the back of the moraine (upstream), there are remnants of glaciofluvial/fluvial terraces. The moraine itself has been partly destroyed. Running waters have washed out the fines, and collapse of large clasts has occurred. Thus, today we can see the canyon filled with such large boulders and cobbles. Washed-out fines and gravels were transported by streams, and accumulated in alluvial fans in front of the Paklenica Canyon, today the area of Starigrad.

DAY 4

Geography and hydrogeography of the Neretva Delta

Gordana Pavlović and Esad Prohić

This delta borders the Adriatic sea (taking up about 25 km of coast), south-eastwards from the town of Ploce at the southern extremity of the Dalmatian region. It extends inland for 20 km, before reaching the boundary of Bosnia Hercegovina and the lower end of the Neretva valley.

The area is characterized by coastal salt marshes, saline lagoons, sandbanks, and wet meadows. It is surrounded by Karstic hills, overgrown with degraded forest. The mean annual temperature is 16° C (winter 8°C, summer 24°C), with an annual precipitation of 1312 mm (winter 160 mm, summer 45 mm). Winds are generally from the east, occasionally from the west. Winters are moist and mild with hot, dry summers. There is in the valley a network of small karstic lakes, some permanent, others only temporary. The whole delta area (500,000 ha) has a very complex hydrographic system with some waters being oligotrophic, and others brackish.

The Neretva River has its source beneath the Zelengora Mountain in the east of Bosnia and Herzegovina (Fig. 4.1). Whereas its upper and middle courses are characterized by canyons and cliffs, its lower course is a vast wetland valley. The river flows further downstream through its large delta into the Adriatic Sea. It is the largest river of the eastern part of the Adriatic basin. Along its course there are several HE power-plants, and their storage lakes. Downstream from the inflows of its tributaries Trebižat and Bregava, the Neretva valley extends into an alluvial fan, "Neretvanske blatije", with the area of 20.000 ha. Its northern part, called Hutovo Blato, belongs to Bosnia and Herzegovina, whereas in its southern part, which is situated in Croatia, the Neretva River forms a large delta (Fig. 4.2).

The last deglaciation caused a sea level rise, whereby sea water covered the karst relief as

Figure 4.1 - Mostar, historic town, owes its name to the famous bridge over the Neretva valley. The Neretva River, with its emerald green, wild water, cuts Dinarides with a deep gorg,e and enters a wide delta, one of the biggest and most picturesque on the Mediteranean.

Figure 4.2 - The delta of the river Neretva in Croatia spreads over an area of approximately 12.000 ha. The high biological production of the river results in the feeding of many sorts of fish at the Neretva mouth. 310 bird species have been registered in the Neretva delta, some of them being European endangered species.

far as to the present Hutovo Blato. Gravels and fine-grained sediments had been deposited in the valley by the Neretva River. The lower parts of the Neretva valley consist of the largest and the most spectacular Mediterranean wetlands on the eastern Adriatic coast. Being under the huge stress of intensive cultivation and urbanization, these wetlands are threatened with destruction. All sorts of anthropogenic activites have changed this ecological system into mostly arable land and it doesn't function as it used to do, namely many animal species are vanishing and many natural processes have been upset.
The delta of the River Neretva in Croatia spreads over an area of approximately 12,000 ha. Today, only three branches have remained out of an earlier twelve, whereas many lagoons and lakes have disappeared. The sea largely influences the delta, where brackish water is a unique habitat

which contributes to the biological diversity of the area. The high biological production of the river provides for the feeding of many sorts of fish at the Neretva mouth. 310 bird species have been registered in the Neretva delta, some of them being European endangered species.

In spite of its deteriorating condition, this area still represents an exceptional example of the biological and landscape diversity for which it is internationally renowned. The lower Neretva valley was included in the Ramsar List of the Ramsar Convention on Wetlands, as well as in the Programme "Important Bird Areas', conducted by the "Bird Life International" organization.

Stop 4.1:
Delta of the Neretva River

The Neretva River emerges from beneath the Zelengora Mountain in eastern Bosnia and Herzegovina. Through canyons, cliffs, and hollows in its upper and middle courses, it forces its way through the Dinaric Alps to spread downstream from the village of Pocitelj in Herzegovina, over a vast wetland valley, and to flow through its large delta into the Adriatic Sea. Neretva is the largest river of the eastern part of the Adriatic basin.

The Neretva Delta in the Republic of Croatia covers about 12,000 ha. Today, in this cultivated area, only fragments of the earlier large Mediterranean wetland are preserved. Five sites with a total area of 1,620 ha, are protected in the categories of ornithological reserve.

Here, the natural values, and the diversity of habitats, depend in the first place upon the water regime affected by the Neretva River. Owing to many underground karst streams of the basin, in the part adjacent with the surrounding limestone terrain, there are a large number of springs carrying large amounts of water, especially in winter. The ground water coming from this adjacent area supplies numerous streams, lakes, and cavities. Many caves and other underground habitats in the surrounding karst are home for rich fauna with many endemic species.

An important factor affecting the delta is the sea, and the bodies of brackish water represent special habitats which contribute additionally to the biological diversity of this whole area. Aquatic habitats, together with large reed-patches, wet meadows, beaches, sand-banks, and saltmarshes, as well as the adjacent karst overground and underground, present a wide variety of habitats, that is the basis for an adequately wide variety of plant and animal life.

Figure 4.3 - The town of Korčula, birth place of Marco Polo, founded in Neolitic times, with its cultural and historical heritage, under Greek, Roman, Byzantine, Croatian, Hungarian, Bosnian, Venician, French, British, Austrian, Italian and finally again Croatian rule, ranks among the favourite tourist destinations in southern Croatia.

Stop 4.2:
The Ploče region

Stratigraphically and structurally, this study area belongs to the geotectonic unit of the Outer Dinarides. The recent tectonic setting is highly complicated, as numerous tectonic phases have left traces in this area. There are four tectonic units on the sheet Ploče: Biokovo, Biokovska Zagora, the Makarska littoral, and the central Dalmatian islands.

The flanks of the Neretva valley are made up of Mesozoic karst limestone, while the bed itself is covered by younger alluvial deposits.

The Quaternary is represented by lacustrine, alluvial, and deltaic sediments. Alluvial deposits consist of the lithologically-heterogenous complex, dominantly composed of clayey sands and silts. A thick and complicated, lithologically heterogenous delta complex has been deposited at the mouth of the River Neretva. This is where the sediments of saline, potable, brackish, and lagunar waters mix with corresponding organisms. The material, carried by the river, is being deposited towards the west, i.e. towards the direction of its course. The territory,

Figure 4.4 - Due to frequent attacks of the Turkish fleet and pirate ships (until the beginning of the 18th c.), several important points on the island were fortified (especially the town of Korčula).

influenced by the ebbs and high tides, is characterized by the sedimentation of most typical deltaic deposits, exhibiting cross stratification. The entire thickness of the complex is estimated to be not more than 30 meters. It is not possible to place the boundaries between genetically different lithological types. Accumulation of this material started as early as Pleistocene, and has continued up until recently.

Stop 4.3:

Island of Korčula

Sabina Strmić

Korčula is an island in the central Dalmatian archipelago; it has an area of 279.03 sq km (length 46.8 km, width 5.3-7.8 km); a population of 17,038; and the coast is rather indented. The highest peaks are Klupca (568 m), and Kom (510 m). The climate is mild; an average air temperature in January is 9.8 °C (in the town of Korčula) and in July 26.9 °C; the average annual rainfall is 1,100 mm; the annual hours of sunshine reach 2,671 hours (Vela Luka). The island is largely covered with Mediterranean flora; at some places there are pine forests. The economy is based on farming, viticulture, fruit growing, fishing, and fish processing, shipbuilding, the processing of synthetic materials, and tourism. Summer tourism has a long tradition on the island; nautical tourism has been recently developed. Major places on the coast are Korčula, Lumbarda, Vela Luka, Račište, and in the interior Blato, Žrnovo, Smokvica, Cara and Pupnat (Fig 4.3). The regional road connects major places on the island. Ferry lines connect the island of Korčula with the mainland.

