A BRIEF INTRODUCTION TO THE GEOLOGY OF ISTRIA

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INTRODUCTION

Istria, the largest Croatian peninsula (its area in the Republic of Croatia is 3130 km^2, which is about 90 % of the total area of Istria) is known, among others, for its very interesting geology. For example, outcrops of rocks of a very wide stratigraphic range (almost 170 Ma) are very well exposed, including some very specific stratigraphic units, the deposits are mostly only slightly tectonised, almost all of the traces of dinosaurs in Croatia are discovered in the area of Istria, there are numerous quarries of very different types of building stone, the best visible boundary of the External Dinarides is located in Istria, etc.

Therefore, it is not unusual that several important international and national geological meetings were already held in Istria, e.g. *the 16th European Micropaleontological Colloquium* (BAUER & POLŠAK, 1979; DROBNE, 1979; DROBNE et al., 1979; HAGN et al., 1979; SOKAČ & VELIĆ, 1979), *the 4th Regional Meeting of IAS* (TIŠLJAR et al., 1983), *the 5th Meeting of Sedimentologists of Yugoslavia* (TIŠLJAR & VELIĆ, 1986), *International Symposium on the Evolution of the Karstic Carbonate Platform: Relations with other Periadriatic Carbonate Platforms* (Trieste, 1987 – VELIĆ et al., 1989), as well as *the 1st Croatian Geological Congress* (Opatija, 1995 – BIONDIĆ et al., 1995; GABRIĆ et al., 1995; TIŠLJAR et al., 1995; VELIĆ et al., 1995a, b), *the 80th Summer Meeting of the Italian Geological Society* (Trieste, 2000 – MATIČEC et al., 2000; SAKAČ & GABRIĆ, 2000; ŠPARICA et al., 2000; TIŠLJAR et al., 2000a, b; TUNIS et al., 2000; VELIĆ et al., 2000; VLAHOVIĆ et al, 2000a, b), the *6th International Congress on Rudists* (Rovinj, 2002 – KORBAR et al., 2002; MORO et al., 2002; TIŠLJAR et al., 2002a, b; VELIĆ et al., 2002; VLAHOVIĆ et al., 2002a, b) and 22nd IAS Meeting of Sedimentology (Opatija 2003 – BERGANT et al., 2003; DURN et al., 2003; VELIĆ et al., 2003; VLAHOVIĆ et al., 2003).

Field trips presented in this Guidebook of the 7th Croatian Geological Congress are based on the traditional division by KREBS (1907), who divided Istria into three large-scale units according to the colour of the prevailing lithology, based on historical Italian names (Fig. 1). **Field trip A1** (GULAM et al., this Vol.) is focused on **Grey Istria** (*Istria grigia*) characterised by turbidite deposits, **Field trip A2** (DURN et al., this Vol.) on **Red Istria** (*Istria rossa*) characterised by carbonate rocks covered by the red Mediterranean soil – *terra rossa*, while participants of the **Field trip A3** (PALENIK et al., this Vol.) will visit the area of the **White Istria** (*Istria bianca*) composed mostly of light-coloured carbonate rocks as well as two interesting quarries located in western Istria.

The geological literature on lstria spans more than two centuries, including some extraordinary studies like Guido Stache's "Die Liburnische Stufe und deren Grenz-Horizonte" (STACHE, 1889). General data on the geology of lstria, including the most important previous publications, can be found in the sheets and explanatory notes of the 1:100,000 scale Basic Geological Map of SFRY, published some sixty years ago: Trst (PLENIČAR et al., 1969, 1973), Ilirska Bistrica (ŠIKIĆ et al., 1972; ŠIKIĆ & PLENIČAR, 1975), Rovinj (POLŠAK & ŠIKIĆ, 1969, 1973), Labin (ŠIKIĆ et al., 1969a; ŠIKIĆ & POLŠAK, 1973), Cres (MAGAŠ, 1968, 1973) and Pula (POLŠAK, 1967a, 1970). The geology of Istria has also been presented in several important papers based on investigations conducted for the Basic Geological Map of SFRY, e.g. POLŠAK (1965a, b, 1967b), ŠIKIĆ & BLAŠKOVIĆ (1965), ŠIKIĆ et al. (1969b), and MAGDALENIĆ (1972). The list of older references should be completed by the discussions of the geology of E–SE Istria, written by Marijan Salopek, especially the classic paper on thrust sheets in Ćićarija and Učka Mts. (SALOPEK, 1954).

From the mid-1960's to the mid-1980's there were no systematic geological investigations of regional significance in lstria. However, it should be noted that, in the 1970's, detailed lithofacies and biofacies investigations of shallow water carbonates in Istria started (e.g., TIŠLJAR, 1976, 1978a, b; SOKAČ & VELIĆ, 1978; TIŠLJAR & VELIĆ, 1986, l987).

Recent investigations for the new Basic Geological Map of the Republic of Croatia (lithostratigraphic map in 1:50,000 scale) started in Istria in the mid-1980's. In the

We dedicate this work to the memory of our dear friend, the late Professor Josip Tišljar (1941–2009), fellow of the Croatian Academy of Sciences and Arts, who was the fourth member of the Istrian team.

course of these investigations new and interesting results have been obtained, which have been increasingly published in Croatian and international journals (VELIĆ & TIŠLJAR, 1987, 1988; MARINČIĆ & MATIČEC, 1988, 1989, 1991; BARIŠIĆ et al., 1994; MATIČEC, 1994; MATIČEC et al., 1996; TIŠLJAR et al., 1994, 1998; VELIĆ & VLAHOVIĆ, 1994; VLAHOVIĆ et al., 1994). Three sheets of the new Basic Geological Map of the Republic of Croatia covering the territory of Istria have been published so far: Rovinj-1 (MATIČEC et al., 2017), Rovinj-2 (BERGANT et al., 2020) and Rovinj-3 (MATIČEC et al., 2015).

