# A brief insight into the Upper Triassic to Miocene sedimentary succession of the External Dinarides, SE of Dubrovnik (southern Croatia)

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## Abstract

The Konavle area located in the very southeast of the Republic of Croatia encompasses a large part of the entire External Dinarides sedimentary sequence, almost 5 km in thickness. It consists of two geologically and geomorphologically different parts, the Donja Banda and the Gornja Banda, separated by one of the most significant faults in the Dinarides, the so-called High Karst Nappe, which divides two regional tectonic units: the less disturbed Adriatic or Dalmatian Zone to the SW and the intensely deformed High Karst Unit to the NE. The Donja Banda as a part of the Dalmatian Zone is composed of Upper Cretaceous carbonates and Palaeogene carbonate and clastic deposits. The Gornja Banda as a part of the High Karst Unit represents a thick sequence of Upper Triassic, Jurassic and Lower Cretaceous carbonate deposits monoclinally inclined towards the SE, passing into Bosnia and Herzegovina where the younger Cretaceous and Palaeogene deposits crop out.

The first part of the field trip includes three stops in the Gornja Banda area, with a detailed elaboration of the deposition of shallow-water deposits of the older part of the AdCP. It comprises upper Toarcian–lower Aalenian coated-grain dominated carbonates, upper Kimmeridgian shallow subtidal and peritidal facies with subaerial exposure breccias, and uppermost Tithonian peritidal, laminite-capped cycles with dasyclads and faecal pellets.

The second part presents some typical examples of the Upper Cretaceous carbonates and Palaeogene carbonate and clastic deposits of the Konavle region, in order to place them in the regional context of the evolution of the AdCP and External Dinarides. It comprises the oldest Upper Cretaceous rocks in the area, the Santonian–Campanian Gornji Humac fm. and a brief overview of the recent seismicity of the Dubrovnik region, Maastrichtian limestones representing the top of the Cretaceous, Palaeocene(–lower Eocene?) carbonates marking the end of the Adriatic Carbonate Platform in Konavle, Eocene Foraminiferal limestones, Palaeogene clastic deposits and a visit to Medieval fortress of Sokol Grad.

## Introduction

The Konavle area belongs to the Dubrovnik–Neretva County in the very southeast of the Republic of Croatia (Fig. 1). It is the southernmost part of Croatia, about 34 km long and 2–12 km wide, located between the Adriatic Sea to the southwest, Bosnia and Herzegovina to the north, and Montenegro to the east. About 8,600 inhabitants live in 32 settlements in an area of 209 km$^2$, of which a little over 2,000 live in the municipal centre, Cavtat.

Konavle is part of the Dinarides, a mountain range that stretches about 650 km along the northeast Adriatic coast from western Slovenia, through Croatia and Bosnia and Herzegovina to Montenegro and Albania. Specifically, it belongs to the External Dinarides (Schmid *et al.*, 2008; Korbar, 2009), created by the tectonic disintegration of a several kilometres thick succession of predominantly shallow-marine carbonates deposited on the Adria Microplate basement (Vlahović *et al.*, 2005).

### Brief geological history of the External Dinarides

The stratigraphic succession of the External Dinarides can be divided into three parts, with the largest part of the carbonate succession comprising the central part – the Adriatic Carbonate Platform (AdCP) succession (Fig. 2). A summary of the entire stratigraphic succession was given by Vlahović *et al.* (2005), based on which we present a concise account below.

The oldest deposits cropping out in the External Dinarides area are of Upper Carboniferous age (Moscovian, approximately 310 Ma), and they, together with most of the Permian rocks are represented by clastic deposits related to the weathering of Pangea.


**Fig. 1.** Location map showing the itinerary of Field Trip A1, location of Stops 1–3 in the Gornja Banda area and Stops 4–9 in the Donja Banda area.

Very diverse deposits accumulated in the Late Permian, with shallow water carbonate deposits becoming more common in the youngest Permian and in the Triassic. The Upper Triassic alternation of early diagenetic and late diagenetic dolomite, for which the German name Hauptdolomit (Main Dolomite) from the Northern Calcareous Alps is mostly used, stands out here. The younger, Jurassic–Cretaceous AdCP dolomites resulted from climate-influenced post-depositional reflux dolomitization (as opposed to synsedimentary peritidal- and deeper burial dolomitization), and subsequent stabilization within a Mesozoic, calcite sea isolated platform (Read *et al.*, 2016). The Triassic–Jurassic transition is marked by an alternation of late diagenetic dolomites and shallow-marine limestones, characterized in the Pliensbachian and early Toarcian by locally numerous shells of lithiotid bivalves, a typical facies in numerous Perimediterranean carbonate platforms.