The island was inhabited as early as the Neolithic (cave Vela Špilja near Vela Luka, cave Jakasova Špilja above the cove of Rasohatica, Žrnovo) and the Bronze Age. A Greek colony existed here in the 6th and the 5th centuries BC; at that time the island was called *Korkyra Melaina* (remains of Greek habitations in Lumbarda, in the vicinity of Blato and in Potirna). From 35 BC, the island was part of the Roman Empire; traces of Roman settlements have been discovered in the vicinity of Lumbarda, Vela Luka (locality Beneficij), Blago, and on Pelegrin. On the collapse of the Western Roman Empire, the island became part of the Ostrogoth state (AD 493), and then came under Byzantine rule (AD 555). In the 9th century, it was taken by the Nerentani/Narentini, and in AD 1000, by Venice. In 1180 the island came under the Hungarian-Croatian king (in 1214 the statute of the town and the island were passed). From 1221, over two centuries, the island had several rulers from Zahumlje, Venice (in 1298, the Genovese fleet defeated the Venetian fleet near Korčula), King Lodovic I (1358), Bosnian rulers (1390), and the Dubrovnik Republic (1413-1417). In the period 1420-1797, the island was under Venice, but it retained its autonomy. Due to frequent attacks of the Turkish fleet and pirate ships (all until the beginning of the 18th c.) ,several important points on the island were fortified (especially the town of Korčula) (Fig 4.4). After the fall of Venice, there was another period of various rulers (1797-1805 Austria, 1805-1813 France, 1813-1815 Great Britain, 1815-1918 Austria). Korčula was under the Italian occupation in the period 1918-1921, and after that was annexed to Croatia. The centre of the island, the town of Korčula, with its cultural and historical heritage, its town ramparts (similar to those of Dubrovnik) ranks among the favourite tourist destinations in southern Croatia. As for the local economy, shipbuilding (town of Korčula, Vela Luka) and stone cutting (extraction of white marble from a quarry on the eastern coast of the island) have been important mainstays for centuries. The famous travel writer, **Marco Polo**, who was, according to some sources, born in Korčula, was said to have been involved. The people of Korčula were famous stonemasons, shipbuilders, and seafarers. They left their mark in stoneworks, sculptures, and buildings all over Dalmatia, but they saved their best works for their own city.

Figure 5.1 - The little isle of St. Mary in the Great Lake, with an ancient Benedictine monastery, and a church dating from the 12th century. This small island has become the symbol of the entire Mljet island, because of its exceptional aesthetic qualities, and strong cultural and spiritual dimensions.

DAY 5

Stop 5.1:

Island of Mljet

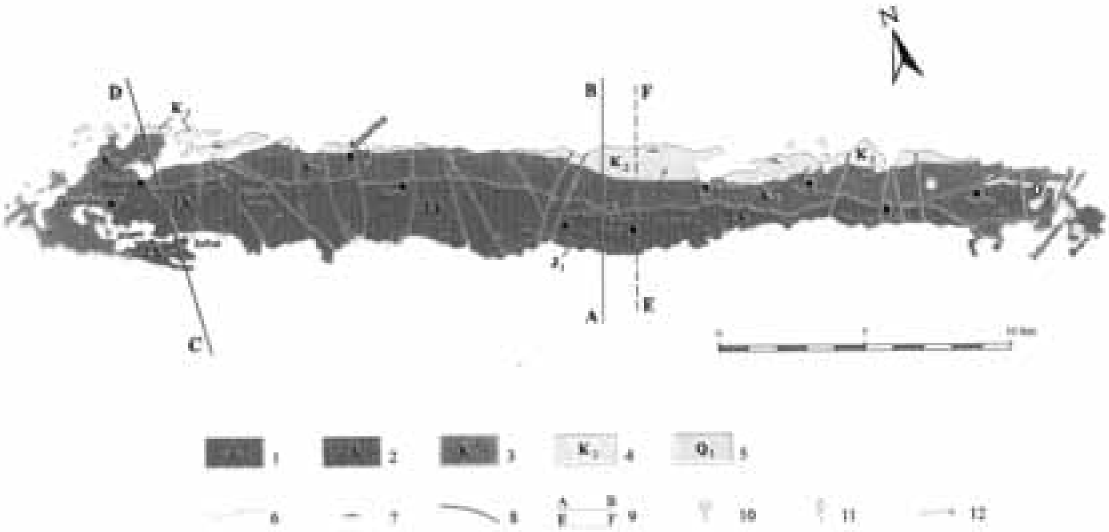
Sabina Strmić

Mljet was proclaimed a national park on 12th November 1960. It covers an area of 3,100 hectares on the northwestern third of the island of Mljet, one of the largest islands in southern Dalmatia. The island is made of strata of limestone and dolomite. The limestone created higher ground; the dolomite created most of the depressions, i.e. the fields. The central part of Mljet is a highland, with three parallel ranges. The highest point is Veliki Grand (514 m). The western and eastern thirds of the island are lower, but the highland features are also present in the relief and landscape.

The climate is Mediterranean with warm, dry summers and mild, wet winters. The average annual precipitation is 973 mm and the annual hours of sunshine are 2,500 hours.

The main motives for proclaiming the island a national park were because of its highly indented coastline and rich plant life that abounds in the forests. From the open sea and through a barely visible passage, the sea seeps into the mainland to form the Veliko Jezero (Fig 5.1), which covers 145 hectares and is 46 metres at its deepest, and the Malo Jezero, which covers 24 hectares and is 29 metres at its deepest point. Although filled with seawater, both are perceived as lakes, as even their names – "jezero" ("lake") confirm. Lakes are the most interesting, but certainly not the only feature of the coastal indentedness and landscape of the National Park. There are also

Figure 5.2 - Geological map of Mljet Island (data from Korolija et al., 1976, 1982; partly modified and updated), Explanation: 1. Upper Jurassic limestone, 2. Jurassic-Cretaceous dolomite, 3. Lower Cretaceous limestone, 4. Alternation of Cretaceous limestones and dolomites (Albian - Cenomanian), 5. Pleistocene quartz sand, 6. Normal geological boundary – continuous transition, 7. Strike and dip of beds, 8. Faults, 9. Profiles: A-B and C-D (geological), E-F (hydrogeological), 10. Fresh-water spring, 11. Brackish spring, 12. Supposed directions of underground water-flow.



numerous coves, bays, and isles, covering a total area of 122.7 hectares.

Mljet is also called The Green Island. Credit for such a name should be given to the western side of the island, which borders the Mljet National Park. Ninety per cent of the Park is covered in forest, primarily by indigenous Aleppo pine (*Pinus halepensis*), which is found all over the island, and especially on the warmer, more sunnier slopes, and around the Veliko Jezero and Malo Jezero.