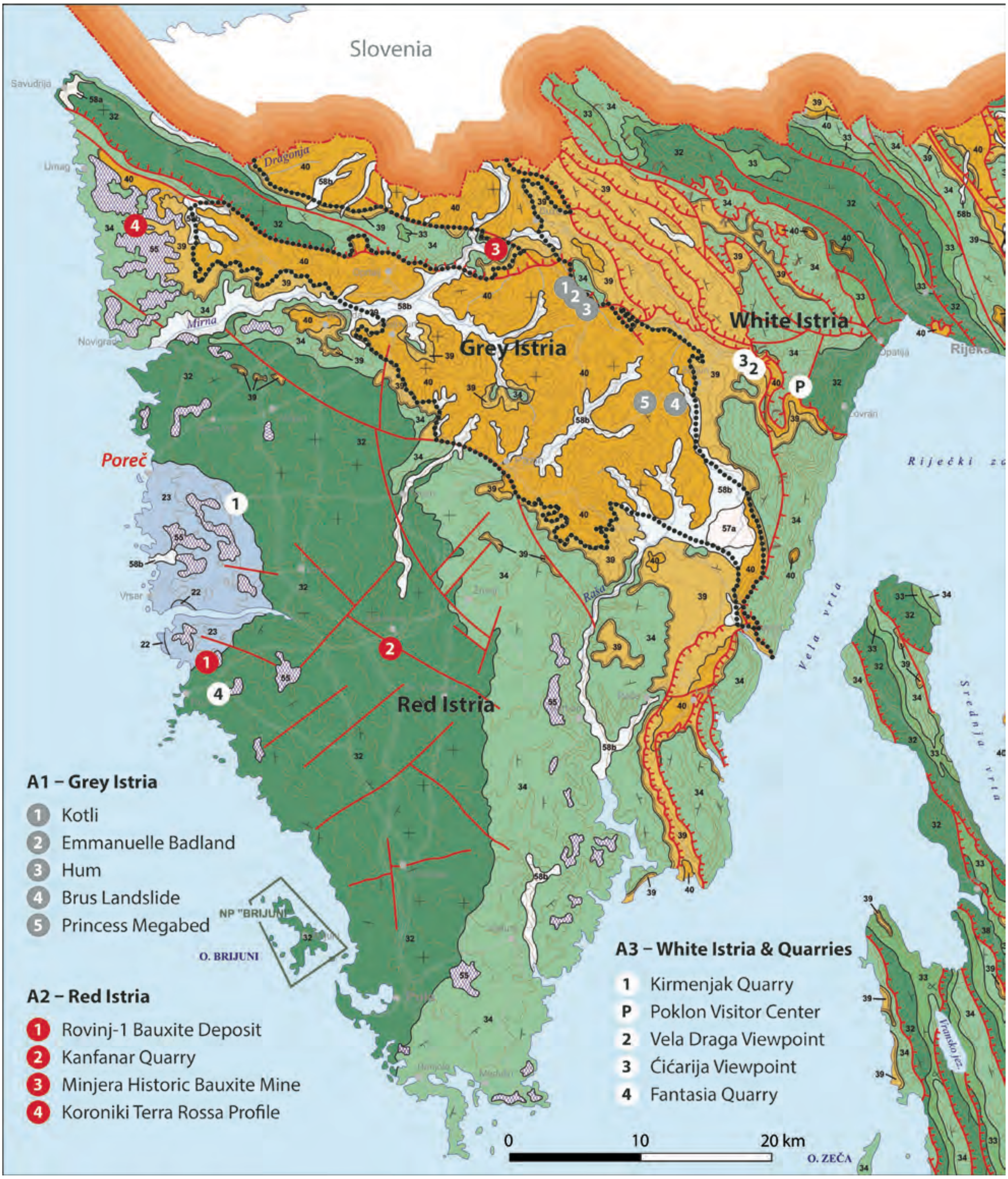

Fig. 1. Geological map of Istria (after CROATIAN GEOLOGICAL SURVEY, 2009) with location of field trip stops: grey circles Field trip A1 – Grey Istria (GULAM et al., this Vol.), red circles Field trip A2 – Red Istria (DURN et al., this Vol.), white circles Field trip A3 – White Istria & Quarries (PALENIK et al., this Vol.). Legend for lithological units (for more details see VELIĆ & VLAHOVIĆ, 2009): 22 – Thick-bedded limestones and dolomites (Middle Jurassic); 23 – Limestones and dolomites (Upper Jurassic); 32 – Limestones and dolomites (Lower Cretaceous); 33 – Dolomites and post-sedimentary diagenetical breccia (upper Albian–lower Cenomanian); 34 – Rudist limestones (Cenomanian–upper Santonian); 39 – Kozina limestones, Foraminiferal limestones and Transitional beds (lower–middle Eocene); 40 – Flysch deposits (middle–upper Eocene); 55 – Terra rossa (Holocene); 57a – Lake deposits (Holocene); 58a – Deluvial–proluvial deposits (Holocene); 58b – Alluvial deposits (Holocene).

New data were obtained also by several specialised investigations (e.g., DALLA VECCHIA et al., 1993, 2000a, b, 2001, 2002; DALLA VECCHIA & TARLAO, 1995; DALLA VECCHIA, 1998; DINI et al., 1998; MEZGA & BAJRAKTAREVIĆ, 1999; DURN et al., 2000; MORO & ĆOSOVIĆ, 2000; MEZGA et al., 2003). Most important recent literature on geology of Istria can be found in this guidebook, in description of field trips **A1** (GULAM et al., this Vol.), **A2** (DURN et al., this Vol.) and **A3** (PALENIK et al., this Vol.).

This introduction to geology of Istria is based on the review papers written as an introduction to field trip guidebooks of the 1st Croatian Geological Congress and 22nd IAS Meeting of Sedimentology (VELIĆ et al., 1995a, 2003).

