FIELD TRIP A3
WHITE ISTRIA

FIELD TRIP A3 – WHITE ISTRIA (PLATFORM CARBONATES, ARCHITECTURAL-BUILDING STONE)

Damir Palenik[1], Igor Vlahović[2], Ladislav Fuček[1], Aleksandar Mezga[3], Bojan Matoš[2], Dubravko Matičec[1], Darko Matešić[2]

[1] Croatian Geological Survey, Sachsova 2, 10 000 Zagreb, Croatia
dpalenik@hgi-cgs.hr; lfucek@hgi-cgs.hr

[2]University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, 10 000 Zagreb, Croatia
igor.vlahovic@rgn.unizg.hr; bojan.matos@rgn.unizg.hr; darko.matesic@rgn.unizg.hr

[3] University of Zagreb, Faculty of Science, Department of Geology, Horvatovac 102b, 10 000 Zagreb, Croatia
amezga@geol.pmf.hr

INTRODUCTION

Based on the geological structure and different soil types, KREBS (1907) divided Istria into three large-scale units: White Istria, Gray Istria and Red Istria, based on historical Italian names *Istria bianca*, *Istria grigia* and *Istria rossa*. That division has remained widely accepted until today.

The term White Istria refers to the areas of Ćićarija Mt. and Učka Mt. in the northeastern part of Istria, as an elevated, karst dominated area predominantly built of light-coloured Cretaceous and Palaeogene limestones. The Gray Istria is the central part of Istria, which represents a depression filled with turbidite deposits (Pazin Flysch Basin), while the Red Istria represents the southwestern and western part of the Istrian peninsula, whose red colour in the name is due to the relatively large amount of red soil (*terra rossa*) that covers the Jurassic, Cretaceous and Palaeogene carbonate rocks.

Besides the White Istria (Učka Mt. and Ćićarija Mt.), the field trip A3 includes two stops that, according to the aforementioned division, belong to the area of Red Istria – Stop 1 (Kirmenjak Quarry) and Stop 5 (Fantasia Quarry), two well-known quarries in the area of the Western Istrian Anticline. The Kirmenjak Quarry represents the largest and stratigraphically oldest site of dinosaur tracks in Croatia found within stylolitized limestones of the Upper Tithonian age. The Fantasia Quarry, protected as a Geological Natural Monument, represents a unique example of the alternation of genetically different types of Lower Cretaceous dolomites with very well-preserved textures and structures.

STOP 1 – KIRMENJAK QUARRY: DINOSAUR TRACKSITE

Aleksandar Mezga, Damir Palenik, Ladislav Fuček, Igor Vlahović

Introduction

Nearly all the remains of dinosaurs on the Adriatic Carbonate Platform (AdCP; remains of which are now cropping out along the NE coast of the Adriatic Sea and its hinterland) are from Cretaceous deposits of the Istrian peninsula. Istria is located on the NW part of the Croatian coast, covering an area of app. 3000 km^2. Among those remains are numerous dinosaur footprints and bones. Although the AdCP was formed as an independent paleogeographic unit during the Early Jurassic (VLAHOVIĆ et al., 2005), there are no dinosaur finds older than Late Tithonian. The sauropod track records on the AdCP include numerous sites from the Upper Albian and Upper Cenomanian deposits. The main feature of AdCP sauropods is their small size when compared to other Cretaceous ichnites (DALLA VECCHIA, 2002), with pes length rarely exceeding 40 cm. Only narrow and medium-gauge sauropods have been recorded on the AdCP so far, with no evidence of gregarious behavior or parallel trackways.

The Kirmenjak dinosaur locality is situated in the Kirmenjak quarry, about 2 km to the south of the Sv. Lovreč–Poreč road, near Kirmenjak village in western Istria. It represents the largest site with dinosaur tracks discovered on the AdCP so far (MEZGA et al., 2007). There are two separated outcrops with footprints located on the formerly active quarry front. The distance between them is about 1 km but they belong to the same trackbearing layer (MEZGA et al., 2017). The northern outcrop (Kirmenjak I) is larger and contains majority of the footprints (Fig. 1) while the southern (Kirmenjak II) has some slightly larger tracks (Fig. 2). The locality is now under the formal protection by the Croatian Government.

Geological setting

The locality belongs to the lower part of the Kirmenjak unit, i.e., to the lowermost part of the second Istrian megasequence according to the presence of black pebble breccias at the site (VELIĆ & TIŠLJAR, 1988). Several shallowing-upward cycles from 0.5 to 1.5 m in thickness can be distinguished. The shallowing-upward cycles usually begin with black pebble breccia or mudstones, followed by fenestral mudstone, and usually end with peloidal packstone/grainstones and grainstones. Dinosaur

Fig. 1. Exposed surface with the dinosaur footprints (Kirmenjak I)

Fig. 2. Kirmenjak II outcrop with the sauropod footprints

footprints were imprinted on top of the shallowing-upward cycle in intertidal fenestral mudstones capped with a thin peloidal packstone/grainstone layer and overlying subtidal mudstone. The formation and preservation of footprints was favoured by a short duration of exposure of muddy sediment and its rapid burial underneath more mud. The oscillatory transgression over the emerged relief marked the beginning of the deposition of the Kirmenjak unit. Depositional transition in the lowermost parts of palaeorelief indicates fresh-water conditions at first, followed by the brackish environments (VLAHOVIĆ, 1999). Deposits in the lower part of the Kirmenjak unit indicate the presence of marsh environments which represent the source for the black pebble breccias (VLAHOVIĆ, 1999). Marshes were gradually replaced with shallow, protected lagoon environments surrounded by wide tidal flats. The dinosaurs walked across these wide tidal flats leaving their footprints.

Ichnology

A total of 971 footprints were registered on the Kirmenjak I outcrop (Fig. 3). Among them, 161 constitute 23 trackways while the others occur individually or in groups. The potential of discovering new tracks is even greater since the quarry front could progress even further in the hillside and expose the new potential areas of trackbearing horizon. The footprints are preserved as imprints (*epichnia* or negative epirelief). There are two different types of footprints discovered on the site – larger circular–elliptic ones and smaller semicircular, horseshoe-shaped ones. Regarding the fact that both types occur within same trackways, it could be concluded that they belong to the same animals. On most of the footprints an expulsion rim is visible, representing compressed waterlogged sediment squeezed from the print by the weight of the dinosaur. Such rims are usually more prominent than the footprints itself and they protect the prints from being obliterated by erosion.

All the footprints at the site belong to the same type of dinosaurs. The arrangement of the footprints in the trackways and their differences in the size and shape

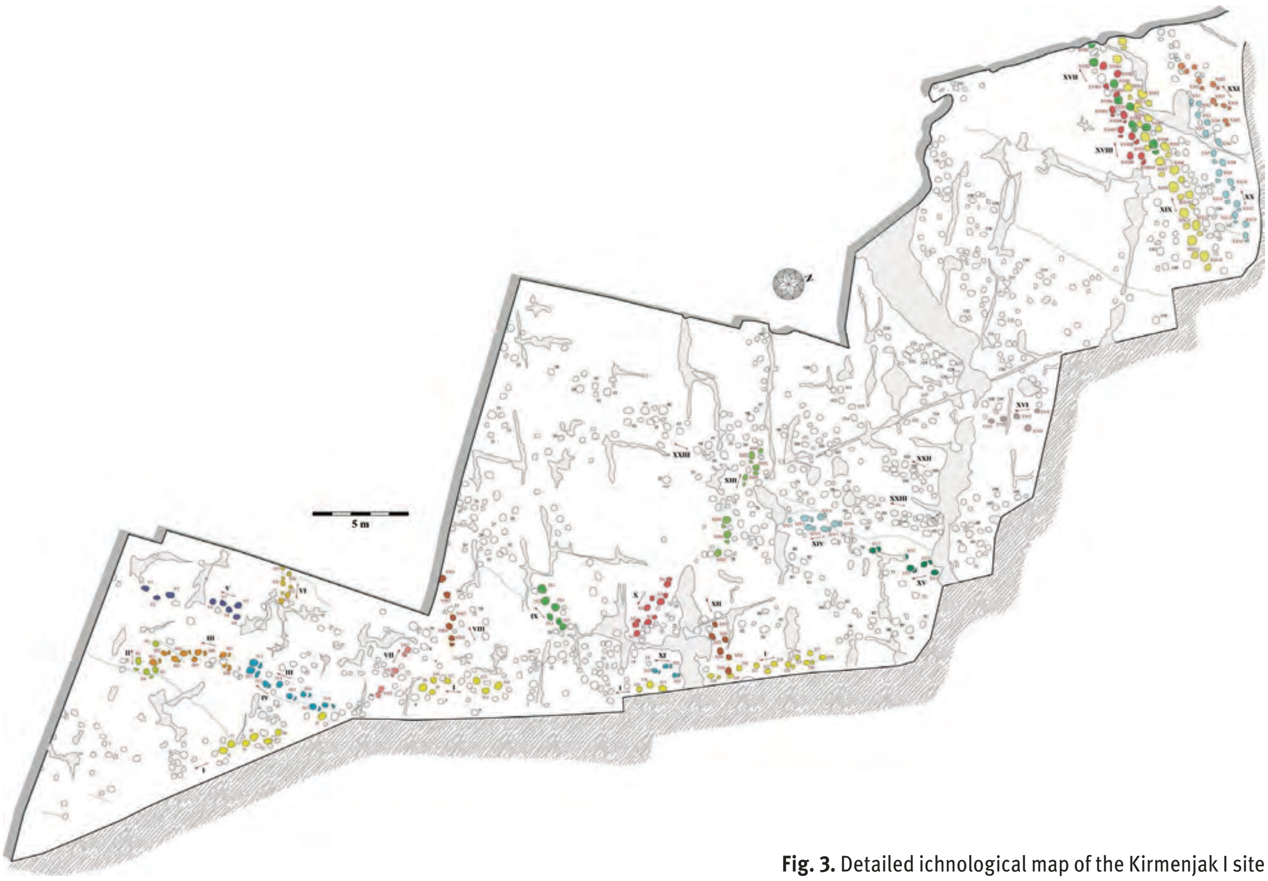

Fig. 3. Detailed ichnological map of the Kirmenjak I site

clearly indicate that the trackways were left by quadrupedal animals. The smaller semicircular footprints represent the manus prints and the larger circular ones the pes prints (Fig. 4). The footprints are attributed to sauropod dinosaurs based on their morphology. The footprints are relatively shallow when compared to their overall dimensions. Although numerous, the state of footprint preservation is far from ideal. In fact, it is difficult to find a footprint with clearly pronounced morphology where the digit impressions would also be recognizable. A large number of footprints are infilled with the sediment that further complicates the recognition of their morphology. When compared to the average size of the Late Jurassic sauropod footprints (e.g., FARLOW et al., 1989; THULBORN, 1990), the Kirmenjak footprints are relatively small, with an average size of 34.5 cm for the pes prints. Manus prints are semicircular to semilunate in shape, wider than long, with the longer axis almost perpendicular to the midline of the trackway. The length of the manus ranges from 5.5 to 26.5 cm with average of 14.2 cm. The manus width ranges from 15 to 29 cm averaging 21.5 cm. The manus prints are wider than long because of the collapse of the footprint margin, which occur anteroposteriorly, causing deformation along its length. Pes prints are oval or elliptical in shape, anteroposteriorly elongated with a somewhat narrower 'heel' impression. The length of the pes prints ranges from 23 to 52 cm with an average of 34.5 cm while their widths range from 18.5 to 43 cm averaging 29.1 cm. None of the pedal prints bears clearly visible digit impressions.