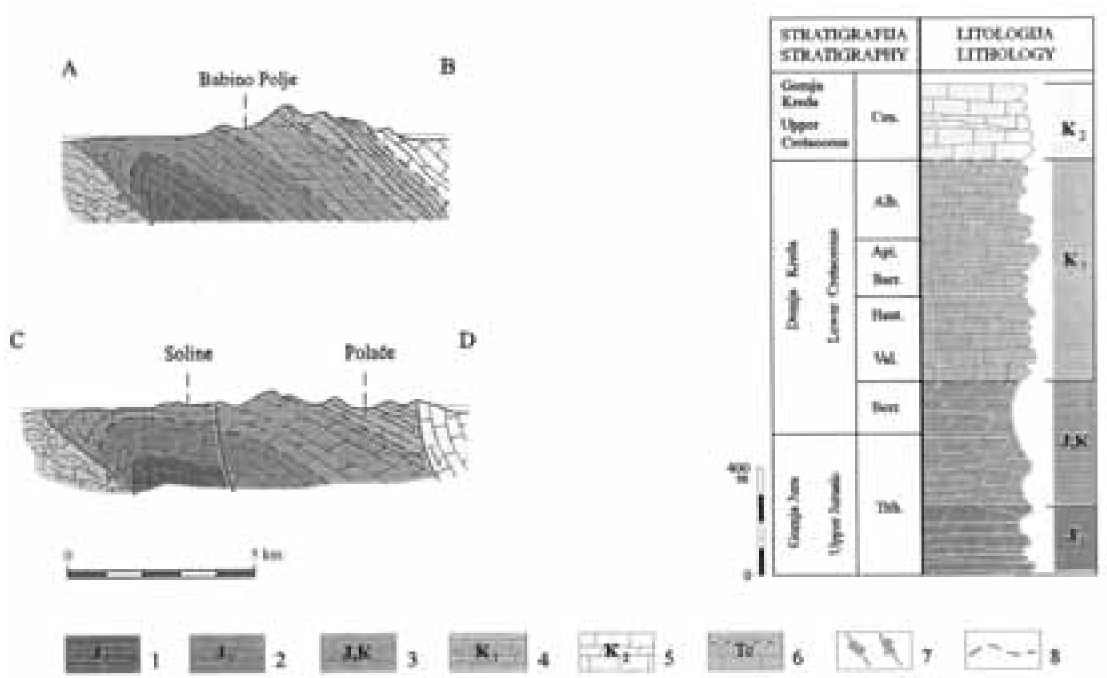
Geology of the Mljet island

Ivan Gušić

The island of Mljet is a part of the Adriatic-Dinaridic carbonate platform, which was one of the largest and most long-lasting Tethyan Mesozoic carbonate platforms (Jenkyns, 1991). It is built up of Upper Mesozoic platform carbonate rocks, with a thin and sporadically developed cover of Quaternary deposits. Mesozoic carbonates are in general well-bedded, have a WNW-ESE zonal strike, and dip towards the NNE (Figs. 5.2, 5.3).

The oldest sediments are Upper Jurassic limestones (about 150 my b.p.), that form the coastal cliffs to the south and southwest of Babino Polje. They range, in age, from the Upper Kimmeridgian to the Upper Tithonian, and contain, in their lower part, the foraminifer *Praekurnubia crusei Redmond* and the dasyclad alga *Salpingoporella? sellii* (*Crescenti*),whereas in their upper parts there are abundant remains of the green dasyclad alga *Clypeina jurassica Favre* and, sporadically, two species of the so-called larger benthic foraminifera (that are not necessarily much larger than 1-2 mm): *Kurnubia palastiniensis Henson* and *Parurgonina caelinensis Cuviller*, *Foury* and *Pignatti Morano*, which prove their Late Jurassic age. They are about 150-200 m thick, and are conformably overlain by the transitional uppermost Jurassic (Upper

Figure 5.3 - Geological profiles and schematized geological column of the Mesozoic deposits of Mljet. Explanation: 1. Middle Jurassic limestones and dolomites (only in profiles), 2. Upper Jurassic limestones, 3. Jurassic-Cretaceous dolomite, 4. Lower Cretaceous limestone (with breccia, conglomerate, and dolomite intercalations), 5. Alternation of limestone and dolomite (mostly Upper Cretaceous), 6. Tertiary limestone and flysch deposits (only in profiles), 7. Faults: left-normal, right-reverse; arrows indicate relative movement of rocks, 8. Geological boundary.



Tithonian)-lowermost Cretaceous (Lower Berriasian) late diagenetic dolomites, indicating extreme shallowing (and sporadically emerging) conditions at the Jurassic-Cretaceous boundary. These dolomites make up the largest part of the NW part of the island, but also extend further to the SE, from the area of the National Park to the west, to the environs of the Maranovići village to the SE. These dolomites, about 400 m thick, are, in turn, conformably overlain by a thick sequence of Cretaceous limestones, that build up the northern and northeastern part of the island (including, also, most of the area of the Mljet lakes). The Cretaceous limestones also form the highest mountain ridges of the island (Veliki Grad, 514 m) and dip toward the NNE into the sea (the Mljet Channel).

The Cretaceous limestones, sporadically interbedded with dolomite intercalations, make an 800 m thick, layer-cake type of sequence, ranging, stratigraphically, from the Berriasian (approx. 140 my b.p.), to the Upper Cenomanian (approx. 93 my b.p.). Chronostratigraphically speaking, all Lower Cretaceous stages are paleontologically well documented with numerous species of green dasyclad algae and "larger" benthic foraminifera, well-known from other Tethyan regions. (especially abundant are species of the dasyclad genus Salpingoporella, and foraminifera of, or related to, the genus Vercorsella, whereas orbitolinids, that are otherwise one of the most widely distributed and stratigraphically most useful Tethyan Cretaceous foraminifera, are relatively scarce).

The Upper Cenomanian deposits, which make the youngest outcropping part of that uninterrupted Cretaceous sequence, contain abundant remains of the well-known Tethyan ostreid bivalve, *Chondrodonta joannae Choffat*.

All these carbonate sediments, both Upper Jurassic and Cretaceous, originated in shallow marine (shallow subtidal to intertidal) environments (shoals, sand bars, backreef lagoons, etc.) of the Tethyan south-margin carbonate platforms, situated in a tropical sea, by the accumulation of both carbonate mud and organic (skeletal) remains, resulting in the production of predominantly mud-supported types of limestone (wackestone to mudstone), whereas the grain-supported types (packstone to grainstone), indicating short-lasting phases of more agitated water and probably caused by periodical storms, are much rarer. Such types of sedimentation correspond to what is usually called a continuous (uninterrupted) sedimentation, though several minor gaps, indicated by fenestral structure, vadose features, and black pebble occurrences (Tišljar, 1986; particularly in the Barremian-Aptian part of the sequence), have been recorded. The sedimentation lasted approximately 50 million years or slightly more, the highest outcropping part of that "continuous" sequence just preceding the temporary flooding (drowning) that would spread over the entire Adriatic-Dinaridic carbonate platform at the Cenomanian-Turonian boundary and in the Early Turonian, respectively (probably caused by the global--eustatic—sea level rise; Jenkyns, 1991; Gušić and Jelaska, 1993). We predict that the sediments indicating the Lower Turonian drowning event should be present under the sea surface, in the Mljet Channel, not far from the NE coast, but this remains to be proved.

Only in the most NW part of the island, west and northwest of the Polače bay, and including the islets at the northwestern tip of the island (Glavat, Maslinovac, Moračnik, Ovrata), younger Upper Cretaceous (Upper Santonian) sediments crop out (not shown in Figs. 5.2 and

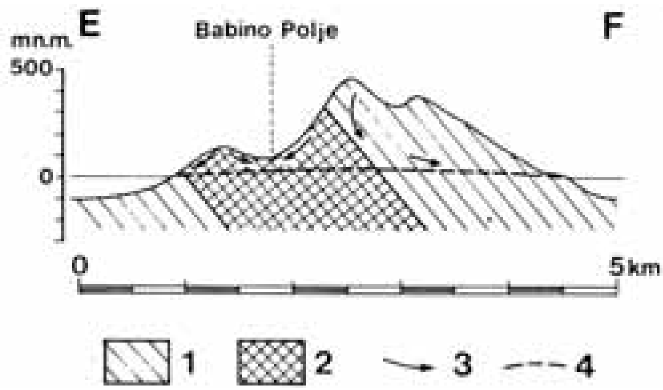


Figure 5.4 - Schematized hydrogeological profile of Mljet Island. Explanation: 1. Mostly limestones, 2. Dolomites, 3. Supposed directions of underground water-flow, 4. Supposed level of underground water.