STRATIGRAPHIC AND PALAEOGEOGRAPHICAL EVOLUTION OF ISTRIA

Although intense synsedimentary and postsedimentary Palaeogene and Neogene tectonics have significantly affected the area of the former Adriatic Carbonate Platform and its overlying deposits, resulting in formation of mostly very complex tectonic structures, there are some localities with quite well-preserved stratigraphic records enabling recognition of important events in the geological history. Istria is probably the most important among them, located on the NW part of the Adriatic coast.

From the geological point of view, Istria can be divided into three regions (Fig. 1):

- the Jurassic–Cretaceous (and partly Eocene) carbonate plain of western and southern Istria,
- the Eocene flysch basin in central Istria, and
- the Cretaceous–Eocene predominantly carbonate area characterised by intense compressional tectonics in eastern and northeastern Istria (Učka and Ćićarija Mts.).

The geological peculiarities of these regions had been noticed historically by the inhabitants of lstria who, as already mentioned, coined specific names for them (KREBS, 1907). *Red Istria* represents the western and southern Istrian plain named after the red Mediterranean soil *terra rossa* covering a large part of the Jurassic, Cretaceous and Eocene carbonates. *Grey Istria* (or sometimes also referred to as *Green Istria* due to the heavy vegetation) is covering the area of central Istria, composed of Eocene turbidite deposits. *White Istria* encompasses area in eastern and northeastern Istria, characterised by karstified outcrops of light-coloured Cretaceous–Eocene limestones.

The Istrian succession consists predominantly of carbonate rocks ranging in age from late Middle Jurassic to Eocene, with subordinate Eocene clastic rocks (turbidites), and Quaternary *terra rossa* and loess deposits. The Istrian late Middle Jurassic to Eocene succession can be divided into four megasequences, i.e. large-scale stratigraphic sequences bounded by important unconformities of different duration, and covered by Quaternary deposits (VELIĆ et al., 1995a, 2003). Evidence for their chronostratigraphic determination will be discussed later. The following large-scale sequences have been distinguished (Figs. 2, 3):

1) M1 Megasequence (Bathonian–lowermost Kimmeridgian);
2) M2 Megasequence (upper Tithonian–lower/upper Aptian);
3) M3 Megasequence (upper Albian–upper Santonian);
4) M4 Megasequence (Eocene).

M1 Megasequence (Bathonian–lowermost Kimmeridgian)

The oldest Istrian megasequence, M1 (Figs. 2, 3), is mainly characterised by a shallowing- and coarsening-upward trend, including in places the *Rovinj breccia* (VELIĆ & TIŠLJAR, 1988), ending in major unconformity U1 with bauxite occurrences and deposits. This Bathonian–lowermost Kimmeridgian megasequence is represented predominantly by different types of shallow-water limestones, which crop out in western Istria, between Poreč and Rovinj (Fig. 2).

During the Bathonian and Callovian restricted shallow subtidal and lagoonal environments prevailed, characterised by medium- to thick-bedded mudstones and fossiliferous wackestones (the *Monsena Unit* – VELIĆ & TIŠLJAR, 1988). Bathonian deposits include evidences of mild synsedimentary tectonics (MARINČIĆ & MATIČEC, 1991). Similar depositional environments continued into the early Oxfordian, with deposition of peloidal packstones and wackestones (the *Lim Unit* – VELIĆ & TIŠLJAR, 1988). During the middle and late Oxfordian prograding sand bars composed of ooids and bioclasts were formed in high-energy shallows and the marginal parts of lagoons (tidal bars of TIŠLJAR & VELIĆ, 1987, or the *Muča Unit* of VELIĆ & TIŠLJAR, 1988). The shallowing-upward tendency continued to the end of the Oxfordian, and during the probable earliest Kimmeridgian resulted in the formation of the regressive *Rovinj* (*Vrsar*) *breccia*, representing the end of this megasequence. Breccia is composed of clasts from the immediate footwall (*Lim* and *Muča limestones*). Complete subaerial exposure and karstification followed, which is shown by the formation of locally high relief associated with an accumulation of source-material for the formation of clayey bauxites. In some places important quantities of bauxite have been formed, e.g., near Rovinj, and to a lesser extent NW from Rovinjsko selo, near Gradina, as well as between Vrsar and Funtana (ŠINKOVEC, 1974). For more data concerning this level see Stops 1 and 2 in VLAHOVIĆ et al. (2003), Stop 1 in DURN et al. (2003) and Stop 1 in DURN et al. (this Vol.).

Middle Jurassic and Oxfordian successions in other parts of the AdCP are also characterised by shallow-water carbonates, deposited mostly within restricted inner parts of the platform (rarely within higher-energy environments as in the southern Adriatic area, with abundant ooids and bioclasts). However, the Kimmeridgian represented a period of significant palaeogeographic changes within the