Fig. 4. A couple of sauropod footprints from the Kirmenjak I site. Larger, circular print, represent the pes print and the smaller semicircular, the manus print.

Twenty–three trackways are recognized on the Kirmenjak I outcrop. There are also numerous groups of footprints on the site in which the trackways of several individuals overlap but the precise allocation of single prints to a specific individual is difficult. Trackways in the northern part of the site are especially interesting because they are closely spaced, parallel and have nearly identical orientation. These trackways are better preserved than the other trackways and they also have a greater depth. Because of the same state of preservation and the same direction it could be assumed that the individuals moved through this area in a small-time span or even together. All the trackways in the Kirmenjak quarry are of the narrow-gauge type where the internal trackway width rarely exceeds 10 cm. This excludes titanosaurians but not diplodocoids as possible trackmakers.

Discussion

The footprints found in Kirmenjak quarry are generally shallow for their dimensions which implies that the carbonate mud in which they were formed was rather solid and hard, with greater imprint resistance. Clearly visible expulsion rims around the tracks verify their preservation as true tracks. The relatively shallow depth of Kirmenjak tracks does not necessarily mean that the substrate on which the dinosaurs have walked was dry and exposed to atmospheric conditions; instead, they could have been formed under the water level where the sediment was more saturated by water. The footprint depths increase from the southern to the northern part of the outcrop, what could reflect the different water saturation of the substrate or a longer exposure to erosion. Obviously, all of the tracks at the outcrop were not formed at the same time. Those which were formed first are more eroded than the tracks which were formed among the last.

According to the calculated parameters, the smallest sauropods on the site were about 7.5 m in length while the largest individuals attained some 14.5 m in length. The size of the sauropods from Kirmenjak quarry was smaller than the size of the other Late Jurassic sauropod 'titans' established from skeletal remains. This could be explained by the presence of new sauropod taxa or simply by the presence of smaller species of a larger genus, if we keep in mind that even all species of the same genus were not of the same size.

The estimated speed of Kirmenjak sauropods ranges from 0.5–2.5 km/h, which is not surprising when compared to the speeds estimated for sauropods in other localities. This is the speed in which sauropods usually moved around. It is observed that the distance between the manus and pes prints in the Kirmenjak trackways depends on the speed of the animal – the greater the speed, the longer the distance. In the case of the slow walk, overlap of prints occurs. The pes prints cover the manus prints. This feature indicates that the animals move their legs in the pairs, e.g., front left foot–hind left foot–front right foot–hind right foot, similar to modern elephants. It is the further proof that the gait of sauropods resembled that of the modern quadrupedal mammals more than reptiles.

The Kirmenjak footprints could be assigned to *Parabrontopodus* ichnogenus and the ichnocoenosis could be assigned to the *Brontopodus* ichnofacies which is characterized by sauropod footprints in the carbonate platform environment (LOCKLEY et al., 1994a). The presence of the large sauropod dinosaurs on the Adriatic Carbonate Platform during the Late Jurassic could be explained by its connection with the Gondwana via its southern margins. The sauropods could have migrated in the area during the emergence phase when the platform was exposed to continental conditions. There had to exist a widespread continental area in order to support a survival of such large terrestrial herbivores as the sauropod dinosaurs.

STOP 2 – UČKA: A BRIEF OVERVIEW OF THE GEOLOGY OF UČKA MT. AT THE VELA DRAGA VIEWPOINT

Igor Vlahović, Bojan Matoš, Darko Matešić, Damir Palenik, Ladislav Fuček, Aleksandar Mezga

Introduction

The area of the Učka Nature Park is about 160 km^2. The northern part of the Park includes the southeasternmost portion of the Ćićarija Mt., while the southern part includes the greater portion of the Učka Mt. More information on the geology of the Park can be found in the geological guidebook of the Učka Nature Park (VLAHOVIĆ & MATOŠ, 2021), on which the description of this stop is based. From the geological point of view the area of the Park can be divided into three structural-tectonic units (Figs. 5 and 6): the Imbricate and Nappe Structure of Ćićarija in the north covering an area of about 78 km^2, the Učka Anticline of roughly the same area in the south, and the Učka Klippe to which the summit area of Učka belongs, with a total area of only 4 km^2.

The part of the Park's area that belongs to Ćićarija is actually almost the same size as the part belonging to Učka. Another interesting fact is that new Poklon Visitor Center of the Učka Nature Park is located on the Ćićarija Mt., a few hundred meters NE of the surface border with the Učka Mt. (Ćićarija structure is here thrusted over the Učka Anticline). The same is the case with the 5,062 m long Učka road tunnel, which is drilled through the contact area of Učka and Ćićarija Mts. – the first third of the tunnel on the Kvarner side geologically belongs to Ćićarija, and if we look at the terrain above the tunnel tube, as much as two-thirds of the tunnel would actually belong to Ćićarija Mt. (Fig. 7).

One of the most important features of all three structural-tectonic units of the Učka Nature Park is their exceptional tectonic disturbance, due to which numerous

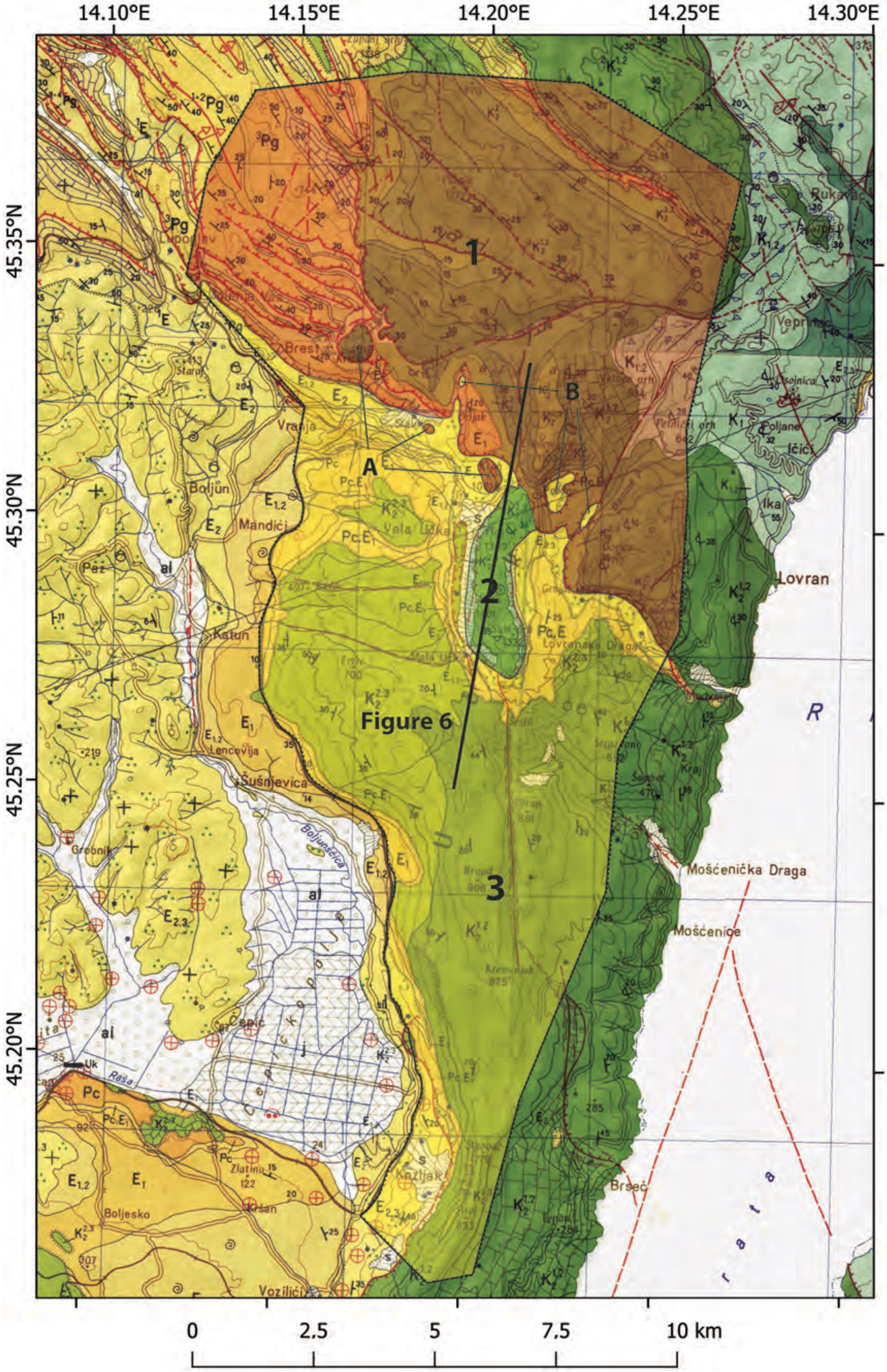

Fig. 5. Division of Učka Nature Park into three structural-tectonic units (VLAHOVIĆ & MATOŠ, 2021): 1) Imbricate and Nappe Structure of Ćićarija in the northern part with three tectonic klippes (A) and three tectonic windows (B); 2) Učka Klippe in the central part; 3) Učka Anticline in the central and southern part. In the middle part the profile line of the geological cross-section shown in Figure 6. The geological map combines the southern part of the Ilirska Bistrica sheet (ŠIKIĆ et al., 1972) and the northern part of the Labin sheet (ŠIKIĆ et al., 1969) of the Basic Geological Map of SFRY in 1:100,000 scale.

