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DAY 3

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

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

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VELIKA PAKLENICA CANYON, OUTLINE OF GEOMORPHOLOGY AND GEOLOGY

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LEGAL STATUS

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

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

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

GEOMORPHOLOGY

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

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

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

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

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

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

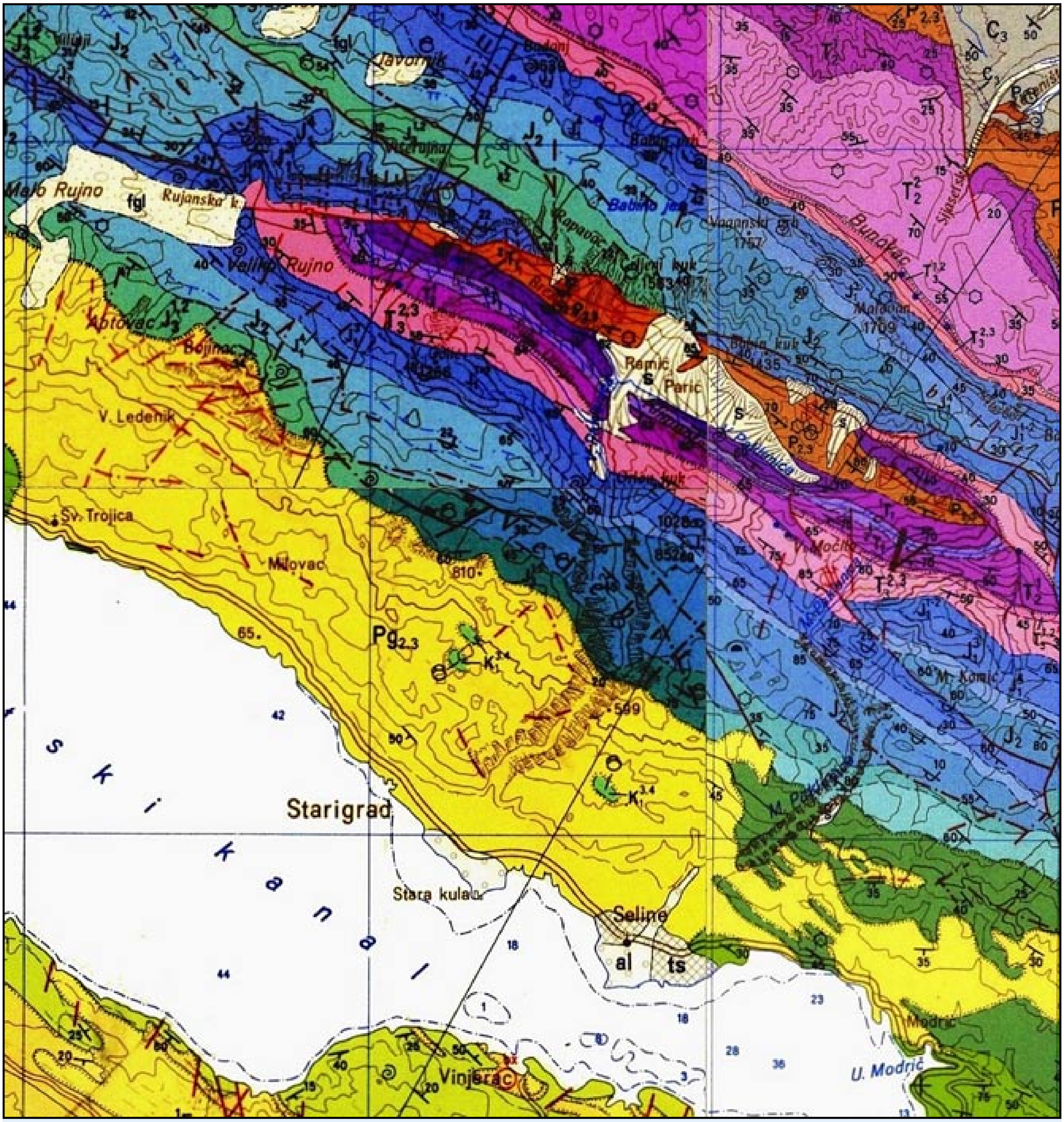

Fig. 14: Geological map of the wider area of Paklenica 1:100.000 (from the General Geological Map sheets Gospić and Zadar (Majcen et al. 1973, Sokač et al. 1976).

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

GEOLOGY

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

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

PALEOZOIC
(J. S.)

Permian

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

MESOZOIC

Triassic

The Early Triassic mixed clastic and carbonate rocks continuously overly the Permian Transitional dolomite. In clastic intercalations typical Scythian fauna was found, including the bivalves *Anodontophora fassaensis*, *Pseudomonotis* (*Claraia*) cf. *tridentata* and *P.*(*C.*) cf. *kittlii*. Source of the clasts is combined – terrestrial and marine. Silicate grains are often cemented with dolomite. Ferrous oolites occur sporadically. Ripple

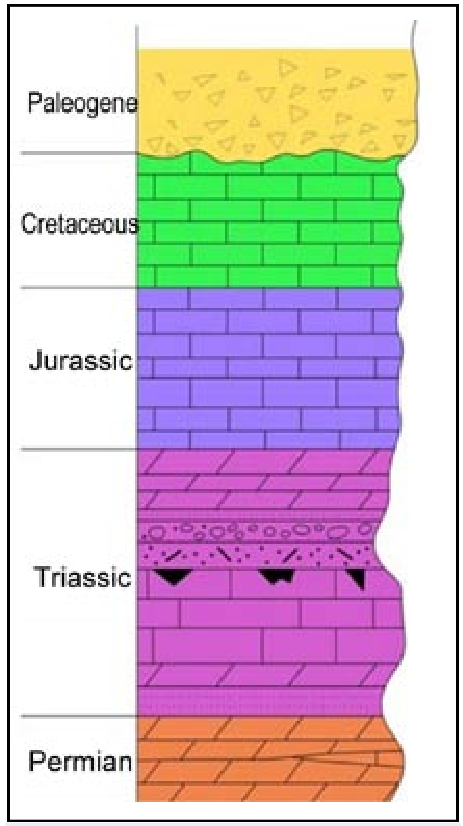

Fig. 15: Schematic geological column of the area of the National Park Paklenica.

marks and cross-lamination in these rocks are typical for a very shallow and turbulent marine environment. Sea-level rise lead to the change in the mode of deposition. Campilian dolomites contain amonites, but the amount of the terrestrial component in these rocks is still high.

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

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

Jurassic

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

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

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

Cretaceous

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

CENOZOIC

Tertiary
(T.M.)

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

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

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

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

Quaternary

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

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

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

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

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


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

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

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

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

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


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

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

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

SELECTED EXAMPLES OF GEOHERITAGE

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

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

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

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

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

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

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

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

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

STOPS

1

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

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

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

Fig. 21: Refurbished old water mill.

2

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

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

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

Fig. 23. Ice-wedge cast infill.

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

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

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

3

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

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

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

STARIGRAD - RAB

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

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

Fig. 26: Ferryboat route from Jablanac to Rab.

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

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

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