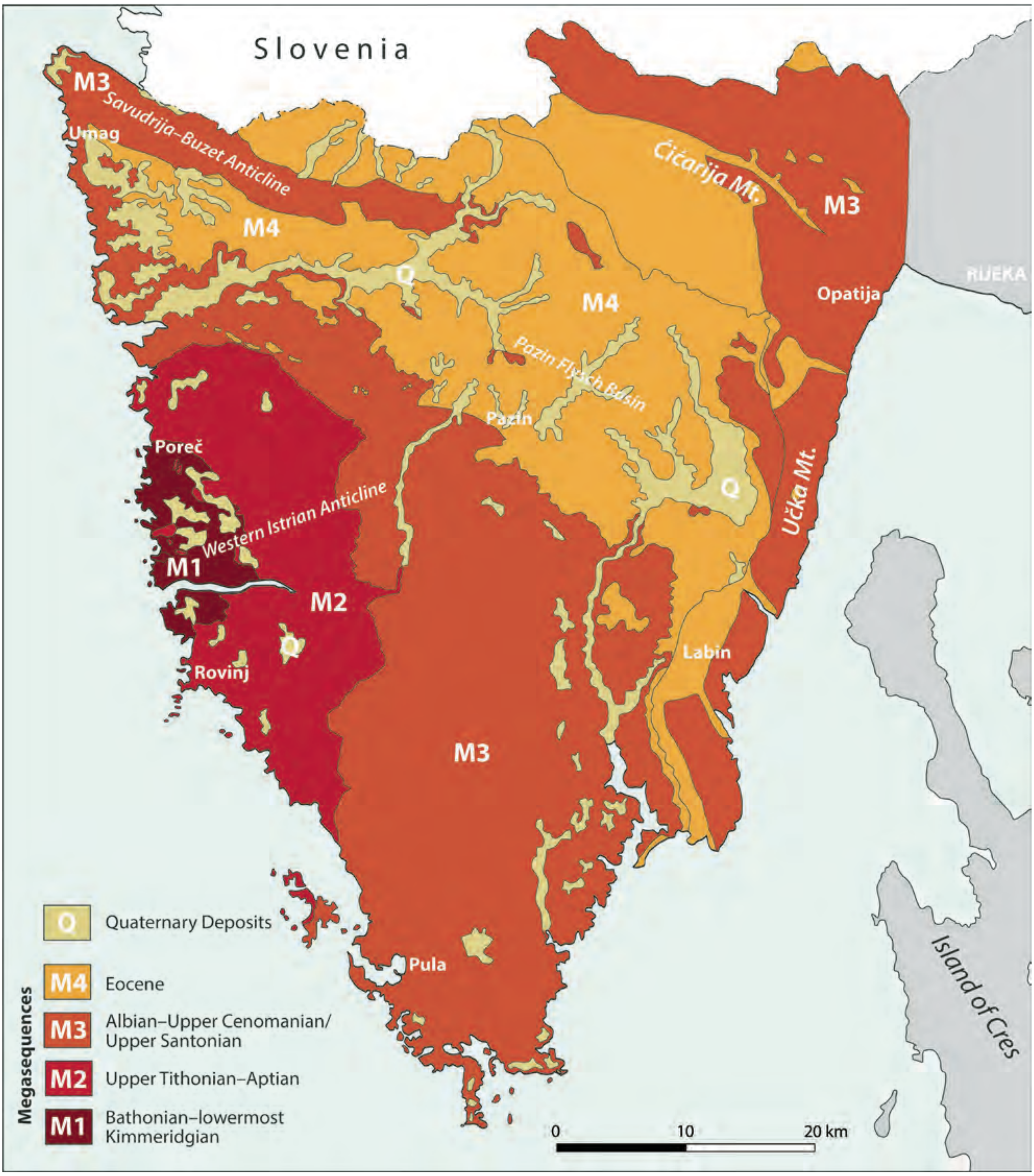

Fig. 2. Map of the Istrian peninsula showing four depositional megasequences separated by regional unconformities, modified after VELIĆ et al. (1995, 2003).

formerly relatively uniform platform realm due to the obduction of ophiolites along the northeastern Adriatic Microplate margin (SCHMID et al., 2008).

The subaerial exposure with bauxite formation in Istria corresponds to the level characterised by significant palaeokarstification in large part of the AdCP (e.g., Kimmeridgian of Biokovo Mt. – TIŠLJAR et al., 1989; TIŠLJAR & VELIĆ, 1991; Stop 8 in BENČEK et al., 2003; NNE part and the platform margin in central and SE Slovenia – DOZET & MIŠIČ, 1997; NW Bosnia – VRHOVČIĆ et al., 1983; E Herzegovina – NATEVIĆ & PETROVIĆ, 1967; W and N Montenegro – VUJISIĆ, 1972; MIRKOVIĆ & MIRKOVIĆ, 1987).

Penecontemporaneously in the central part of the platform deeper troughs with temporary connection to the open sea were formed, characterised by deposition of limestones with cherts and ammonites (FURLANI, 1910; CHOROWICZ & GEYSSANT, 1972; VELIĆ et al., 1994; BUCKOVIĆ, 1995; Stops 2 and 5 in BUCKOVIĆ et al., 2003). These deeper areas were surrounded by reefs