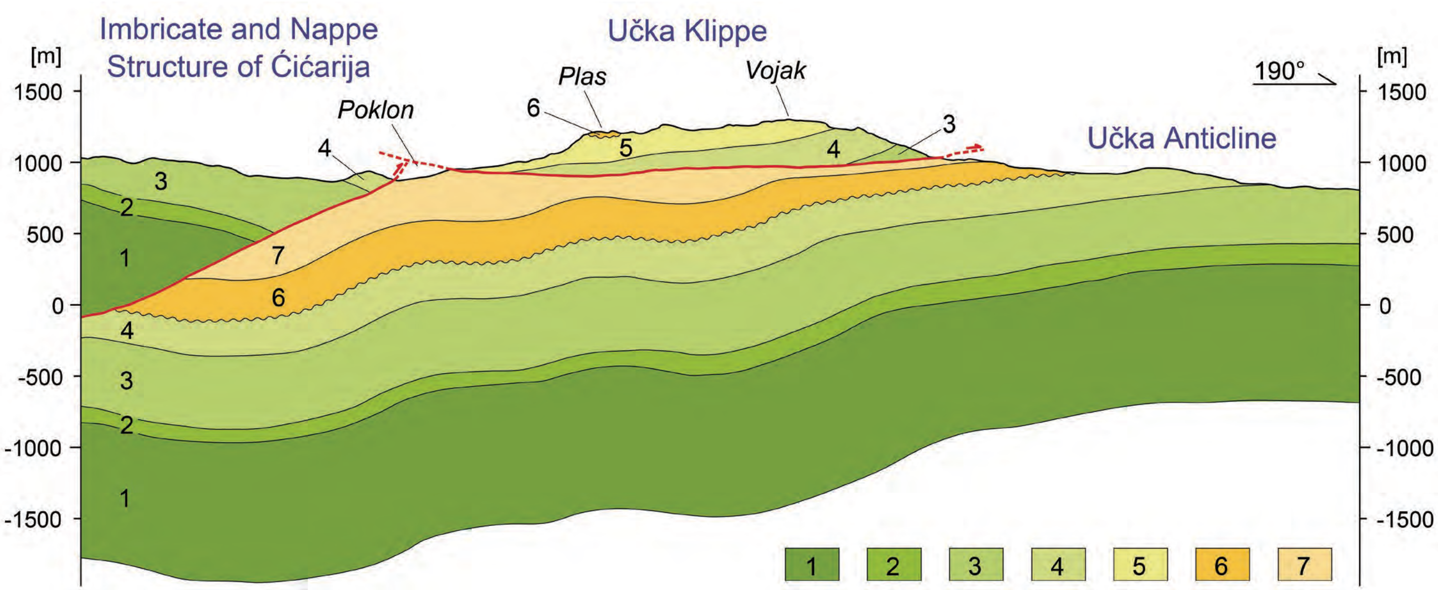

Fig. 6. Schematic geological cross-section showing contact area between three structural-tectonic units of the Učka Nature Park – Imbricate and Nappe structure of Ćićarija, Učka Klippe and Učka Anticline (for position of the profile line see Figure 5). Legend: 1 – Dragozetići–Crna fms. (Valanginian–Albian); 2 – Sis fm. (Upper Albian–Lower Cenomanian); 3 – Milna–Sv. Duh fms. (Middle Cenomanian–Lower Turonian); 4 – Gornji Humac fm. (Upper Turonian–Coniacian); 5 – Učka fm. (Coniacian–Santonian); 6 – Foraminiferal limestones fm. (Lower–Middle Eocene); 7 – Transitional and turbidite deposits fm. (Middle–Upper Eocene).

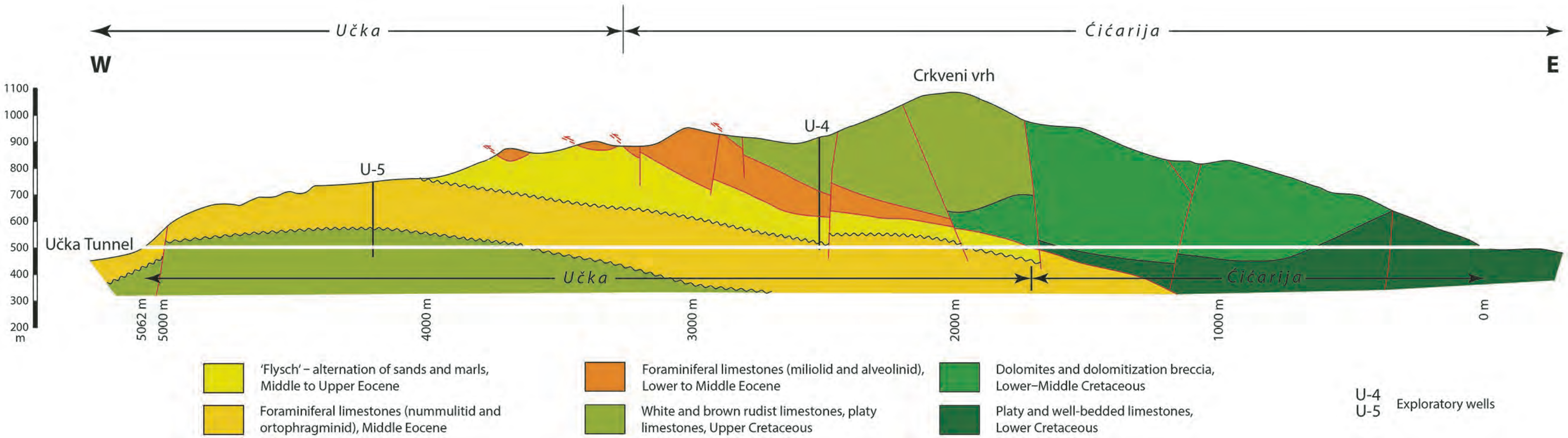

Fig. 7. Schematic geological cross-section made for the Učka road tunnel project (after BABIĆ et al., 1974, in VLAHOVIĆ & MATOŠ, 2021). As the area of the tunnel includes thrust contact between two large structural-tectonic units (the Učka Anticline on the left, western part and the Imbricate and Nappe Structure of Ćićarija on the right, eastern part of the profile), contacts on the surface and in the tunnel do not match. On the surface, approximately two thirds of the area above the tunnel belongs to the Ćićarija mountain range (see black markings above the profile; in adition both klippens west of the contact belong to Ćićarija), while approximately two thirds of the tunnel route belong to Učka (see markings in the lower part of the profile). At the very contact point of Učka and Ćićarija, a large cavern was drilled in the tunnel, which today is used for water supply.

fracture systems are developed, greatly facilitating the chemical weathering of carbonates and the mechanical weathering of turbidite deposits ('flysch'). Therefore, a large part of the Park area is covered with thinner or thicker soil and vegetation, while the outcrops are mostly tectonically very disturbed.

At this stop, we will briefly consider two structural-tectonic units, the Učka Anticline, which belongs to the stable Istria, i.e., it represents a much less disturbed part of the Adriatic Microplate, and the Učka Klippe, which belongs to the Dinaric Mountain range. The third unit, the Imbricate and Nappe Structure of Ćićarija, also representing a part of the Dinarides, will be discussed at the next Stop.

It is important to note that the given order of description does not correspond to the time sequence of the structural formation: the extensive Učka Anticline is the oldest structure, a subsequent change in the main compression direction resulted in a collision alongside its northern edge and the formation of the Imbricate and Nappe Structure of Ćićarija, and ultimately the tectonic transport of the Učka Klippe to the south. Present-day relations are masked due to the erosion that occurred during the long-lasting subaerial exposure phase (the study area has been exposed to intense karstification over the last 30 million years), so it can be assumed that a significant portion of the original deposits, especially in the Ćićarija area, is missing.

The Učka Anticline

The structural-tectonic unit of the Učka Anticline occupies the central and southern part of the Učka Nature Park (Fig. 5), with a total area slightly larger than 78 km^2. It is a gentle, open fold with an approximate N–S axial plane orientation, which clearly differs from the orientation of the structures in the neighbouring Dinarides (characterised by typical Dinaric strike – NW–SE).

According to data from the Basic Geological Map of the Labin sheet (ŠIKIĆ et al., 1969), the oldest Cretaceous deposits of the Učka Anticline are of Cenomanian age, and the youngest are of the Upper Turonian–Coniacian age. The recent data provided by the Croatian Geological Survey indicate that very close to the Park area, in the area of Mošćenica, there are also older, Albian rocks. The western limb of that extensive fold is composed of a continuous succession from older to younger Upper Cretaceous deposits, numerous bauxite occurrences at the Cretaceous–Palaeogene boundary, and a sequence of Kozina deposits and foraminiferal limestones dipping outside the Park boundaries under the turbidite deposits of the Pazin Flysch Basin. The Palaeogene deposits also crop out on the surface at the very top of the Anticline, at an altitude of c. 1000 m above the sea level, where they represent the footwall of the overlying Učka Klippe. In addition, Palaeogene deposits cover the northern edge of the Učka Anticline, i.e., the area bordering the Imbricate and Nappe Structure of Ćićarija, and descend to the east towards Lovranska Draga and the area close to the sea near Medveja. The eastern limb of the Učka Anticline descends all the way to the coast of the Kvarner Gulf, but there are no elements on the adjacent islands that would indicate the continuation of similar structures. By comparing the successions, it is evident that the youngest Cretaceous rocks on northern parts of the islands of Cres and Krk are significantly older than those on Učka, but even more important is a totaly different orientation of their structures, characterised by a typical Dinaric strike, NW–SE. That is why the so-called Kvarner fault is often mentioned in geological literature (Korbar, 2009, and references therein), which is assumed under the sea between the eastern coast of Istria and the islands of Cres and Lošinj. The Kvarner fault represents the boundary between the relatively undisturbed part of the Adriatic Microplate in Istria and the Kvarner islands as parts of the External Dinarides.