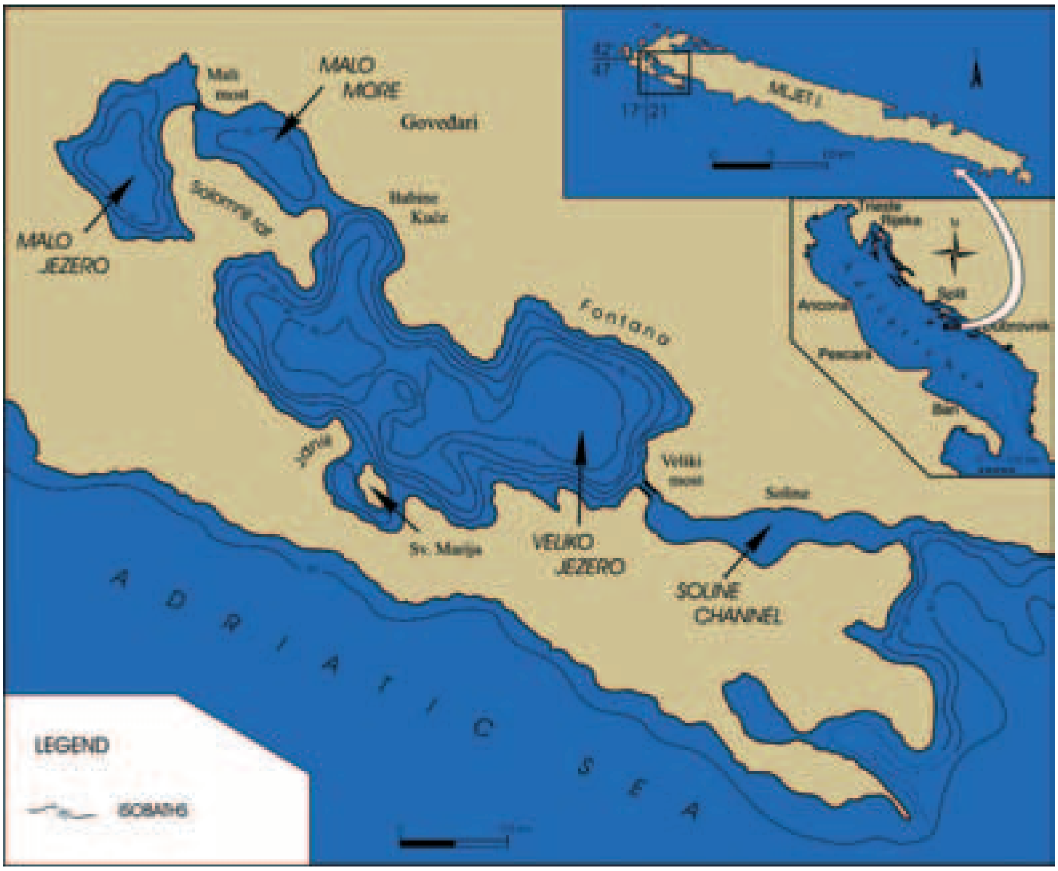


Figure 5.5 - Location and bathymetry of theMljet Lakes (after Vuletić, 1953).

5.3). They are in tectonic (fault) contact with Cenomanian limestones, and they belong to another tectonic unit. Their age has been proved by the presence of the larger benthic foraminifer *Scandonea samnitica*.

In the southeastern part of the island, in the environs of Maranovići, Korita, and especially in the Saplunara and Blaca Coves, there are deposits of quartz sand of Early Quaternary (Pleistocene) age. They are probably of Eolian origin, but were deposited in a shallow water environment. Recent (Holocene) sediments of clay and silt can be found in some karst dolines and uvalas, called Blatina (near Blata, Sobra, and Prožura), or Slatina (near Kozarica), which are periodically inundated.

Structurally, Mljet is a monocline, tilted towards the NE. It represents a northeastern, normal, limb of a southwestwardly overturned fold. From the regional-geologic and tectonic point of view, Mljet belongs to a large overthrust that strikes below the sea in a NW-SE direction, and a few miles southwestwardly from the island, it is thrust over the younger, clastic sediments—Paleogene Flysch and Neogene marine deposits (Fig. 5.3).

Concerning the hydrogeological characteristics, Mljet is built up of highly permeable limestones, and relatively low permeable dolomites (Fig. 5.4). Because of their superpositional layer-cake setting in the middle of the Mljet monocline, the influence of the dolomite upon the underground accumulation of water is negative, and there are no significant springs or surface water flows, nor significant subsurface fresh-water accumulations.

According to the engineering-geological characteristics, the limestones and dolomites are compact, hard, and stable rocks and are clearly distinguished from the sandy and clayey deposits

with their changeable physical qualities.
Mljet is certainly influenced by two epicentral localities: the environs of Dubrovnik and the mouth of Neretva River. Earthquakes of up to VIII MSC (destructive) in the western, and up to IX MSC (ruinous) in the eastern part of the island are possible.

Stop 5.2:

Recent carbonate sedimentation in the lakes of Mljet Island

Mladen Juračić

Veliko and Malo jezero (Large and Small Lake, i.e. Mljet Lakes) are located in the western part of the Mljet Island (Adriatic Sea) (Fig. 5.5). Due to its scenic beauty, ecological peculiarities, and environmental values, this western part of the island was proclaimed a National Park in 1960. The Mljet Lakes are semi-enclosed, relatively deep depressions, connected with the open sea by a narrow, shallow Soline Channel. Being connected with the sea, they contain saline water and, therefore, are not true lakes. However, due to their depth (46 and 29 m respectively), they can hardly be termed lagoons, because the latter are usually defined as *shallow* semi-enclosed water bodies (Phleger, 1969), "having depths that seldom exceed a couple of meters" (Kjerfve and Magill, 1989). Therefore for these, and other similar marine water bodies apparently disconnected with the sea, found along the eastern Adriatic coast (e.g. Mir Lake on Dugi otok, Dragoon (Rogoznica) Lake near Rogoznica), a term ***marine lake*** was proposed (Vaniček et al., 2000).
Most of the water exchange between the Mljet Lakes and the sea under current climatic conditions occurs through very shallow, narrow straits. The Veliki most (*Large Bridge*) strait between the Soline Channel and Veliko jezero is 10 m wide and 2.5 m deep, whereas Mali most (*Small Bridge*), the strait between Veliko and Malo jezero is even smaller: 2.5 m wide, and 0.5 m deep. Tidal currents drive water exchange, and the mixing is constrained only to the surface layer. Due to the summer heating of the surface layer, water stratification develops, which gives rise to temporary stagnant conditions, with hypoxia and even anoxia in the bottom waters (Benović et al., 2000). Therefore, stress producing environmental factors for organisms are encountered (Vaniček et al., 2000; Ćosović et al., 2002).

Lake formation

Lake morphology, along with a knowledge of the geodynamic evolution of the broader area, allows us to reconstruct how and when the lakes originated. Depressions in which marine lakes are located are typical karstic depressions (*dolina* and *uvala*), developed in Mesozoic limestones and dolomites. One can assume a tectonic predisposition of the location of depressions, and a subaeral corrosional process in the development of depressions. Therefore, the formation of deep dolinas (*sinkholes*), occurred while their bottom was above sea level. In the time span since the formation of limestones, there have been several such periods. But, as the corrosional geomorphological processes in limestone terrains are quite fast in humid climatic conditions, it can be presumed that periods in near geological history with lowered sea level had an important role in their morphogenesis.
During Pleistocene, the sea level repeatedly oscillated, and during glacials, was up to 140 m lower than the present level. During the Last Glacial Maximum (LGM), between 30,000 and 19,000 years before present (y BP), the global sea level was approximately 130 m lower than present (Lambeck et al., 2002). Most probably, dolinas in which today's lakes have been formed, were remodelled, if not formed, during last glaciation. In those times, karstic corrosional processes must have been intensive, and sinking water with dissolved carbonates drained underground towards the sea, which was SW from Mljet Island. It has been generally accepted that the sea level rise was very fast and steplike from 18,000 to 6,000 yBP (with an average of 1 cm y^{-1}, but with jumps of over 4.5 cm y^{-1}; Blanchon and Shaw, 1995), while afterwards, the sea level rise attenuated. During Lower Holocene, from 10,000 to 6,000 yBP, conditions were favourable for the formation of Mljet freshwater lakes (similar to the present-day Vrana lake on Cres Island; Wunsam et al., 1999). The seal evel and the groundwater level (i.e. erosional base), rose above the bottom of the dolinas and hindered the subsurface draining of rainwater. Depending on climatic conditions (humid/arid), percolation of freshwater towards the sea or seawater towards

the lakes could occur.
Additional preferable conditions for the formation of marine lakes originated relatively recently (in the last 2,000 to 4,000 years), when the sea level reached approximately its current position, and enabled the surface exchange of water between the lakes and the sea due to tidal currents through the Soline Channel. There is a possibility that the connection between the sea (Soline Channel) and Veliko Jezero, and between Veliko and Malo Jezero was done by men digging the narrow isthmus. New results of the investigation of subbottom sediments in the Soline Channel, indicate that 4600 yBP there were freshwater/brackish conditions in which marshy plants (Chara/Nitella) flourished, and freshwater/brackish snails lived (*Lymnea stagnalis*, *Ventrosia cissana*) (Govorčin et al., 2001).