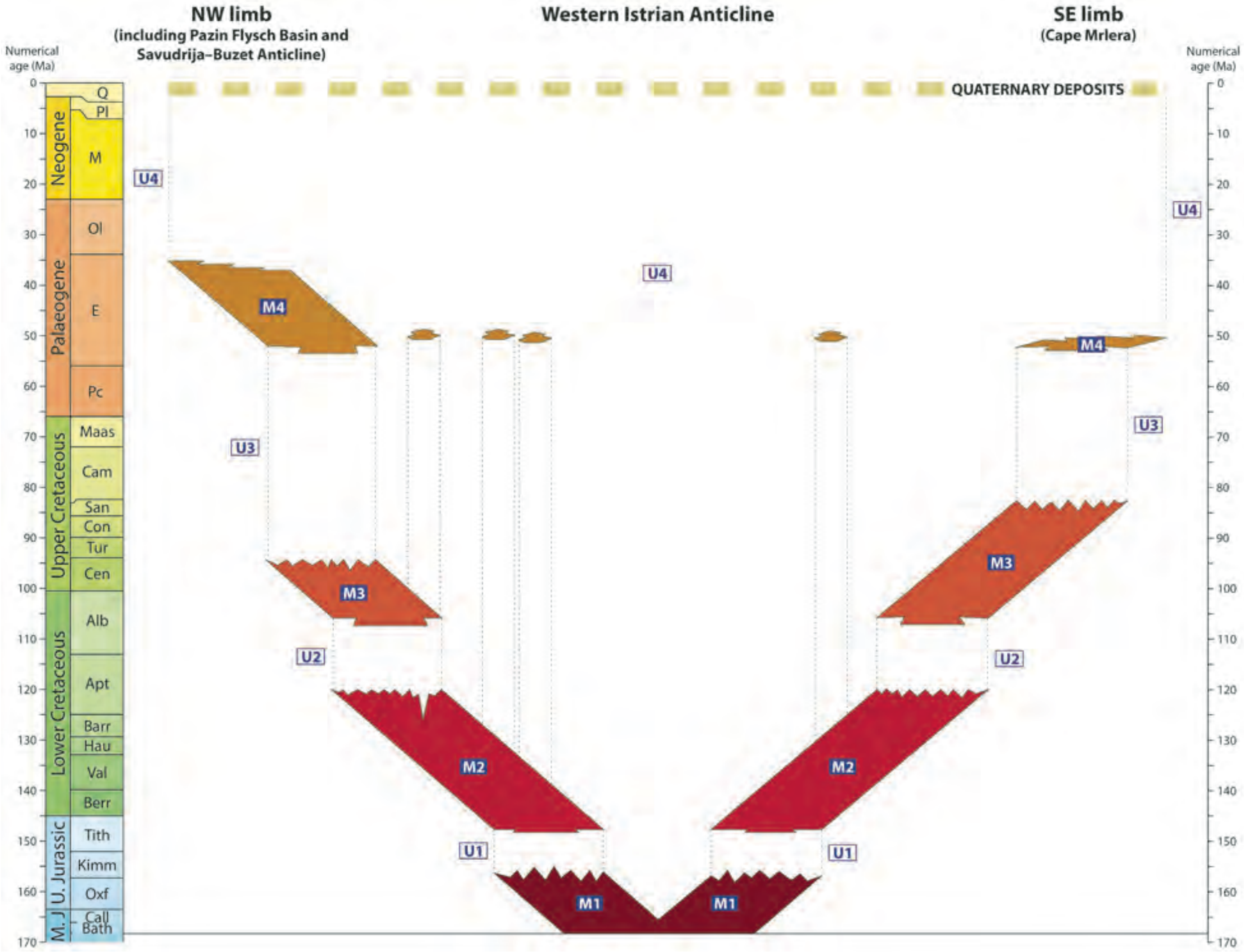

Fig. 3. Schematic geological columns of the Istrian peninsula showing four depositional megasequences (M1–M4) separated by regional unconformities (U1–U4); modified after VELIĆ et al. (2003). Vertical scale in Ma.

and ooid shoals, and were, during the late Kimmeridgian and Tithonian, completely filled by their progradation.

The Kimmeridgian succession along the NE margin of the AdCP is characterised by transgression over the area which was subaerially exposed since Early Jurassic (BUKOVAC et al., 1974, 1984).

During the Tithonian the entire area was again united into a relatively uniform shallow water carbonate platform, representing the beginning of the M2 Megasequence in Istria.

M2 Megasequence (upper Tithonian–lower/upper Aptian)

The second megasequence of Istria is very complex due to its facies heterogeneity and significant thickness. Peritidal deposits characterised by peloid limestones and LLH-stromatolites predominate, with subordinate breccia with clayey matrix formed during short-lasting subaerial exposures (in Tithonian, Hauterivian, Barremian), early- and late-diagenetic dolomites (during Berriasian), and grainstones (bioclastic sand bar deposits typical for upper Valanginian and upper Barremian). Deposits of the M2 Megasequence crop out in the form of an arc (Fig. 2) from Poreč, near Kanfanar and Bale, to the coast from Rovinj to the Brijuni islands.

M2 Megasequence started in the late Tithonian with an oscillating transgression, i.e. dm–m scale shallowing-upward cycles deposited in subtidal, intertidal and supratidal environments (see Stops 1 and 2 in VLAHOVIĆ et al., 2003 and Stop 1 in DURN et al., this Vol.). These limestones, known as architectural-building stone *Pietra d'Istria* or *Kirmenjak*, are composed of black-pebble breccia/conglomerates, mudstones and fenestral mudstones with desiccation cracks (including probably the oldest dinosaur tracks in Istria – MEZGA et al., 2003; Stop 1 in PALENIK et al., this Vol.). The uppermost part of the upper Tithonian limestones is heavily late-diagenetically dolomitised (Stop 1 in VLAHOVIĆ et al., 2003).

Relative shallowing during the Berriasian and older Valanginian resulted in the alternation of subtidal and intertidal limestones which were almost completely late-diagenetically dolomitised and early-diagenetic dolomites deposited in supratidal environments. This alternation of late- and early-diagenetic dolomites is known as the *Fantasia dolomite* (VELIĆ & TIŠLJAR, 1988; see Stop 3 in VLAHOVIĆ et al., 2003 and Stop 4 in PALENIK et al., this Vol.).

In the late Valanginian mainly subtidal parasequences prevailed, sporadically characterised by a coarsening-upward tendency. A similar situation, but with numerous short-lasting subaerial exposure surfaces, continued in the

Hauterivian and a major part of the Barremian, when shallowing-upward cycles were characterised by frequent LLH-stromatolites (see Stop 4 in VLAHOVIĆ et al., 2003), numerous subaerial exposure surfaces and peritidal breccia. Footprints of dinosaurs have been found in such Barremian rocks on the island of Veli Brijuni, as well as bones on the sea floor near the western coast of Istria (Stop 5 in VLAHOVIĆ et al., 2003).

By the end of the Barremian, bioclastic carbonate sand bars characterised by cross-bedding were deposited in shallow subtidal–intertidal environments. The transition to the Aptian was characterised by a change in the depositional system into restricted lower subtidal and/or lagoonal environments with sporadic pelagic influences, due to a relatively important relative sea-level rise connected with oceanic anoxic event OAE-1a (HUCK et al., 2010). Therefore, the lower Aptian deposits are characterised by thick-bedded to massive floatstones with *Bacinella irregularis* oncoids and requieniid rudists (*Toucasia* sp.), which are well-known as the architectural-building stone *Istarski žuti* (*Yellow Istrian* – named after its yellowish colour).