In the northernmost part of the Učka Anticline very important elements indicating the character of the tectonic contact with the Ćićarija structures can be recognized, which also indicate the relative age and order of formation of the structures in the Učka Nature Park. The area of the NW slopes of Učka, between Vranja, Vela Učka and the Peruč pass (the highest point of the Lupoglav–Veprinac road, where the road to the highest peak of Učka, Vojak, branches off) is marked by the refolded structures of the Učka Anticline, with folds of the Dinaric strike visible on the surface. A good example of such folds is the anticlinal structure of Vela Draga, because the intense weathering of heavily fractured rocks in its core resulted in gradual widening and deep canyon incision. This indicates that the large-scale Učka Anticline was formed first, followed by several folds with Dinaric strike (NW–SE), as a result of the tectonic collision with the Imbricate and Nappe Structure of Ćićarija in its frontal part. Based on the succession of deposits and the aforementioned structural relationships, it is possible to reconstruct an approximate time frame of the formation of these structures. The Učka Anticline was formed after the deposition of turbidite deposits (because it contains such deposits even on its highest part), which means probably by the end of the Eocene. This fact implies that the folding of the northern part of the Učka Anticline due to the tectonic collision with the Ćićarija range probably took place at the beginning of the Oligocene, a little more than 30 million years ago. It should also be noted that the Anticline was significantly uplifted, because rocks originally deposited in marine environments at a depth of several hundred meters are today cropping out at the elevation of 1000 m above the sea.

The contact with the neighbouring Imbricate and Nappe Structure of Ćićarija along the NE part of the Učka Anticline is also interesting. Two occurrences of younger Palaeogene deposits surrounded by Cretaceous rocks in the form of tectonic windows are visible on the surface, one relatively close to Poklon and the other somewhat further to the southeast. The occurrence of tectonic windows together with several small klippe structures composed of Ćićarija rocks found on top of the marginal part of the Učka Anticline clearly indicate that the contact of Ćićarija Mt. and the Učka Anticline was formed by thrust tectonics, which was definitely proven during the construction of the Učka road tunnel (Fig 7).

The Učka Klippe

The structural-tectonic unit of the Učka Klippe is a very small area (less than 4 km^2) occupying the summit area of Učka (Figs. 5 and 6). It is the highest part of the Park, with altitudes mostly above 1000 m a.s.l., so it also includes the highest peaks: Vojak (1396 m), the nameless peak on the ridge north of Vojak (1352 m), Suhi vrh (1333 m), Plas (1285 m) and Jazvina (1104 m).

The Učka Klippe consists of mostly Cretaceous deposits thrusted over the Palaeogene foraminiferal limestones and turbidite deposits ('flysch') belonging to the underlying structural unit of the Učka Anticline. Although the thrust contact is mostly covered by thick vegetation and screes, the Učka Klippe represents one of the best examples of thrust structures in the Dinarides. The contact with the Imbricate and Nappe Structure of Ćićarija in the north is not well visible because similar stratigraphic units are in contact, but it can be clearly recognized in the area of Peruč, where the road to the Vojak peak branches off from the main road: at a distance of only several tens of meters, there are outcrops of turbidites belonging to the Učka Anticline to the west, Upper Cretaceous deposits of the Učka Klippe to the south and the lowest part of foraminiferal limestones belonging to the Imbricate and Nappe Structure of Ćićarija to the east.

In addition to the well-defined thrust structure the stratigraphic succession of the Učka Klippe also attracts the attention of geologists, especially its younger Cretaceous deposits different in age and origin from all Cretaceous rocks found in the underlying unit of the Učka Anticline and the neighbouring Ćićarija massif. The older part of the Cretaceous deposits in the Učka Klippe unit, clearly visible in its southern part, corresponds to the youngest Cretaceous deposits in the other two structural units, but in the Učka Klippe these rocks are overlain by even younger Cretaceous rocks not found in other parts of the Park (those areas were at that time already uplifted and subaerially exposed). This younger part of the succession consists of two units: the older one characterised by the deposition of calcisphaera limestones in deeper marine environments similar to the deposits of the older Sveti Duh unit, which forms the cliffs along the road to the Vojak peak, and the overlying younger shallow marine rudist limestones building the summit area of Učka Mt. and the area to the north. Within the deposits close the Vojak peak a rich microfossil assemblage has been found (including *Murgella lata*, *Pseudorhapydionina mediterranea*, *Scandonea samnitica*, *Dicyclina schlumbergeri*, *Nummofalotia apula*, etc.), indicating the Upper Santonian age (VLAHOVIĆ et al., 2003), i.e., an age of approximately 84–85 Ma.

Since in the area of the Učka Klippe Paleogene deposits were not determined on geological maps, the question arose whether younger Cretaceous deposits were also deposited but subsequently eroded. However, around the Plas peak an outcrop with transgressive Palaeogene foraminiferal limestones on top of Upper Santonian deposits was found (MATEŠIĆ, 2017), and during the research for the geological guidebook of the Učka Nature Park another similar outcrop was documented a little further south.

The presence of the deposits that cannot be found anywhere else in the vicinity is evidence that the Učka Klippe was transported tectonically from some more remote areas. In the whole area of the stable Istria, such young Cretaceous deposits are only found in the very south, on the Marlera peninsula SE of Medulin (MORO et al., 2002). However, that area is certainly not the place from which Učka Klippe originates: not only because there are no structural elements that would indicate such a significant tectonic transport from the south, but also because those rocks differ significantly from the contemporaneous rocks near the Vojak peak. Therefore, only the area NE of Ćićarija can be assumed as the potential source area for the Učka Klippe, and preliminary research did not rule out such a possibility. Therefore, it may be concluded that the Učka Klippe unit is just a small erosional remnant of a former nappe which thrusted over the entire Imbricate and Nappe Structure of Ćićarija onto the apical part of the Učka Anticline, therefore being the youngest of three structural-tectonic units in the Učka Nature Park.

Viewpoint over Vela Draga – view of the Učka Anticline and the Učka Klippe

The viewpoint located on the northern slopes of the Vela Draga provides a magnificent view of almost the entire canyon, from the eastern end over which the summit area of of the Učka Klippe is clearly visible (Fig. 8), to the south to the abandoned railway line from Lupoglav to Raša (Fig. 9). all the way to the west towards Boljunsko polje (Fig. 10). Vela Draga is around hundred metres deep canyon stretching from the entrance to the Učka road tunnel to the west close to the Vranja village, and then turning to the SW to Boljunsko polje.

The origin of Vela Draga is connected to tectonic processes which resulted in the present-day tectonic structure of the northern edge of the Učka Anticline. Namely, after the uplift of the Anticline, when the turbidite deposits of the eastern part of the Pazin Flysch Basin were significantly uplifted from their original position, a change in the stress field took place, resulting in compression almost perpendicular to the previous one: instead of the main stress oriented E–W, which formed the Učka Anticline structure, the new stress was oriented NE–SW, typical for the Dinarides. Therefore, the area of the Učka Anticline northern edge is folded into several large folds, and the part of Vela Draga between the Učka tunnel and Vranja represents the core of relatively large anticline.

The erosion gradually opened and widened fracture systems formed parallel to the Vela Draga anticline axis, enabling gradual incision of the canyon. The influence of surface water was also important, especially because in the hinge zone of the Učka Anticline impermeable turbidite deposits crop out, resulting in large quantities of surficial water concentrated above the entrance into the canyon. The dissolution of carbonate rocks during both surfical and underground long-lasting karstification process could have been significant, and it is possible that at least part of the present-day appearance of the canyon was also a consequence of the cavern collapses, especially at the very eastern end of Vela Draga.

As a result of intense tectonic fracturation of rocks and significant vertical erosion, numerous erosional columns composed of foraminiferal limestones can be found along the canyon (Figs. 11 and 12). These interesting geomorphological forms also represent a great challenge for alpinists and sport climbers, so that for almost 100 years, from the first ascent of the famous Italian climber Emilio

Fig. 9. View from the Vela Draga viewpoint to the south: at the bottom of Vela Draga there is an embankment of the abandoned railway line from Lupoglav to Raša, at both ends of which there are tunnels. On the other side, high cliffs of foraminiferal limestones can be seen, which represent the western limb of the extensive Učka Anticline, which dips to the west under the turbidite deposits of the Pazin Flysch Basin.

Fig. 8. View from the Vela Draga viewpoint to the east: in the foreground the canyon of Vela Draga, which forms the eroded central part of the extensive anticline structure in the NW part of the Učka Anticline structural-tectonic unit, and in the distance a much steeper relief of the Učka Klippe structural-tectonic unit

Fig. 11. View to the east from the beginning of the embankment of the abandoned Lupoglav to Raša railway line: in the higher part of the Vela Draga canyon, in the northern limb of the large-scale anticline formed by the refolding of deposits of the Učka Anticline, close to a contact with the Imbricate and Nappe Structure of Ćićarija, there is an entrance to the Učka road tunnel (in the central part of the photo)

Fig. 10. View from the Vela Draga viewpoint to the west: the canyon of Vela Draga continues towards Boljun Polje where the Palaeogene foraminiferal limestones dip under the turbidite deposits of the Pazin Flysch Basin

Fig. 12. View from the embankment of the abandoned Lupoglav to Raša railway line towards the Vela Draga viewpoint. The high cliffs composed of Palaeogene foraminiferal limestones have been used for sport climbing ever since 1931. Those geomorphologically interesting tower-like forms were formed due to intense tectonic fracturation and selective erosion along fracture systems.

Comici back in 1931, they have remained popular meeting place until today.

At the very bottom of the canyon the oldest deposits crop out, dark gray Kozina limestones with numerous miliolids and gastropods of the genera *Cosinia and Stomatopsis*, and along the canyon slopes younger foraminiferal limestones mostly composed of entire and broken alveolinids and nummulitids crop out.

Pupićina Peć in Vela Draga – what were people doing there several thousand years ago?

Vela draga is also a very important archaeological site where it has been proved that humans lived from approximately 12,000 years ago (about the end of the last ice age) until the Roman times. Pupićina Peć, which was described for the first time by MALEZ (1960), was thoroughly researched, and after careful and long-lasting excavations, archaeologists found very valuable evidences about who and how lived in that semi-cave (MIRACLE, 2001; MIRACLE & FORENBACHER, 2005; BOSCHIAN, 2006; LIGHTFOOT et al., 2011).

In the period between ten and eight thousand years BCE the people who lived in Pupićina peć (Fig. 13) fed on the meat of wild game they haunted in the vicinity (e.g. bones of roe deer, deer, boar, but also of wild cattle, chamois, badgers, rabbits, beavers, foxes, weasels and wild cats were found there) and made use of their fur to make clothing, their teeth to make jewellery and their horns to make weapons and tools. Besides that, the remains of shells that they brought from the sea some 20 km away that were, as well as traces indicating that they gathered plants were also found.