Sediments and sedimentation in the Mljet Lakes

Sedimentation conditions and sediments encountered in the Mljet Lakes are rather interesting. In Malo jezero, in shallower parts up to a depth of 20 m, coarse-grained (gravelly-sandy) sediments prevail, whereas in deeper parts (up to the maximum depth of 29 m in Malo jezero), fine-grained mud is found (Vuletić, 1953). A similar sediment pattern is also found in Veliko jezero.
The peculiarity of the sedimentation environment in the Mljet Lakes is due to the anoxic conditions. After Vuletić (1953), in water deeper than 19 m in the Malo jezero, no dissolved oxygen, but dissolved H_2S was found. However, during subsequent investigations, anoxic conditions in the water column were not encountered. It indicates the episodic formation of anoxia. In the sediment core from Malo jezero, a microlamination with alternating dark and white laminae (up to 7 pairs in 1 mm!) was found. Vuletić (1953) was the first to register them, and afterwards they were described in detail by Seibold (1958). Both of them believed that those were varve, i.e. that one pair of laminae corresponds to one year.
Dark laminae have elevated concentrations of organic matter (organic detritus, presumably of terrestrial origin) and pyrite (FeS_2) (Vuletić, 1953). Such sediments are characteristic for sedimentation in anoxic conditions in the water column. Seibold (1958) presumed that they were deposited during autumn and winter when rainwater washes away terrigenous plant material.
However, a sedimentation rate of 2.6 mm/y presumed after ^{137}Cs distribution i8n sediment from Malo jezero, indicates that laminae were formed episodically, not necessarily seasonally, but as a consequence of discrete episodic events (e.g. phytoplankton bloom, heavy rain).
Today, in the water column in Veliko jezero, oxic conditions prevail (however, with instrumentally registered episodic hypoxic and anoxic events), whereas deeper in the sediment core ,microlamination has been registered. It indicates that in former periods, anoxic events occurred more frequently. Vuletić (1953) calculated a sedimentation rate of 1.03 to 3.17 mm/y in Veliko jezero using tephra layers, which is in range with the presumed sedimentation rate of 2.6 mm/y in Malo jezero.
Other interesting sedimentation characteristics in the Mljet Lakes is the origin and nature of white laminae found in alternation with dark laminae in sediments. The first investigations of the Mljet Lakes sediments (Vuletić, 1953), indicated the existence of aragonite, and presumed that white laminae consist of aragonite mud ("drewit") formed by single crystals, and that the deposition of aragonite is restricted to the Malo jezero only. Aragonite deposition was connected with H_2S saturated water. However, Seibold (1958, p 109) refuted Vuletić, and according to the x-ray diffraction analysis, stated that the mineral present was calcite, and in rhomboedric crystals 8 μm long. New investigations confirmed that white laminae are composed of aragonite crystals, presumably precipitated during so called "whitings" of lake (sea) water. Aragonite needles were found in suspended matter samples both in Malo and Veliko jezero. However, along with aragonite needles, different calcite and Mg-calcite biogenous fragments were found in the sediments.
Aragonite deposition, up to now, has been registered only either in tropical and subtropical seas (Bahamas, Florida, Persian-Arabic Gulf), or in alkaline freshwater lakes (Thompson et al., 1997). The long-lasting dilemma (Shinn et al., 1989), is whether precipitation of aragonite

needles is physico-chemicaly induced (*e.g.* Milliman et al., 1993) or biologically governed (*e.g.* Stockman et al, 1967; Thompson and al., 1997).

Another peculiarity of the sedimentation in the lakes indicating warm water influence is a large recent colony (aprox.600 m^2) of coral *Cladocora ceaespitosa* that makes a coral bank (reef). It is located at the entrance to the Veliko jezero at depth of 5 to 10 m.

In the shallow channel area (Soline Channel) on the sea bottom, biogenous, well-sorted carbonate sand is found, which forms symmetrical ripples, with a "wavelength" of 3-6 m. They are formed most probably due to relatively strong tidal currents in the channel. In the open marine environment at the entrance to the Mljet Lakes at a water depth of 38 m, coarse-grained, biogenous, very poorly sorted sand (with a substantial share of fragments larger than 2 mm) is found. It rests on the seabottom below wave base.

One can conclude that the sedimentation rate in the Mljet lakes is relatively high (sediment cover exists on the whole bottom, excluding only the submarine elevation NE of Sv. Marija islet). Coarse-grained, prevalently biogenous sediments prevail in the shallower and coastal zone, whereas in deeper parts, the accumulation of mud, of both biogenous and terrigenous origin, occurs.

In order to obtain the whole picture of recent and subrecent sediments in Mljet lakes, it would be necessary to make subbottom profiling to determine the thickness of the Holocene sediments, and find out if older Pleistocene sediments exist in deeper parts of the lakes.

DAY 6

City of Dubrovnik

The city of Dubrovnik is situated in the very south of the Republic of Croatia. The favourable geographical position of Dubrovnik has made its development based on maritime and trading activities very successful throughout its history. New archaeological excavations have proved that the settlement in the foundation of today's city existed in the 6th century or even earlier. The intensified traffic between the East and the West during and after the Crusade wars in the 12th and 13th centuries, induced the prosperity of maritime and mercantile centers in the Mediterranean and the Adriatic, and Dubrovnik was one of them. During the 15th century, Dubrovnik became the most significant seafaring and mercantile center in the Adriatic, third only to Venice and Ancona.

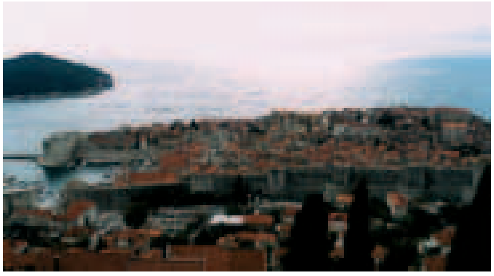


Figure 6.1 - The city of Dubrovnik.

A small sovereign state without an army brought its defensive system to perfection by skilful diplomacy and wide consular activities. The 16th century was the golden age of the Republic of Dubrovnik, as the splendour and power of the Venetian Republic declined. Dubrovnik reached an impressive level in its urban and architectural development, which has been sustained to the present day.

In the 17th century, a general crisis in maritime affairs in the Mediterranean and a disastrous earthquake, forced the Republic of Dubrovnik to fight for its existence and for political protection of its sovereignty. In the 18th century, Dubrovnik found an opportunity for economic revival in sea faring trade under a neutral flag, before the arrival of Napoleon and the fall of the Republic of Dubrovnik in 1808. At the Congress in Vienna in 1815, the region of Dubrovnik became a part of Dalmatia and Croatia, and it has been sharing the same political destiny with them ever since.

Following the proclamation of independence of the Republic of Croatia and the Serbian aggression in Croatia, Dubrovnik was attacked in October 1991. Today the cultural and historic heritage of Dubrovnik, which was barbarously damaged during the aggression, has been mostly renovated.