Upper Aptian deposits in Istria indicate a relatively rapid shallowing, resulting in subaerial exposure. This regional unconformity (U2 on Fig. 3) was the result of a relative sea-level fall caused by the interaction of eustatic changes and synsedimentary tectonics on the Istrian part of the Adriatic Carbonate Platform. These movements resulted in the variable duration of shallow-water environments on different parts of the platform, as well as in the different intensity of erosion of the Aptian and Barremian deposits. Finally, the end of the M2 Megasequence was marked by deposition of carbonate breccia and conglomerates, with clay and dark grey swamp deposits, which are well exposed in numerous quarries in western Istria, from Punta Furlan, Baderna, Heraki, Selina, Kanfanar, Bale, Negrin and Barbariga to Veli Brijun. Between Selina and Negrin, uneroded relics of Upper Aptian deposits have been found. The deepest erosion, locally to the Barremian, was reported from west of Heraki to Červar (VELIĆ et al., 1989).

For more information on the youngest, Aptian part of this succession and the regional unconformity U2 see Stop 6 in VLAHOVIĆ et al. (2003), Stops 3 and 4 in DURN et al. (2003) and Stop 2 in DURN et al. (this Vol.).

M3 Megasequence (upper Albian–upper Santonian)

The third megasequence of Istrian deposits (Figs. 2 and 3) is thick and characterised by a very variable facies succession.

After extensive subaerial exposure during the late Aptian and early Albian, at first a gradual, and later a complete ingression occurred during the middle Albian, which was fully accomplished by the beginning of the late Albian. Thus the shallow-water platform carbonate system was re-established for the next 10–20 Ma over the whole area of the Adriatic Carbonate Platform that today belongs to Istria.

Several depositional systems can be recognized within the M3 Megasequence:

a) peritidal and foreshore sedimentary system during the middle and late Albian;
b) significant differentiation of sedimentary systems during the latest Albian and early to middle Cenomanian;
c) drowned platform system during the late Cenomanian and early Turonian;
d) mostly shallow-water sedimentary system during late Turonian, Coniacian and Santonian.

Middle and upper Albian deposits

The lower part of this unit is characterised by an oscillating transgression in the middle Albian, covering the previously completely subaerially exposed area of Istria. In the late Albian a thick sequence of thin-bedded (5–20 cm) grainy limestones was deposited in peritidal and foreshore environments. These are mostly well sorted, fine-grained intraclastic-peloidal packstone–grainstones alternating with foraminiferal-peloid packstones–wackestones, with rare LLH-stromatolites. The uppermost part of the Albian deposits is commonly represented by limestone breccia (mostly formed in peritidal environments during severe storms), grainy limestones with gently inclined cross-bedded sets and current ripples, and diagenetic quartz deposits (Stop 5 in DURN et al., 2003).

Uppermost Albian and lower–middle Cenomanian deposits

The transition from the Early to the Late Cretaceous was marked by the establishment of different sedimentary environments in northern and southern Istria (VLAHOVIĆ et al., 1994).

In northern Istria (the Umag–Savudrija–Buzet area), stable peritidal conditions continued into the earliest Cenomanian. The younger part of the early Cenomanian and the older part of the middle Cenomanian were characterised by the facies differentiation of a formerly united depositional area. In the western part of northern Istria, subtidal mudstones and peloid wackestone–packstones with benthic foraminifera and rudist debris were succeeded by cycles with thicker subtidal members consisting of mudstones and foraminiferal-bioclastic wackestones and thinner intertidal fenestral mudstones and LLH-stromatolites. In the central part of northern Istria, near Marušići, a large prograding carbonate sand body composed of well-sorted bioclastic packstone–grainstones was deposited in upper shoreface and foreshore environments. In the eastern part of northern Istria bioclastic, storm-deposited wackestones, packstones and grainstones, and locally mudstones and chert nodules and layers were deposited on a gently inclined inner carbonate ramp. By the end of the Cenomanian, such a highly differentiated depositional area was filled up, resulting in the re-establishment of united environments characterised by an irregular alternation of light-coloured mudstones and rudist floatstones.

In southern Istria, the latest Albian and early to middle Cenomanian shoreface depositional system was formed, influenced by synsedimentary tectonics, resulting in deposition of slumps, tempestites, carbonate sand and rudist clinoforms and biolithite bodies (TIŠLJAR et al., 1998; VLAHOVIĆ et al., 2011). The boundary between these deposits and the middle to upper Cenomanian limestones is sharp, represented by a change from massive and thick-bedded clinoform bioclastic bodies into thin-bedded (5–25 cm) limestones deposited in low energy shallow-water environments. In the following succession, peloid-bioclastic wackestone–packstones and peloid grainstones predominate, while 30–70 cm thick rudist biostromes and chondrodontid coquinas are infrequent.

A more detailed description and interpretation of the uppermost Albian to middle Cenomanian part of the succession is presented at Stops 7 and 8 in VLAHOVIĆ et al. (2003)

An interesting feature of this unit in southern Istria are chert nodules and lenses found within well-bedded peloid packstones ("limestones with chert" – POLŠAK, 1965b). Although these limestones contain calcitised radiolarians and sponge spicules (which is why they were formerly interpreted as being of deep-marine origin), they appear in a succession of typical peritidal facies. The chert nodules and lenses were formed by early-diagenetic silicification of carbonate mud in low-energy lagoons (TIŠLJAR, 1978a).

Upper Cenomanian and lower Turonian deposits

By the end of the Cenomanian and at the beginning of the Turonian, a drowned platform depositional system was established over most of the Adriatic Carbonate Platform, including southern Istria, resulting in the deposition of "limestones with ammonites" (POLŠAK, 1965b), i.e. mudstone–wackestones with planktonic fauna (common calcispheres and planktonic foraminifera with rare ammonites), as a result of a global eustatic rise related to the oceanic anoxic event OAE-2 (GUŠIĆ & JELASKA, 1993).