There is no evidence that Pupićina Peć was used in the period between 8000 and 5500 BCE either as a dwelling place or a shelter, but the period between 5500 and 3500 BCE is very well documented. Major changes affecting the lives of people took place at that time as systematic agriculture and animal husbandry were introduced, so that shepherds who raised sheep and goats, less often cows and pigs, lived in Pupićina Peć. Abundant remains of dishes made of baked clay and more advanced tools made of chert and volcanic glass were also found there (although chert can be found in vicinity, volcanic glass must have come from far away areas).

Fig. 13. Archaeological excavation in Pupićina Peć, which explored the layers with extensive relics of the life activities of the humans who inhabited the semi-cave for shorter or longer periods during the last 12,000 years

An even younger layer at Pupićina Peć dates back approximately to 1500 BCE, with the remains of typical Bronze Age dishes, but also of needles and spindles as proof of more advanced techniques of clothes making. The youngest layer dates to the first centuries CE, when shepherds probably brought Roman ceramics with them, of which only a few remains left.

STOP 3 – ĆIĆARIJA: GEOLOGICAL AND STRUCTURAL ARCHITECTURE OF THE CENTRAL PART OF THE ĆIĆARIJA MT.

Damir Palenik, Igor Vlahović, Dubravko Matičec, Ladislav Fuček, Bojan Matoš, Aleksandar Mezga

Introduction

Ćićarija Mt., with its characteristic imbricate and thrust structure, belongs to the tectonically very complex marginal area of the NW Dinarides. The fold and thrust belt of Ćićarija Mt. stretches along the NE edge of the Istrian peninsula, and along its SW margin, Ćićarija is morphologically uplifted above the surrounding terrain, including its highest peak Veliki Planik (1,272 m a.s.l.). With its NW–SE strike typical for the Dinarides, Ćićarija Mt. is located between the Brkini syncline (comprised of Palaeogene deposits – limestones and flysch deposits) to the NE, the Pazin flysch basin to the SW, and the Rječina valley to the SE (ŠIKIĆ & PLENIČAR, 1975). Ćićarija Mt. can be subdivided into two parts: the SW part predominantly built of Palaeogene deposits and NE area built mostly of Cretaceous deposits. The entire area is intensely tectonized by numerous faults with a dominant typical Dinaric NW–SE strike (locally deviated to NNW–SSE), but also by NNE–SSW striking transversal faults.

In a morphological sense, the thrust and imbricated structure of SW Ćićarija forms a series of morphological terraces on top of each other (Fig. 14).

Each individual morphological terrace typically consists of a sequence of older Palaeogene foraminiferal limestones thrusted above younger foraminiferal limestones or above transitional marly deposits, only locally including thin flysch deposits.

Description of the central part of the Ćićarija Mt.

The study of central part of the Ćićarija Mt. was conducted within a work on the Basic Geological Map of the Republic of Croatia 1:50,000 Scale project. The main objectives of investigation were focused on the geological composition, reconstruction of the tectonic movements, and identification of the kinematics of the formation of

Fig. 14. Panoramic picture of the Ćićarija Mt. and surrounding area. View from Učka Mt. towards imbricated structures of Ćićarija in the northwest. The tectonic transport of the Ćićarija structures is towards the southwest (to the left) (modified from PALENIK, 2020).

geological structures in this part of the NW Dinarides. The new Basic Geological Map of the central part of the Ćićarija Mt. and the marginal area of the Pazin flysch basin in the 1:50,000 scale covers a total area larger than 220 km^2 (Fig. 15). On the new geological map, thirteen informal lithostratigraphic units have been identified, named after typical penecontemporaneous units already defined in other parts of the former Adriatic Carbonate Platform (GUŠIĆ & JELASKA, 1990; FUČEK et al., 1995, 2012; VLAHOVIĆ et al., 2005). A well-established vertical and lateral relationships of the studied deposits, along with a comparison to penecontemporaneous units of the wider area of Istria and other parts of the former AdCP, were necessary prerequisites for the interpretation of the Ćićarija area tectogenesis.

The reconstruction of the tectogenesis of the study area included construction of 11 geological cross-sections normal to the typical Dinaric strike of the main structures. Geological cross-sections show the interpretation of subsurface relationships of structures based mostly on surface data (Fig. 16).

Interpretation

The Palaeogene imbricated structure of the SW part of the Ćićarija Mt. was formed as a result of compression and thrusting of northeastern hinterland composed of Cretaceous and Palaeogene deposits causing significant contraction of the area. Based on constructed geological cross-sections, it can be concluded that the Palaeogene imbricated structure of the SW part of the Ćićarija represents a *thin-skinned deformation* of exclusively Palaeogene deposits that are multiple times repeated, which are physically separated from the underlying Cretaceous basement by a shallow, regional-scale, detachment fault that dips towards the NE at a very low angle (Fig. 17). Regional detachment probably involved the lowermost part of the Foraminiferal limestones, i.e., miliolid limestones, which contain a substantial bituminous content and as such could be suitable for the development of the sliding surfaces and shear planes. Thrust contact of the entire Ćićarija Palaeogene imbricated structure and overlaying Cretaceous deposits dips at the very low angle towards the NE, indicating SW-directed tectonic transport (Fig. 18).

In the area of the Palaeogene imbricated structure reverse faulting show typical *ramp and flat geometry*. Marls from the Transitional deposits, and very rarely (or locally marls from the lowermost part of the flysch sequence) are proposed as detachment horizons within the imbricated structure system (Figs. 19 and 20).

For determination of fault kinematics in relation to the past and present stress fields, collected data of field

Fig. 15. Location map with shaded study area (modified from PALENIK, 2020)

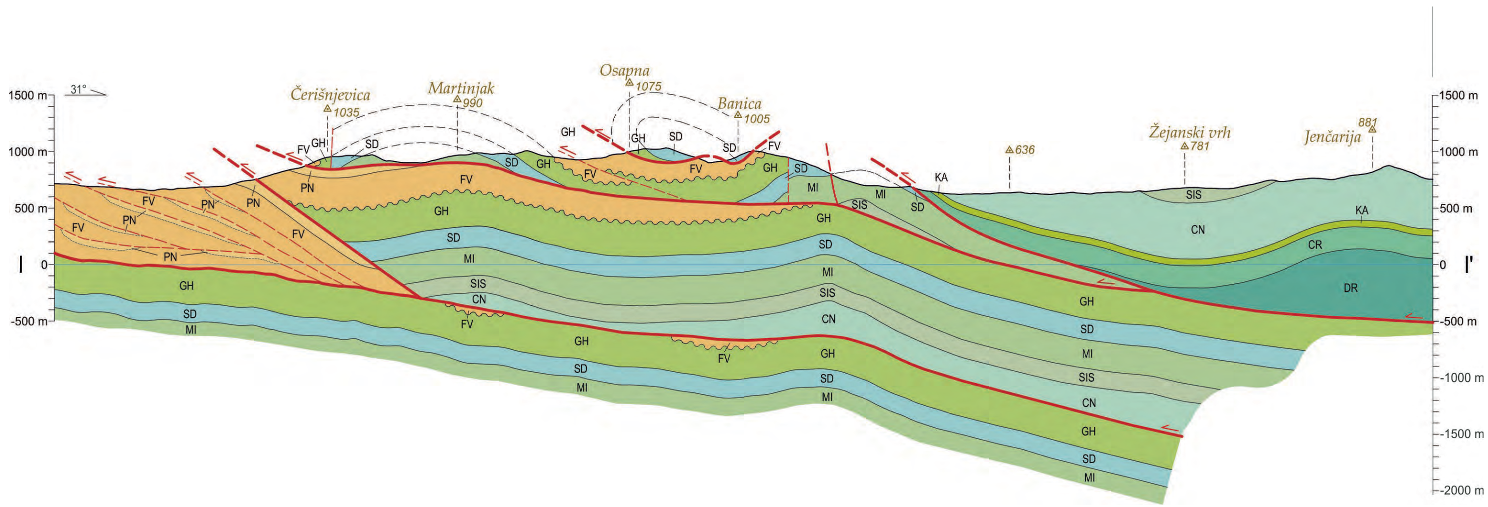

Fig. 16. An example of a typical transversal (SW–NE oriented) geological cross-section in the Ćićarija Mt. area. (PALENIK, 2020) Legend: DR – Dragozetići fm. (Berriasian–Hauterivian); CR – Cres fm. (Barremian); KA – Kanfanar fm. (Aptian); CN – Crna fm. (Albian); SIS – Sis fm. (Upper Albian–Lower Cenomanian); MI – Milna fm. (Middle–Upper Cenomanian); SD – Sv. Duh fm. (Upper Cenomanian–Lower Turonian); GH – Gornji Humac fm. (Upper Turonian–Coniacian); FV – Foraminiferal limestones fm. (Lower–Middle Eocene); PN – Transitional deposits fm. (Middle Eocene).