An important change occurred during the Toarcian, when the interplay of extensional tectonics and the Toarcian oceanic anoxic event (T-OAE; Sabatino *et al.*, 2013) significantly slowed down carbonate sedimentation and created two deeper troughs along the northeastern edge (Slovenian–Bosnian Trough) and the southwestern edge (Adriatic Basin) of the present-day External Dinarides, separating the former extensive shallow water carbonate area into several palaeogeographical entities: shallow-marine carbonate platforms (e.g. Apenninic Carbonate Plat-

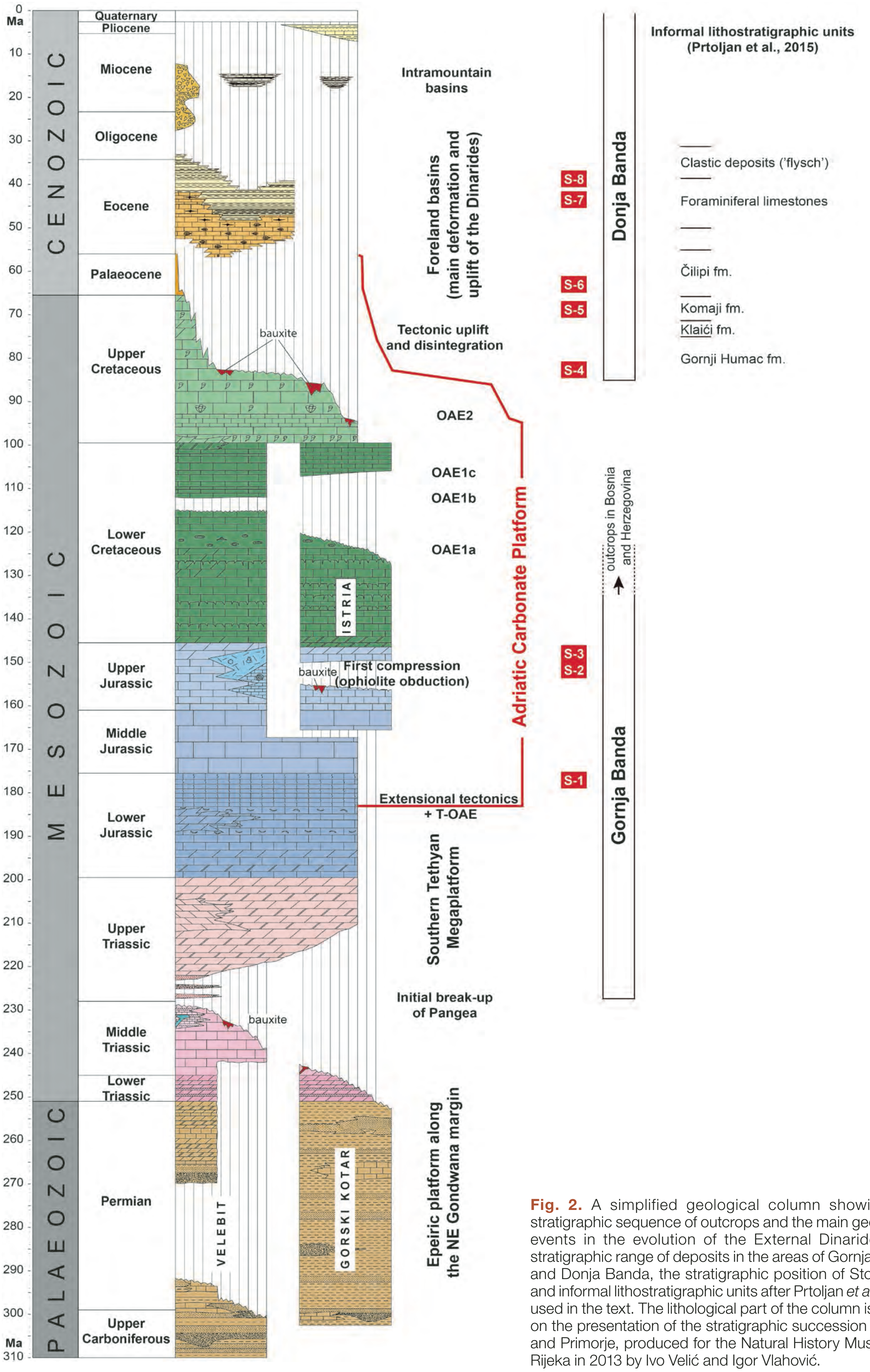



**Fig. 2.** A simplified geological column showing the stratigraphic sequence of outcrops and the main geological events in the evolution of the External Dinarides, the stratigraphic range of deposits in the areas of Gornja Banda and Donja Banda, the stratigraphic position of Stops 1–8 and informal lithostratigraphic units after Prtoljan *et al.* (2015) used in the text. The lithological part of the column is based on the presentation of the stratigraphic succession of Istria and Primorje, produced for the Natural History Museum of Rijeka in 2013 by Ivo Velić and Igor Vlahović.