Dubrovnik has preserved the beauty of a medieval town (Fig 6.1). Its outstanding cultural and historical monuments have earned it a place on UNESCO's World Heritage List.

Stop 6.1:

The spring of the Ombla

Renato Buljan and Tomislav Paviša

The spring of the Ombla (Fig. 6.2) is the largest karst water object in the southern Adriatic region. It yields more than 139 m^3/s of perfectly clear water, which provides for municipal supply, and a future hydroelectric power station. Just for comparison, the total water consuption in Israel is not more than 70 m^3/s. This typical karst spring occurs on the boundary between Mesozoic carbonate rocks wich thrust onto a thick Eocene flysch complex. The flysch beds in the spring area are eroded to sea level, and Ombla is at the lowest point. The flysch beds laterally to the east and west rise more then 150 m above sea level. The spring area of Ombla consists of three zones of concentrated discharge: Glavni izvor (The principal spring), Baba, and Crkvica; the principal spring yields 80% of the water discharged at Ombla. During low water levels, the springs function independently and the water is discharged at different levels.

After the construction of the hydro-system at Trebišnjica, the surface area of the Ombla spring catchment is about 600 km^2 (Milanović, 1977). The largest part of the catchment contains numerous shallow sinkholes, and the remnants of ponors (swallow holes), pits, and fissures, which enables direct infiltration of rainwater into the underground. The average annual yield of the Ombla spring area is Qsr=24.4 m^3/s. The minimum yield measured was Qmin=3.0 m^3/s, and the maximum Qsr=138 m^3/s (Žugaj and Bonacci, 1994).

The terrain of the Ombla catchment basin consists of Upper Triassic; Jurassic, Cretaceous, and Eocene carbonate rocks, Eocene flysch deposits, and different types of Quaternary deposits (Marković, 1971). Carbonate rocks prevail in the catchment area. They have a typical Dinaric strike and bed inclination towards the NE, with dip angles from 20°- 50°. In a hydrogeological sense, it is possible to differentiate a complex of very permeable carbonate rocks, with fissure-dissolution porosity with a sporadic occurrence of dolomitic layers and a complex of impermeable clastic flysch rocks which function as a full barrier.

One of the major problems was the determination of the directions of the groundwater flow through which the supply of water from the hinterland to Ombla occurs. Since the tectonic and structural framework in a lithologically uniform environment have a major impact on the formation of the subsurface channel network, it was necessary to determine the structural relationships prior to the hydrogeological relationships.

The regional structures have a strike ranging from NNW-SSE to NW-SE. The position of the deposits, and the reflections of the faults on the surface, indicate reverse faulting-thrusting near-surface structural relationships. The structure is dominated by the thrust contact of the regional structural unit of the Dinaricum onto the Epiadriaticum (Herak, 1991). Behind the crest of the nappe, the concordant succession and the monocline bed inclination towards NE, distinguish the structural unit Hutovo-Slano-Brgat (Prelogović et al., 1994; Fig. 6.3). The Ombla catchment basin is situated within this unit. The major feature of the unit is faulting. Besides the major role of the series of reverse faults, which determine the individual structures, of prime importance are transcurrent faults, with dextral tectonic displacement towards the SE along the fault zones of the Slivnicki fault and Zubački fault, and the relatively wide fault zone striking NE-SW along the line Ombla - Hum. Sinistral tectonic transport of the zone is evident. The

Figure 6.2 - Front of the overthrust above Ombla spring.

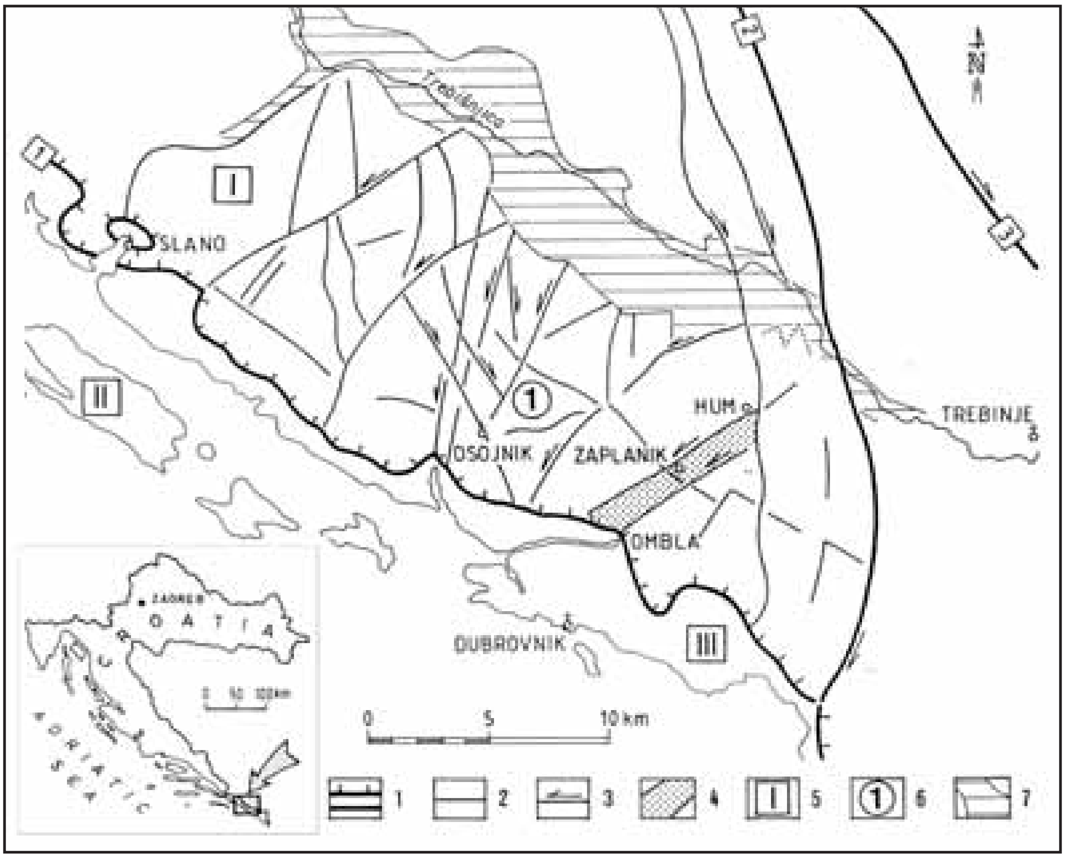


Figure 6.3 - Regional structural sketch.
1. the most important faults of the regional structural fabric: fault of the front of the overthrust of the Dinaricum (1), Slivnica fault (2), Zubak fault (3); 2. others more important faults; 3. faults with marked displacement; 4. zone Hum-Ombla; 5. Dinaricum (I), Adriaticum (II), Epiadriaticum (III); 6. structural unit 1. the The most important faults of the regional structural fabric: fault of the front of the overthrust of the Dinaricum (1), Slivnica fault (2), Zubak fault (3); 2. other more important faults; 3. faults with marked displacement; 4. zone Hum-Ombla; 5. Dinaricum (I), Adriaticum (II), Epiadriaticum (III); 6. structural unit Hutovo-Slano-Brgat; 7. extension zone.

fault zone Hum-Ombla consists of several parallel faults, and their branches with a general strike direction 50°-230° and a steep to opposite (antitectic) fault plane dip angles from 70° - 85°. It cuts through the reverse faults, and reaches the crest of the Dinaricum knappe. This type of tectonic kinematics, together with the favourable orientation in regard to the regional stress (12°-192° direction) and the prevailing sinistral tectonic dislocation, permitted the continuous extension of the Hum-Ombla fault zone, the contraction and subsidence of individual segments along the series of faults with antitectic inclination thus forming an extensional duplex structure (Davis, 1984).