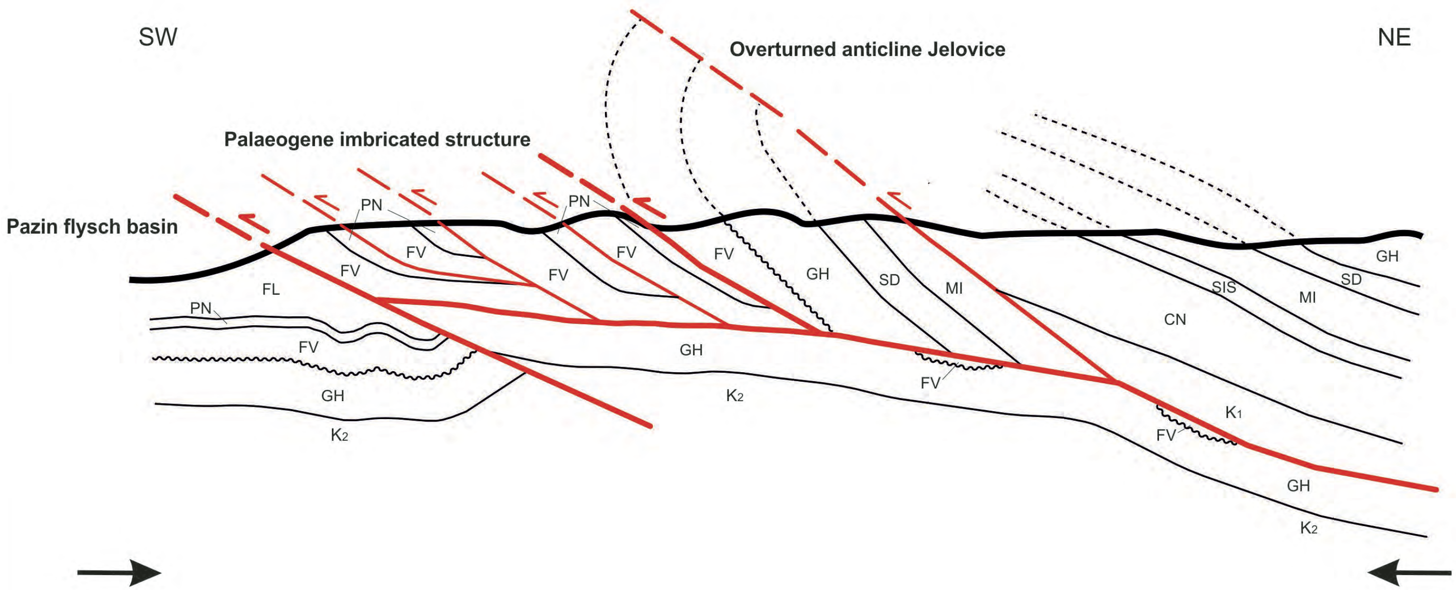

Fig. 17. Schematic presentation of the thrust sheet of the Cretaceous deposits tectonically transported towards the SW and the formation of the Palaeogene imbricate structure of the SW part of the Ćićarija Mt. (PALENIK, 2020; not to scale).. Legend: K_1 – Lower Cretaceous deposits; K_2 – Upper Cretaceous deposits; CN – Crna fm. (Albian); SIS – Sis fm. (Upper Albian–Lower Cenomanian); MI – Milna fm. (Middle–Upper Cenomanian); SD – Sv. Duh fm. (Upper Cenomanian–Lower Turonian); GH – Gornji Humac fm. (Upper Turonian–Coniacian); FV – Foraminiferal limestones fm. (Lower–Middle Eocene); PN – Transitional deposits fm. (Middle Eocene); Flysch deposits (Middle–Upper Eocene). The arrows at the bottom of the picture indicate the NE–SW oriented compressional stress.

Fig. 21. The position of the Fantasia quarry within the Visitor Center "The Fantasia Quarry" – yellow arrow. Source: *Google Earth Pro*.

ro- and microcrystalline dolomites with numerous decorative and effective structural-textural features, there was an interest in exploiting Fantasia dolomites as an architectural-building stone. However, these dolomites proved to be an extremely hard material that delaminated along the sharp contacts of early-diagenetic and late-diagenetic dolomite, so this idea was soon abandoned. In the abandoned quarry, the western, northern and eastern fronts remained vertically sawed and polished, which enabled detailed geological, especially sedimentological research of different types of dolomites with numerous well-preserved structural and textural features (TIŠLJAR, 1976). In 1987, the Fantasia quarry (*Cava di Monfiorenzo*) was declared a protected geological monument of nature, for which late professor Josip Tišljar, fellow of the Croatian Academy of Sciences and Arts, was certainly the most deserving person.

Description of dolomites in the Fantasia quarry

A total of 13 layers of dolomite are visible in the Fantasia quarry, which are only one part of the sequence of deposits of the informal lithostratigraphic unit defined as the Rovinj fm. (VLAHOVIĆ, 1999; MATIČEC et al., 2020). On the surface, the outcrops of the Rovinj fm. are found in a continuous belt that stretches along the Western Istrian Anticline from Poreč, across the Lim channel, Žbandaj and all the way to the coast south of Rovinj. In a normal superposition sequence, the dolomites of the Rovinj fm. are located between the Zlatni rt fm. (ZR) below and the Materada fm. (MA) above (Fig. 22). The total thickness of the Rovinj fm. is very variable, in average around 35 m. The Berriasian age of the dolomite deposits of the Rovinj fm. was confirmed by the occurrence of green algae *Humiella sardiniensis* (OTT & FLAVI-

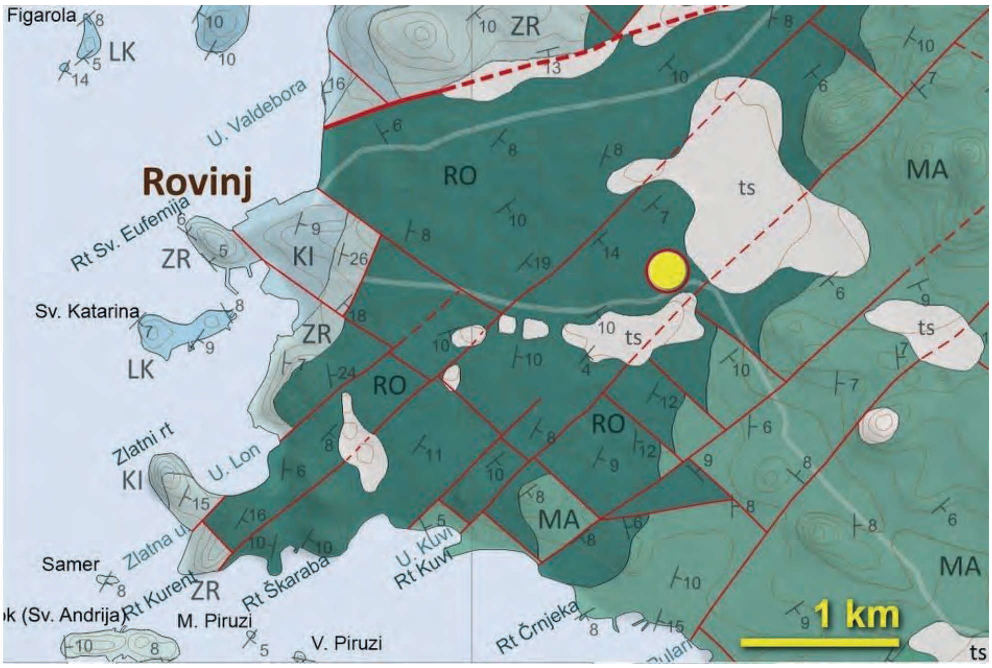

Fig. 22. A detail of the Geological Map 1:50,000 of the Rovinj area, the yellow circle marks the position of the Fantasia Quarry (MATIČEC et al., 2020)

Fig. 23. Eastern front of the Fantasia quarry before the construction of the Visitor Center with well visible alternation of light gray layers of early diagenetic and dark gray layers of late diagenetic dolomites

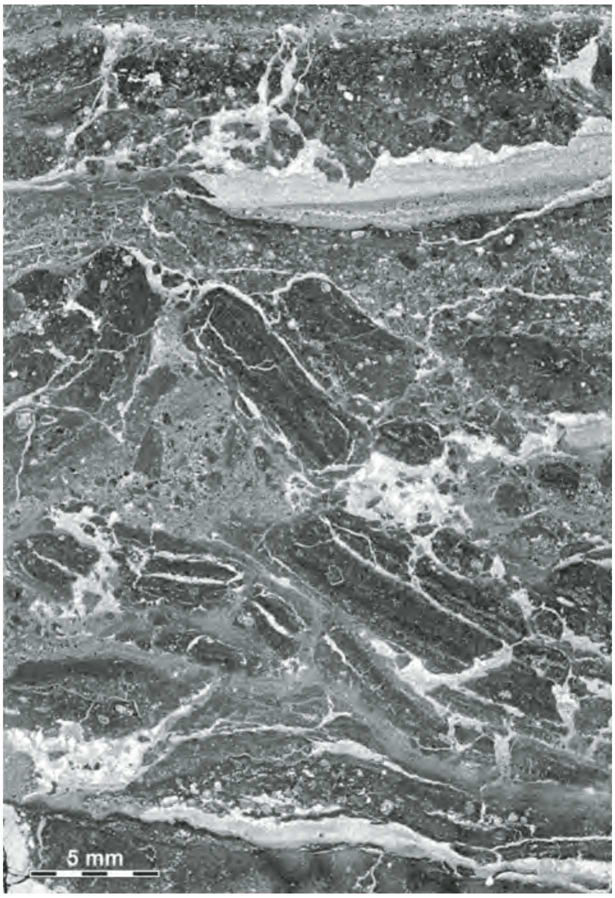

Fig. 24. Laminated dolostromatolite within a light-coloured microcrystalline dolomite

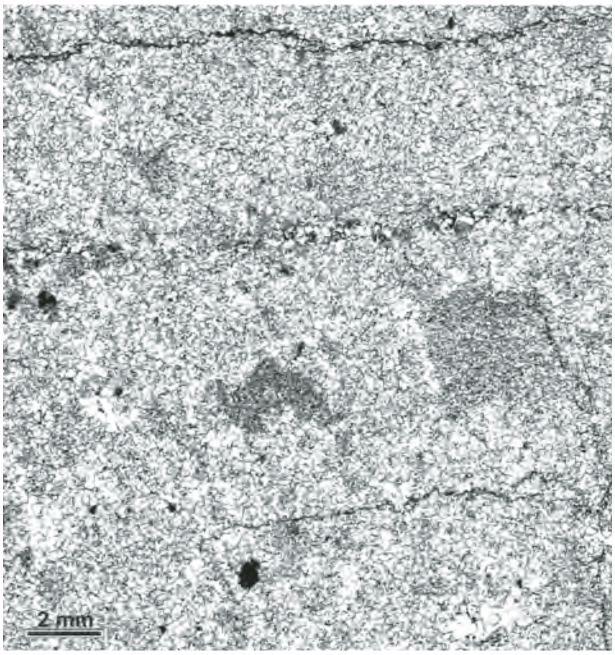

Fig. 25. The late diagenetic dolomite with a coarse crystalline structure composed of large hypidiomorphic dolomite crystals with almost completely destroyed primary structural and textural features

ANI) and *Clypeina radici* SOKAČ, small benthic foraminifera, gastropods similar to certain species of the genus *Nerinea*, and relatively frequent pellets from the *Favreina* group, but also based on the superpositional relationships of the Zlatni rt fm. below and the Materada fm. above.

The alternation of light gray and dark gray layers of dolomites is the macroscopically easily observable feature of the Rovinj fm. (also known as Fantasia dolomite after this locality; Fig. 23). The thickness of individual layers is variable, between 15 and 170 cm. The light gray to almost white layers represent synsedimentary, early diagenetic or primary dolomites of cryptocrystalline structure formed relatively quickly after the deposition and containing numerous preserved and visible structures as well as fossil content (Fig. 24).