These deposits are described at Stop 9 in VLAHOVIĆ et al. (2003).

This drowning event, which left traces on a large part of the Adriatic Carbonate Platform, was not recorded in northern Istria – on the contrary, upper Cenomanian beds became subaerially exposed and covered by bauxites and transgressive Eocene deposits (see Stop 6 in DURN et al., 2003; Stop 3 in DURN et al., this Vol.). The succession of Cenomanian deposits in northern Istria compared to southern Istria indicate the important role of synsedimentary tectonics recorded in neighbouring areas (ŚRODOŃ et al., 2018), which locally modified changes in bathymetry caused by global eustacy to a significant extent (VLAHOVIĆ et al., 1994).

Upper Turonian, Coniacian and Santonian deposits

During the late Turonian, Coniacian and Santonian a shallow-water platform depositional system was re-established over large part of modern-day Istria. It was represented by well-bedded limestones with an alternation of thin layers of mudstone, bioclastic wackestone/packstone and stromatolite laminae in the older part, and mostly thin-bedded rudist coquinas/microcoquinas/biostromes in the younger part of the succession (TIŠLJAR, 1978a). Rudist biostromes are infrequent, because they were mostly destroyed in relatively high-energy environments, with biodetritus deposited in their vicinity. The youngest part of the Cretaceous succession is missing, as a result of a long-lasting subaerial exposure caused by synsedimentary tectonics.

For more information on the upper Santonian deposits see Stop 10 in VLAHOVIĆ et al. (2003).

M4 Megasequence (Eocene)

The fourth megasequence in Istria comprises a relatively thick succession of carbonate and clastic rocks (Figs. 2 and 3). Its greatest part crops out in the Pazin Flysch Basin and neighbouring areas. For more information on the Eocene succession see Stops 11 and 12 in BERGANT et al. (2003) and Field trip A1 (GULAM et al., this Vol.).

Stratigraphic hiatus between the Upper Cretaceous and Eocene deposits (DROBNE, 1977; in places even Lower Cretaceous and Eocene deposits – MATIČEC et al., 1996) is variable from area to area. Different members of the Eocene succession were transgressively deposited over different parts of the Cretaceous succession, due to the synsedimentary tectonic movements (MATIČEC et al., 1996). Consequently, the succession of Eocene deposits is very variable both laterally and vertically. In general, the deposits can be divided into the so-called Kozina deposits, Foraminiferal limestones, Transitional beds and Flysch.

Kozina deposits are only locally present, since they were deposited in the lowest parts of the palaeorelief. They are characterised by deposition during oscillating transgression, and are mostly represented by fresh-water to brackish and lagoonal deposits of the lower Eocene age ("Cuisian"/Ypresian, DROBNE, 1977). These deposits are presented at Stop 6 in DURN et al. (2003) and Stop 3 in DURN et al. (this Vol.).

Foraminiferal limestones in Istria can be divided into three or four lithostratigraphic types deposited from the "Cuisian"/Ypresian to the middle–late Lutetian (ĆOSOVIĆ & DROBNE, 1998), which are mostly in superpositional relationships. These are usually referred to as miliolid, alveolinid, nummulitid and orthophragminid (or discocyclinid) limestones. The foraminiferal limestones are composed of whole and broken larger foraminifera tests, with subordinate detritus of molluscs, ostracods, echinoderms, bryozoans and corallinacean algae, as well as glauconite grains and planktonic foraminifera in the uppermost part. The succession of foraminiferal limestones represents a gradual change of different environments, from the restricted inner part of the carbonate platform (miliolid limestones), through shallower and deeper parts of shoreface environments (alveolinid and nummulitid limestones) to deeper parts of a relatively open carbonate ramp (orthophragminid limestones). Although described varieties are not always of the same age due to the different palaeogeographic position, a general deepening-upward trend is always present. Such a tendency is a consequence of the complex interaction of synsedimentary tectonics and a relatively low sedimentation rate (due to deposition in environments which were no longer ideal for carbonate production, as well as a significant redeposition of the material to deeper parts of the basin).

Transitional beds comprise a range between slope and deep marine deposits. So-called 'marls with crabs' represent the lower part of the Transitional beds as a thin package of nodular-shaped clayey limestones composed of fine-grained matrix with variable amount of glauconite. The fossil content is composed of planktonic foraminifera, bioclasts of benthic organisms and the often well preserved shells of crabs and echinoderms. The upper part of the Transitional beds consists of up to several tens of meters thick massive 'globigerina marls' rich in planktonic foraminifera and glauconite grains, deposited in significantly deeper environments of middle to late Lutetian age (middle Eocene).

Istrian flysch deposits crop out in the Pazin Flysch Basin, Brkini Flysch Basin, at Učka Mt., and partly on Ćićarija Mt. They are generally characterised by an alternation of hemipelagic marls and gravity-flow deposits. The prevailing turbiditic succession of calcareous and calcareous–siliciclastic sandstones and marls is randomly intercalated with thick carbonate debrite beds, usually referred to as megabeds. The flysch deposits are middle to upper Eocene in age (BENIĆ, 1991). The depth of their deposition was concluded to be of bathyal range based on morphotype associations of smaller benthic foraminifera (ŽIVKOVIĆ, 1996). The total thickness of Istrian flysch deposits is estimated at up to 350 m. For more information on turbidite deposits and very important postsedimentary processes recorded in them see Field trip A1 (GULAM et al., this Vol.)

Quaternary deposits

Deposits of all four megasequences of Istrian carbonates and clastic deposits are irregularly covered by a relatively thin Quaternary deposits. The most important are loess and terra rossa (for more information on Quaternary deposits see Stops 2, 7 and 8 in DURN et al., 2003, and Stop 4 in DURN et al., this Vol.), although there are also other types of palaeosols and soils (including swamp deposits – e.g. MEISCHNER, 1995).