The hydrogeological, geophysical and hydrological indicators show that most of the groundwater from the hinterland is drained into the Hum-Ombla fault zone. This zone is the main drainage area of the studied hydrogeological system, through which concentrated water flow under pressure occurs towards the Ombla spring area (Buljan, 1999). The hydrological analysis of the H-Q diagram, show that the underground retention area of the Ombla hinterland can also be divided into two parts, in accordance with the

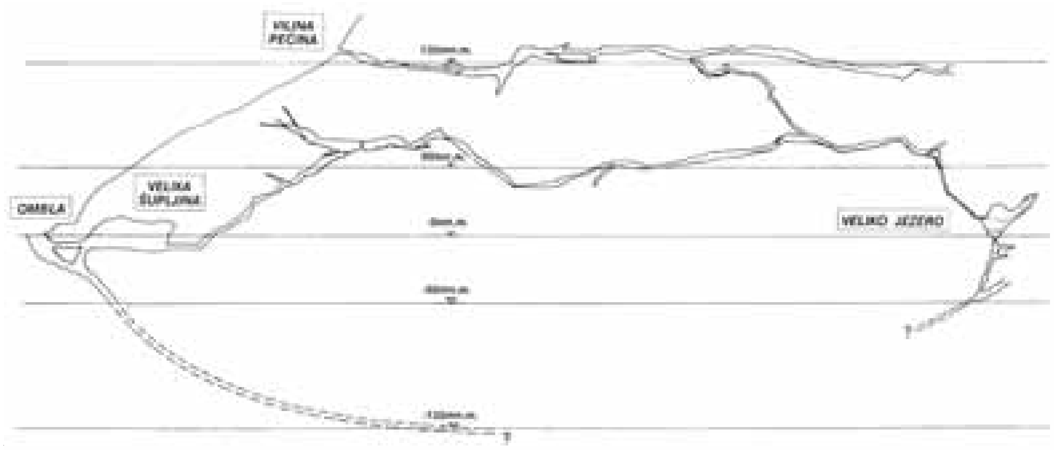


Figure 6.4 - Discovered levels of karst cavities in theOmbla spring hinterland.

The area upstream from Zaplanik consists of an underground area, in which large quantities of water are accumulated through laminated flow. After the construction of the retention in the Ombla hinterland, this area should form an underground reservoir. The area downstream from Zaplanik is a narrow, deeply karstified area (the Hum-Ombla fault zone). Due to the existence of karst channels between this area and the discharge zones, restricted groundwater flow shows pressurised turbulent flow characteristics (during high waters up to 50 cm/s; Paviša, 1998).

The position of the Ombla spring area is structurally predisposed. The spring area occurs within an extensional duplex structure at the intersection of the Hum-Ombla fault zone, and the crest of the nappe that consists of carbonate and flysch rocks. Due to permanent neotectonic uplifting of the carbonate rocks in the Dinaricum nappe crest zone, and the erosion of flysch rocks, the discharge zone was lowered to sea level.

During the study of the terrain in the spring hinterland, it was necessary to determine the karst water channel directions towards the spring area. The dominant channel in the hinterland of the spring area has siphon morphology. It is an up flow spring. Speleological investigations were performed to the depth of -35 m (Krašovac, 1985). Behind the spring there is a large spring cave (80 m long, 40 m wide and 8 m high), which is the direct hinterland of the spring. The four main conduit levels in the crest of the Dinaricum nappe (Viline pećine-caves and active water channels; Fig. 6.4) occur in the Pločice fault zone (Fig. 6.5). In the immediate vicinity of the spring, the active water transport conduits are located below the discharge zone, and reach depths of up to -150 m below sea level. It is presumed that all the conduits are connected in the vicinity of the spring zone. Spelaeological investigations so far have not proven this completely, but there is a considerable air current through the discovered channels.

The idea for the design of an underground dam and reservoir in the Ombla hinterland was facilitated by the annual yield of Ombla, and the porosity and the permeability of the catchment carbonate complex. The existence of the laterally occuring impermeable flysch complex, which rises above the planned dam height, is of key importance, since retention of the reservoir could be attained. The construction of the dam will cause the groundwater level to rise. The reservoir will contain conduits, channels connected with fault systems, fissures and other phenomena connected with karstification. The dam profile is planned some 200 m within the carbonate rock mass to a height of 130 m above sea level, i.e. to the maximum height of 410 m above the lowest contact between the carbonate rocks with flysch deposits and the top of the dam, and a length of over 1000 m. The lateral foundations of the dam will be positioned within flysch deposits, which are located up to 300 m above sea level to the east and to the west of the spring zone. All

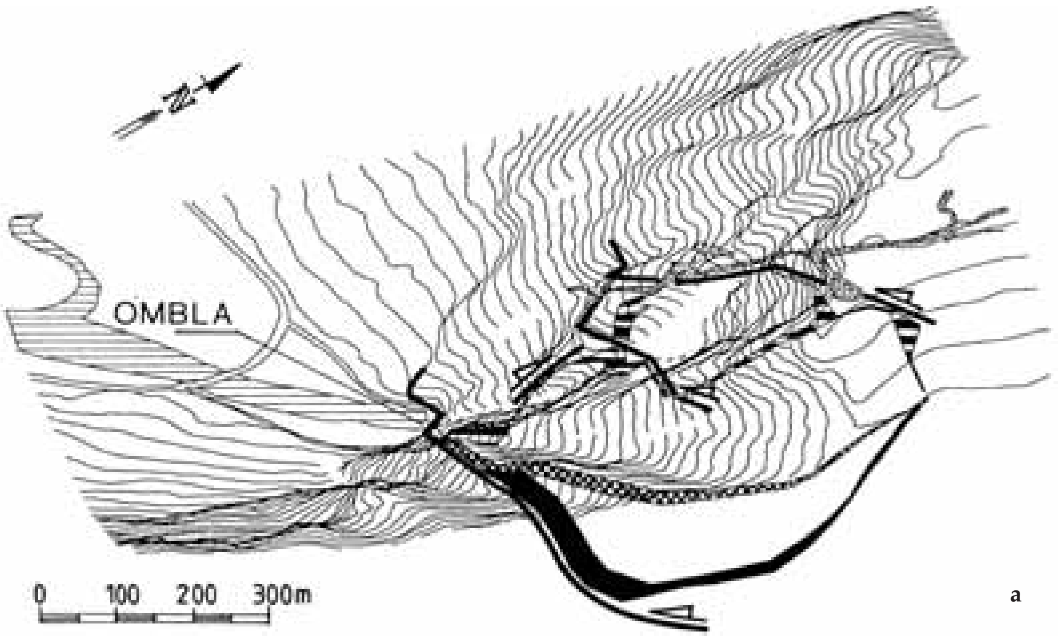


Figure 6.5 a,b - The comparision of the Pločice fault zone position and four levels of subsurface cavities.

the vital power plant facilities are also planned below the surface, in order to preserve the natural landscape as much as possible.

The design of the Ombla hydroelectric power plant (Sever, 1998; Fig. 6.6), is based on the principle of a groundwater pressure rise due to the construction of an artificial backwater in the underground. The backwater will be constructed with the aid of a grout curtain, performed from three grout-injection galleries, at elevations 5, 65, and 134 m above sea level. Furthermore, spatial concrete plugs are to be constructed in all active and fossil channels. In the upper course, the groundwater level will rise above its natural elevation. This retention concept is based on the fact that according to the permeability measurements of the rock masses, and the flow measurements, the rocks along the profile of the curtain are of low permeability and that more than 90% of the water flows through the main influent channel to the discharge zone. The water level in the reservoir through most of the year will be at 130 m above sea level. During the dry season, minimum flow falls below 4 m^3/s, the water level is expected to drop to 70 m above sea level (Jović, 1997).