The late diagenetic or "secondary" dolomites are represented with the dark gray layers formed subsequently, by post-sedimentary dolomitization. It is characterized by coarse crystalline structure and lack of visible textures and fossil content (Fig. 25). Bedding surfaces between different types of dolomites are mostly very uneven, but sharp.

Among the structural–textural features, especially in the light gray early diagenetic dolomites, the most common is a laminated texture as a reflection of the succession of flat, slightly wavy or curly cyanobacterial laminae–interlayers of varying thickness, and fenestral structures with irregular and laminoidally arranged fenestrae. In the light gray dolomite of the layer 3 there are uneven mottled intervals that could be the result of bioturbation, and in the top part of the layer there are three horizons of desiccation cracks with rare tepee-structures (Fig. 26). On the western wall of the quarry, various examples of the load-cast structures formed by intrusion of consolidated parts of the denser upper layer into the underlying semi-consolidated hydroplastic deposits are clearly visible. Good example is the intrusion of consolidated layer 5 into the semi-consolidated layer 4 (Fig. 26), as well as several such examples on the northern wall of the quarry. At the top of the layer 5 (on the western wall of the quarry) there are two examples of the eroded upper part of the layer 5 and channel-like filling with coarser-grained material from the layer 6. Besides, the layers 5 and 6 are marked by numerous shrinkage cracks, which are mostly filled with sediment from the upper layer.

Layer 8 contains numerous deformations of unconsolidated sediment (soft-sediment deformation), such as plastic deformations of sediment in the form of slump-folds, vertical extrusion water escape structures, i.e. escape of water in the flower-like deformed interlayers (Fig. 27), flame structures, diapir-like uplifts, injected sediment and numerous other examples of unconsolidated sediment deformations (including tearing, brecciation and deformation of semi-consolidated parts of the sediment). All of these structures may indicate seismites that were probably formed on a relatively gently tilted local slope inclined towards the south due to earthquakes.

Another type of structures that can be observed are the structures created within the consolidated, brittle rocks (brittle deformation structures). These are small-scale reverse faults found in layers 10 and 11. There are several of them, the largest one has a movement of about 5 cm (Fig. 28), the smaller ones are characterized by a movement of about 1 cm, but all of them indicate southward tectonic transport.

Interpretation of structures and textures in the Fantasia quarry dolomites

Based on the obtained results of research on structures, especially in the light gray early diagenetic dolomites or "primary dolomites", it can be concluded that the depos-

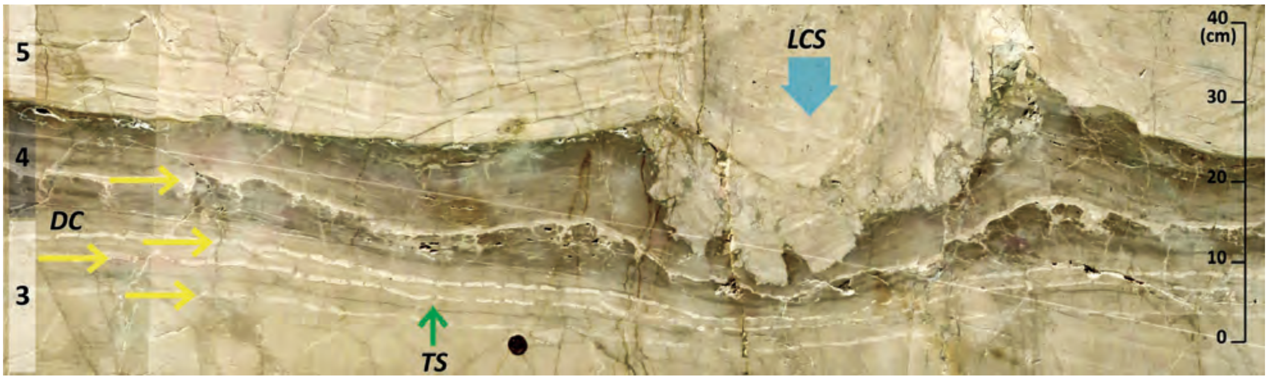

Fig. 26. In the top part of layer 3 there are three horizons of desiccation cracks – DC (yellow arrows) and rare tepee structures – TS (green arrow). LCS – pressing of consolidated sediment from layer 5 into semi-consolidated layer 4 (load-cast structure; blue arrow). Height of the outcrop c. 50 cm.

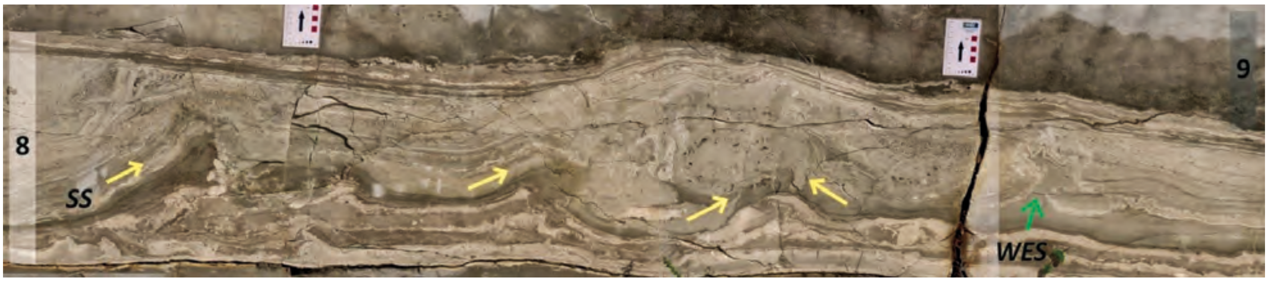

Fig. 27. Layer 8 with numerous soft-sediment deformation – SS plastic deformation slump structures – yellow arrows, WES water escape structures – green arrow. Height of the outcrop c. 70 cm.

Fig. 28. Brittle deformation structure – small-scale reverse fault cutting through the layers 10, 11 and 12 – red arrow. Height of the outcrop c. 80 cm.

its were formed in a very shallow marine environments where the effects of increased water energy under the influence of stronger waves or storms were occasionally recorded. In addition, numerous evidences for the synsedimentary deformation are visible in the rocks, partly in a soft, unconsolidated deposits, and partly in a partially or almost completely consolidated deposits.

Most of the structures created by the deformation of soft sediments are formed in water-saturated non-cohesive sediments in which liquefaction as a mechanism of deformation occurs in situ due to the disruption of the system of mutual support between the grains caused by the increase in the pore fluids pressure (ALLEN, 1982).

There are several types of structures indicating deformations in uncosolidated sediments (soft sediment deformation structures) – from load cast structures, diapir-like and dyke-like structures, plastic deformation slump-like structures, flame structures, etc.

Particularly noteworthy are the large load cast structures that are visible in layers 4, 5 and 6 on the western and northern quarry walls. They indicate the embossing of the consolidated sediment from above into the uncosolidated soft sediment below. This resulted in the displacement of soft sediment from the sides and the creation of diapir-like structures as well as sedimentary dykes that in places pass through thin cracks into the overlying sediment. Load cast structures are formed at the contact of two lithotypes of different densities and/or degrees of sediment connectivity, where the consolidated overlying deposits are pressed into the softer, unconsolidated underlying sediment. They are the result of the gravity force, so they have a pronounced vertical component, and as the cause is often proposed seismic activity that causes liquefaction of the sediment. Such assumed synsedimentary tectonic activity was already recognized in the evolution of this part of the former Adriatic Carbonate Platform (MATIČEC et al., 1996; TIŠLJAR et al., 1998; VLAHOVIĆ et al., 2005, 2011).

An alternative interpretation of the origin of structures in the Fantasia Quarry shown in Fig. 26 was given by LOCKLEY et al. (1994b), based exclusively on photos from TIŠLJAR et al. (1983). These authors assumed that these could be dinoturbations by sauropod dinosaurs. However, clear evidences for such interpretation are missing.

Another type of synsedimentary structures visible in the Fantasia quarry are deformation structures formed in almost or completely consolidated deposits – brittle deformation structures. Among them, the most important are the small-scale reverse faults cutting through layers 10 and 11 with dip of c. 50°. There are several such faults, with the largest and best visible fault having a displacement of about 5 cm, and the smaller ones having a displacement of approximately 1 cm. It is important to emphasize that the tectonic transport of these reverse faults is southward, which corresponds to the direction indicated by the aforementioned deformations soft sediment deformations.

Considering that almost all the structures in the layers 8, 10 and 11 indicate movement towards the south, it can be concluded that the entire block was probably gently inclined towards the south, which is in accordance with the position in the SE limb of the gentle Western Istrian Anticline.

Based on the observation of a limited number of outcrops, it can be assumed that these were very likely very gentle slopes, in the range of 1–3°. Namely, earthquakes with a magnitude greater than 5.5 on the Richter scale can cause slumping even on slopes of only 0.25° inclination, and an approximate earthquake magnitude of 5 on the Richter scale can be assumed as the limit below which sediment liquefaction occurs, and above which folding or faulting occurs under ductile–brittle conditions (CHAKRABORTY et al., 2019).

Significant influence of synsedimentary tectonics in Istria is also indicated by the occurrence of Palaeogene foraminiferal limestones on top of very different levels of Cretaceous deposits, oldest among them being just 10–12 My younger than deposits in the Fantasia quarry (MATIČEC et al., 1996), as well as a very clear tectonic activity recorded in the oldest Late Cretaceous deposits (TIŠLJAR et al., 1998; VLAHOVIĆ et al., 2005, 2011). This is evidence of the gradual uplifting of the anticlinal area of Istria much earlier than tectonic deformation in other parts of the Adriatic Carbonate Platform.

References

ALLEN, J.R.L. (1982): Sedimentary Structures: Their Character and Physical Basis. Developments in Sedimentology, 30, 2 vols., 663 p., Elsevier, Amsterdam.

BABIĆ, Ž., BENČEK, Đ., KOVAČEVIĆ, S. (1974): Inženjerskogeološki i geofizički radovi za tunel "Učka". Zbornik radova 3. jugosl. simp. hidrogeol. inž. geol., 2, 1–7, Opatija.