BASIC CHARACTERISTICS OF TECTONICS OF ISTRIA

The tectonic pattern of the Croatian part of Istria is composed of three structural units (Fig. 2). The Western Istrian Anticline comprises the largest part of western and southern Istria, being composed of carbonate deposits of the Middle and Upper Jurassic in its oldest part, surrounded by Cretaceous and Eocene carbonates. The area of the Učka Anticline along the eastern margin of the Istrian peninsula represents a more deformed part of the same unit. The second unit, the Pazin Flysch Basin, is composed of a relatively thin Eocene limestones and thick flysch deposits, cropping out in the central and NW parts of the peninsula. The third unit, the only part of Istria belonging to the Dinarides, is composed of structures of Ćićarija Mt. and the Učka Klippe in the northern and eastern part of Istria (see Stop 10 in VLAHOVIĆ et al., 2003, and Stops 2 and 3 in PALENIK et al., this Vol.), built mostly of Upper Cretaceous and Eocene carbonates.

The oldest evidence of tectonic activity in Istria has been found in the upper Bathonian deposits (MARINČIĆ & MATIČEC, 1991). However, Middle Jurassic outcrops can be found only in the coastal area north of Rovinj, and partly in the Limski kanal, excluding the possibility for regional correlation of their effects. These movements resulted with locally subaerially exposed deposits and a more variable relief of the depositional area due to the mild compression oriented 40–220° (in today geographic coordinates).

After a brief stratigraphic hiatus, marine deposition was reestablished until the beginning of the Kimmeridgian, when the area of Istria was subaerially exposed (through the most of the Kimmeridgian and early Tithonian). This regionally well-expressed unconformity (U1 on Fig. 3) was caused by the obduction of ophiolites along the northeastern Adriatic Microplate margin (SCHMID et al., 2008).

Tectonic activity during the Cretaceous was caused by mild synsedimentary tectonic movements occurring throughout the period, because the Western Istrian Anticline had already been formed in the Early Cretaceous (MATIČEC et al., 1996). The oldest evidence of its existence is from the Hauterivian, although elements of synsedimentary tectonics are visible in even older, Berriasian rocks (see Stop 4 in PALENIK et al., this Vol.). The hinge of this gentle brachyanticline structure probably remained subaerially exposed throughout the rest of the Cretaceous, i.e. until the Eocene transgression. There are several evidences supporting that, including:

- The exposed succession NE of the anticline axis towards the Pazin Flysch Basin is more or less continuous from the Bathonian to various levels of the Upper Cretaceous. There is no evidence for intense tectonic activity (the present structure is characterised by bed inclinations of only up to 8°), nor eroded material.
- Eocene foraminiferal limestone outcrops have been found directly overlying the Valanginian, Hauterivian, Barremian, Albian and Cenomanian deposits.

– Bauxites from the footwall of the Eocene limestones were deposited in the palaeorelief of both Cenomanian and Albian limestones. This fact, together with the transgressive Eocene foraminiferal limestones covering deposits of very different ages, excludes the possibility of continuous deposition of a complete Lower and Upper Cretaceous succession and its subsequent complete erosion prior to deposition of the Eocene foraminiferal limestones.
– The subaerially exposed area was inhabited by dinosaurs from Tithonian to the Maastrichtian as indicated by their footprints and bones. Such animals needed a large quantity of fresh potable water and terrestrial vegetation for their survival.
– Similar succession can be traced offshore towards the SW, along the extension of the core of the Western Istrian Anticline (VESELI, 1999).

All determined Cretaceous synsedimentary tectonic movements and the structures that they formed indicate the same orientation of stress, in accordance with the orientation of the Western Istrian Anticline. The hinge of the Western Istrian Anticline dips northeastward (towards 35°) and the greatest regional stress were oriented 125–305°.

By the end of the Cretaceous, almost the entire Adriatic Carbonate Platform, including the area of Istria, was subaerially exposed, with stratigraphic hiatus of very variable duration. The Late Cretaceous tectonic events initiated the disintegration of the former carbonate platform area, and marked the end of typical, productive platform carbonate sedimentation, since renewed marine conditions in the Eocene were mostly controlled by intense synsedimentary tectonics.

The Eocene transgression was a consequence of a new deformation. The intensity of these movements was witnessed by the formation of foreland basins filled by turbiditic deposits, as synorogenic deposits indicating the final uplift of the Dinarides. The result of this tectonic activity is visible along the Adriatic coastline by the so-called Dinaric strike of structures (NW–SE). However, as already mentioned and discussed in more details in description of Stop 2 of the Field trip A3 (PALENIK et al., this Vol.), only a minor part of Istria was included into the Dinarides, i.e. the areas of Western Istrian Anticline (including the Učka Anticline along the eastern margin of the Istrian peninsula) and Pazin Flysch Basin were not intensely tectonically deformed and they represent undeformed part of the Adriatic Microplate, i.e. Dinaric foreland. Deformation of the contact area with the Dinarides (Ćićarija Mt. and Učka Klippe), indicate several phases of deformation: (1) formation of the Pazin Flysch Basin, a typical foreland basin filled by turbiditic deposits; (2) formation of the Učka Anticline along the eastern margin of Istria with specific N–S strike and Eocene flysch deposits uplifted to 1,000 m asl; (3) refolding of the northern part of the Učka Anticline structures by typical Dinaric deformation (main stress oriented NE–SW) and formation of the complex Ćićarija Mt. fold and thrust structures; (4) thrusting of Učka Klippe (today an erosional remnant of the assumed much larger Učka Nappe structure) characterised by a very specific lithology on top of the Učka Anticline; (5) intense weathering of the Ćićarija Mt. area resulting in erosion of other parts of the assumed Učka Nappe.

Neotectonic deformation in the entire External Dinarides is a consequence of the N–S oriented greatest regional stress. Neotectonic activity comprised either the formation of new neotectonic structures, reactivation of inherited old brittle structures into the regional strike-slip faults, or rotation of already existing structures to adjust to the new stress orientation.

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