The uniqueness of the design of this power plant is that the influent channel connects the waters from the power plant with the main influent channel of Ombla in the lake Veliko jezero, 300 m upstream from the profile of the grout curtain (Fig. 6.6). The evacuation of high waters will be performed through the basic outlet, with two cone plugs each of which can give passage to the maximum centennial flow, and the waters from the turbines will be discharged into the spring cave. All other facilities have some special characteristics, but in general they have the basic

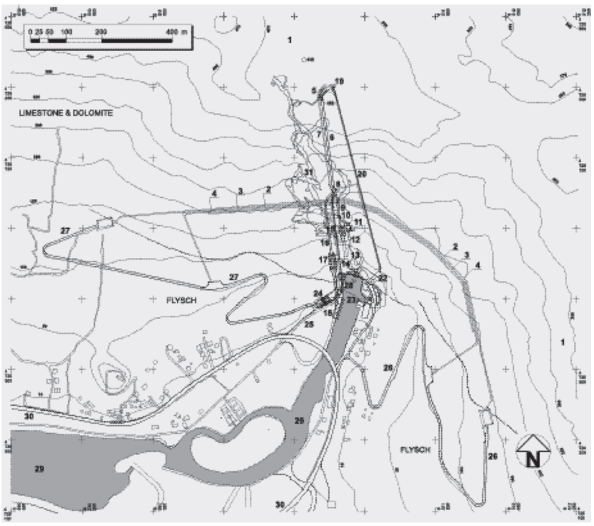


Figure 6.6 - Review sketch of the Ombla power plant facilities:
1. underground reservoir; 2. grout curtain and gallery no. 1; 3. grout curtain and gallery no. 2; 4. grout curtain and gallery no. 3; 5. intake structure (for HPP) in Large cave; 6. headrace tunnel; 7. intake structure access tunnel; 8. vertical shaft; 9. penstock; 10. penstock gate house; 11. power house; 12. tailrace tunnels; 13. powerhouse spillway in Spring cave; 14. access tunnel; 15. switchyard and transformers; 16. bottom outlet tunnel; 17. bottom outlet gate house with dissipation chambers; 18. bottom outlet spillway chamber; 19. water supply intake structure in Large cave; 20. water supply tunnel; 21. water supply intake tunnel in fossil cave; 22. pumping station; 23. Spring pond; 24. control building; 25. access road to the HPP; 26. left flank access road; 27. right flank access road; 28. parking lot and access platform; 29. Rijeka Dubrovačka; 30. Adriatic highway; 31. fossil cave.

properties of classical subsurface hydro-energetic facilities. The Ombla hydroelectric power plant Ombla will consist of four production units with accompanying objects. Two of them have Francis turbines, with a flow of Qi=24 m^3/s, and synchronic generators of 30 MVA, and two with flow of Qi=6 m^3/s, and generators of 8 MVA. During an average hydrological year, the production of 223 GWh of electric power is expected.

The construction of the underground reservoir, besides the production of electric power, will allow a more economic and better water supply of Dubrovnik and its surroundings without the aid of pumps, and will reduce the problems with water turbidity during high waters.

Stop 6.2:

The bridge over the Rijeka Dubrovačka

Vladimir Jurak and Slobodan Šestanović

The bridge over the Rijeka Dubrovačka is designed as a suspension bridge, with a 141.50 m high pylon as the main support. The total length of the bridge, complete with the abutments, is 518.23 m, and total width between the cornices is 12.60 m while the height from the sea level to the bottom of the supporting structure is 50.30 m at the midspan (Fig 6.7).

The location of the bridge over Rijeka Dubrovačka and the access road on its west side is built of carbonate rocks. The following rocks have been determined: Senonian rocks, consisting of stratified limestones and massive dolomites on the west side of the bridge; on the east side of the bridg,e the upper part of Senonian (Maastrichtian) has been determined, and is represented by: massive dolomites, massive limestones and dolomites in alternation, massive limestones with Rudists, and platy limestones and dolomites in alternation. The Palaeocene-Eocene rocks (Pc, E), contain kozinias, miliolitic, alveolinic, and nummulitic limestones (Fig. 6.8).

The investigated area belongs to a regional structural (morphostructural) unit of the Adriatic. According to recent findings, interlayer faults and tectonic narrowing of the area, represented by an overturned fold, can be interpreted as the consequence of stress during the subduction of Adriatic micro-plate under the Adriatic.

If GSI is applied for the engineering-geological classification of the rock mass for foundation purposes, the following can be concluded: the fault zone and the surface zone (weathered surface, in places up to 4,50 m thick), have GSI from 20 to 40, and are therefore classified as the rock mass of poor quality.

Figure 6.7 - The bridge over the Rijeka Dubrovačka.

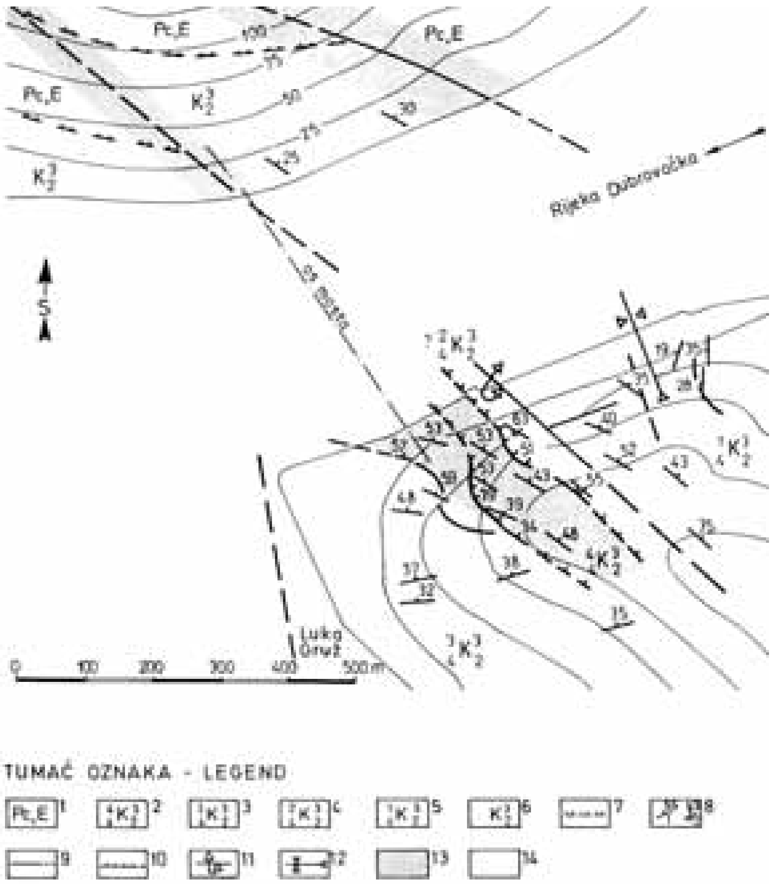


Figure 6.8 - Schematic Engineering-geological Map (geology from: Jurak et al. 1989). Legend: 1. Kozinias, miliolidic, alveolinic, and nummulitic limestones; 2. Platy limestones and dolomites in alternation; 3. Massive limestones with Rudists; 4. Massive limestones and dolomites in alternation; 5. Massive dolomites; 6. Stratified limestones and massive dolomites; 7. Geological boundary – transgressive; 8. Dip of bed (1 normal, 2 overturned); 9. Fault; 10. Reverse fault; 11. Overturned anticline; 12. Part of brachysyncline; 14. Geological Strength Index 20-40 (poor: fault zones); 15. Geological Strength Index 60-80 (good).

Platy limestones and dolomites in alternation, have GSI between 40 and 60, and are classified as rock mass of fair quality. Limestones with Rudists, layered limestones and massive dolomites, and Palaeocene-Eocene limestones (Pc,E), have GSI between 60 and 80 (good quality).

The area of Dubrovnik is located in a zone for which, with 63 % probability, the maximum earthquake intensity of 9 grades of the MCS scale is expected in a recurrent period of 500 years. For seismic calculation of the bridge structure, the maximum average, acceleration of 0,35 g for the east bank and 0,38g for the west bank are adopted.

According to the study conducted by the Hydrometeorological Institute, the expected maximum velocities of bura (north-eastern wind), north-western wind and sirocco are 50 m/s, 38 m/s and 33 m/s, respectively.

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Back Cover:
field trip route.

FIELD TRIP MAP

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