BOSCHIAN, G. (2006): Geoarchaeology of Pupićina Cave (Geoarheologija Pupićine peći). In: Miracle, P.T., Forenbaher, S. (eds.): Prehistoric herders of northern Istria: the archaeology of Pupićina cave – Pretpovijesni stočari sjeverne Istre: arheologija Pupićine peći. Arheološki Muzej Istre, Vol. 1, 123–162, Pula.

CHAKRABORTY, P.P., SHARMA, R., KUMAR, P. (2019): Earthquake-induced soft sediment deformation (SSD) structures from the Bilara limestone formation, Marwar basin, India. J. Earth Syst. Sci., 128:162.

DALLA VECCHIA, F.M. (2002): Cretaceous dinosaurs in the Adriatic–Dinaric Carbonate Platform (Italy and Croatia): paleoenvironmental implications and paleogeographical hypotheses. Memorie della Società Geologica Italiana, 57, 89–100.

FARLOW, J.O., PITTMAN, J.G., HAWTHORNE, J.M. (1989): *Brontopodus birdi*, Lower Cretaceous sauropod footprints from the U.S. Gulf Coastal Plain. In: Gillette, D.D., Lockley, M.G. (eds.). Dinosaur Tracks and Traces, 371–394. Cambridge University Press, Cambridge.

FUČEK, L., VELIĆ, I., VLAHOVIĆ, I., OŠTRIĆ, N., KOROLIJA, B., MATIČEC, D. (1995): Novi podaci o stratigrafiji donje krede otoka Cresa (New data on the Lower Cretaceous stratigraphy of the island of Cres). In: Vlahović, I., Velić, I., Šparica, M. (eds.): Zbornik radova (Proceedings), 1. Hrvatski geološki kongres (1st Croatian Geological Con-

gress), Opatija 18.–21.10.1995., 1, 167–172, Zagreb.
FUČEK, L., MATIČEC, D., VLAHOVIĆ, I., OŠTRIĆ, N., PRTOLJAN, B., KORBAR, T., HUSINEC, A. (2012): Osnovna geološka karta Republike Hrvatske M 1:50 000 – list Cres 2 (Basic Geological Map of the Republic of Croatia 1:50,000 Scale – Cres 2 Sheet). Hrvatski geološki institut, Zagreb.
GUŠIĆ, I., JELASKA, V. (1990): Stratigrafija gornjokrednih naslaga otoka Brača u okviru geodinamske evolucije Jadranske karbonatne platforme (Upper Cretaceous Stratigraphy of the Island of Brač). Jugosl. akad. znan. i umjet., Institut za geološka istraživanja., OOUR za geologiju, 160 p., Zagreb
KORBAR, T. (2009): Orogenic evolution of the External Dinarides in the NE Adriatic region: a model constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates.– Earth-Science Reviews, 96, 296–312.
KREBS, N. (1907): Die Halbinsel istrien: landeskundliche Studie. B.G. Teubner Verlag, Wien.
LIGHTFOOT, E., BONEVA, B., MIRACLE, P.T., ŠLAUS, M., O'CONNELL, T.C. (2011): Exploring the Mesolithic and Neolithic transition in Croatia through isotopic investigations. Antiquity, 85, 73–86.
LOCKLEY, M.G., HUNT, A.P., MEYER, C.A. (1994a): Vertebrate tracks and the Ichnofacies Concept: implication for paleoecology and palichnostratigraphy. In: Donovan, S. (ed.): The Paleobiology of Trace Fossils, Johns Hopkins University Press, Baltimore, 241–268.
LOCKLEY, M.G., MEYER, C.A., HUNT, A.P., LUKAS, S.G. (1994b): The distribution of sauropod tracks and trackmakers. In: Lockley, M.G., Dos Santos, V.F., Meyer, C.A., Hunt, A.P. (eds): Aspect of Sauropod Paleobiology, Gaia, 10, 233–248.
MALEZ, M. (1960): Pećine Ćićarije i Učke u Istri. Prirodoslov. istraživanja, 29, Acta geologica II, 162–256.
MATEŠIĆ, D. (2017): Geološka karta vršnog dijela Učke. Diplomski rad, Rudarsko-geološko-naftni fakultet Sveučilišta u Zagrebu, 51 p., Zagreb.
MATIČEC, D., VLAHOVIĆ, I., VELIĆ, I., TIŠLJAR, J. (1996): Eocene limestones overlying Lower Cretaceous deposits of Western Istria (Croatia): Did some parts of present Istria form land during the Cretaceous? Geologia Croatica, 49/1, 117–127.
MATIČEC, D., FUČEK, L., VELIĆ, I. TIŠLJAR, J. VLAHOVIĆ, I., MARINČIĆ, S. (2020): Geološka karta M 1:50000 područja Rovinj–Limski kanal–Kanfanar–Barbariga. In: Fuček, L., Matičec, D., Vlahović, I., Palenik, D.: Geološka studija spomenika prirode Kamenolom Fantazija – Cava di Monfiorenzo, Hrvatski geološki institut, Zagreb.
MEZGA, A. (2007): Kad su dinosauri šetali Hrvatskom... Priroda, 959, 7–8/07.
MEZGA, A., CVETKO TEŠOVIĆ, B., BAJRAKTAREVIĆ, Z. (2007): First Record of the Dinosaurs in the Late Jurassic of the Adriatic–Dinaridic Carbonate Platform (Croatia). Palaios, 22/2, 188–199.
MEZGA, A., BUCKOVIĆ, D., ŠANTAK, F. (2017): New dinosaur tracksite in the Late Jurassic of Kirmenjak Quarry (Istria). Rivista Italiana di Paleontologia e Stratigrafia, 123/3, 443–454.
MIRACLE, P. (2001): Feast or famine? Epipalaeolithic subsistence in the northern Adriatic basin. Documenta Praehistorica, 28, 177–197.
MIRACLE, P.T., FORENBAHER, S. (2005): Neolithic and Bronze-Age Herders of Pupićina Cave, Croatia. Journal of Field Archaeology, 30/3, 255–281.
MORO, A., SKELTON, P.W., ĆOSOVIĆ, V. (2002): Palaeoenvironmental setting of rudists in the Upper Cretaceous (Turonian–Maastrichtian) Adriatic Carbonate Platform (Croatia), based on sequence stratigraphy. Cretaceous Research, 23/6, 489–508.
PALENIK, D. (2020): Geološka građa i rekonstrukcija tektogeneze središnjega dijela Ćićarije (Geological Structure and Reconstruction of Tectogenesis of the Central Part of the Ćićarija Mt.). Unpublished PhD Thesis, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, 261 p.
ŠIKIĆ, D., PLENIČAR, M. (1975): Osnovna geološka karta SFRJ 1:100 000, Tumač za list Ilirska Bistrica, L33-89 (Basic Geological Map of the SFRY 1:100,000; Geology of the Ilirska Bistrica sheet). Institut za geološka istraživanja Zagreb, Geološki zavod Ljubljana (1967), Savezni geološki zavod, Beograd, 51 p.
ŠIKIĆ, D., POLŠAK, A., MAGAŠ, N. (1969): Osnovna geološka karta SFRJ 1:100 000, List Labin, L33-101. Inst. geol. istraž. Zagreb (1958–1967), Sav. geol. zavod, Beograd.
ŠIKIĆ, D., PLENIČAR, M., ŠPARICA, M. (1972): Osnovna geološka karta SFRJ 1:100 000, List Ilirska Bistrica, L33-89. Inst. geol. istraž. Zagreb, Geol. zavod Ljubljana (1958–1967), Sav. geol. zavod, Beograd.
THULBORN, R.A. (1990): Dinosaur tracks. Chapman and Hall, London, 410 p.
TIŠLJAR, J. (1976): Early-diagenetic and late-diagenetic dolomitization and dedolomitization in the Cretaceous sediments of West and South Istria (Croatia). Geol. vjesnik, 29, 287–321.
TIŠLJAR, J., VELIĆ, I., RADOVČIĆ, J., CRNKOVIĆ, B. (1983): Upper Jurassic and Cretaceous peritidal, lagoonal, shallow marine and perireefal carbonate sediments of istria. Ekskurzija A. In: Babić, Lj., Jelaska, V. (eds.): Contributions to Sedimentology of Some Carbonate and Clastic Units of the Coastal Dinarides. 4th I.A.S. Regional Meeting, Excursion Guide-Book, 13–35, Split 1983, 7–11, Zagreb.
TIŠLJAR, J., VLAHOVIĆ, I., VELIĆ, I., MATIČEC, D., ROBSON, J. (1998): Carbonate facies evolution from the Late Albian to Middle Cenomanian in southern Istria (Croatia): influence of synsedimentary tectonics and extensive organic carbonate production. Facies, 38, 137–152.
VELIĆ, I., TIŠLJAR, J. (1988): Litostratigrafske jedinice u dogeru i malmu zapadne Istre (zapadna Hrvatska, Jugoslavija). Geološki vjesnik, 41, 25–49.
VLAHOVIĆ, I. (1999): Karbonatni facijesi plitkovodnih taložnih sustava od kimeridža do gornjega alba u zapadnoj Istri (Carbonate Facies of Shallow Water Depositional Systems from Kimmeridgian to the Upper Albian in Western Istria – in Croatian). Unpublished PhD Thesis, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, 327 p.
VLAHOVIĆ, I., MATOŠ, B. (2021): Na samom rubu Dinarida – Geologija Parka prirode "Učka" (On the Very Edge of the Dinarides – The Geology of Učka Nature Park). Park prirode Učka, Ičići, 213 p.
VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I., MATIČEC, D., SKELTON, P., KORBAR, T., FUČEK, L. (2003): Main events recorded in the sedimentary succession of the Adriatic Carbonate Platform from Oxfordian to the Upper Santonian in Istria (Croatia). In: Vlahović, I., Tišljar, J. (eds.): Field Trip Guidebook: Evolution of Depositional Environments from the Palaeozoic to the Quaternary in the Karst Dinarides and the Pannonian Basin. 22nd IAS Meeting of Sedimentology. 19–58, Croatian Geological Survey, Zagreb.
VLAHOVIĆ, I., TIŠLJAR, J. VELIĆ, I., MATIČEC, D. (2005): Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. Palaeogeography, Palaeoclimatology, Palaeoecology, 220, 333–360.
VLAHOVIĆ, I., MIKŠA, G., MRINJEK, E., HASIOTIS, S.T., VELIĆ, I., TIŠLJAR, J., MATIČEC, D. (2011): Response of tracemakers to temporary platform drowning: Lower Cenomanian of Southern Istria (Western Croatia). Palaios, 26/9, 567–577.