form, Apulian Carbonate Platform and Adriatic Carbonate Platform) divided by the deeper marine basins. The Adriatic Carbonate Platform (Gušić & Jelaska, 1990; Velić *et al.*, 2002; Vlahović *et al.*, 2002, 2005) was one of the largest and best preserved Mesozoic platforms in the Perimediterranean region. Although the Adriatic Carbonate Platform is the most commonly used name today, the platform is also referred to as the Adriatic–Dinaric Carbonate Platform (e.g., Jenkyns, 1991; Jelaska, 2003), Adriatic–Dinaridic Carbonate Platform (e.g., Pamić *et al.*, 1998; Cvetko Tešović *et al.*, 2001; Korbar, 2009), Adriatic Platform (e.g. Husinec & Read, 2006, 2022), or Dinaric Carbonate Platform (e.g., Črne & Goričan, 2008; see also Field trip A2, this vol.).

During the Middle Jurassic, deposition on the platform was characterized by the long-term gradual subsidence (Husinec & Read, 2022), whilst during the Late Jurassic, especially the Kimmeridgian, the first compressional event caused by the obduction of ophiolites along the northeastern margin of the Adria Microplate occurred, resulting in significant facies differentiation. Some areas of the SW part (in today's geographic coordinates) of the AdCP were subaerially exposed for several million years (in places with significant bauxite deposits), some parts became temporary intraplatfom troughs (Gorski Kotar, northern Dalmatia), while shallow-marine carbonate production continued in the remaining part (Vlahović *et al.*, 2005).

The uppermost Jurassic and Lower Cretaceous deposits are predominated by typical subtidal to intertidal carbonates with a few significant disconformities. The facies are stacked into meter-scale parasequences, which are in turn arranged into bundles, and then into disconformity bounded 3rd-order sequences; the cycles have retained evidence of orbital (Milankovitch) forcing of sea level (e.g., Husinec & Read, 2018; Husinec *et al.*, 2022, 2023). The only significant flooding event recorded on the AdCP during the latest Jurassic–Early Cretaceous is associated with OAE 1a, which is locally marked by deposition of relatively shallow water, but dysaerobic laminated carbonates (Husinec *et al.*, 2012). A major part of the upper Aptian is missing due to a regional emergence phase that lasted until early or late Albian. Albian deposits were typically accumulated in very shallow environments and are very similar throughout the AdCP. Oceanic anoxic events 1b and 1c were documented by chemostratigraphy but, unlike OAE1a, they are not associated with deepening and dysaerobic conditions on platform top (Husinec & Read, 2018). The Cenomanian succession is marked by significant facies differentiation that marks the onset of the final disintegration of the platform, as a result of the gradual approach of the Adria Microplate to the Eurasian Plate. The beginning of the uplift of individual large structural blocks began c. 100 My ago, around the Albian–Cenomanian boundary (Srodon *et al.*, 2018), and therefore some parts of the AdCP, like northern Istria, were already emergent during the Late Cenomanian (and some parts even in the Early Cretaceous – see Matičec *et al.*, 1996). Deposition in the younger part of the Late Cretaceous was thus characterized by significant palaeogeographic dynamics, although almost the entire AdCP was temporarily drowned during the late Cenomanian and early Turonian due to events related to the OAE-2 (Gušić & Jelaska, 1990; Korbar *et al.*, 2012; Brčić *et al.*, 2021). Subsequent partial drowning of individual tilted blocks was also locally recorded. During the Late Cretaceous the platform gradually finally emerged in stages, mainly between the late Turonian and Santonian, affected also by the development of a forebulge of the progressively approaching Dinaridic orogeny (Korbar, 2009). At the end of the Cretaceous, almost the entire AdCP was emergent, with the exception of small areas in the extreme NW (near the Slovenian–Italian border NE of Trieste) and the areas of southern Dalmatia and the southern part of Bosnia and Herzegovina (Korbar, 2009). In the Konavle area, the sedimentation continued until the end of Palaeocene, followed by the emergence marking the cessation of typical shallow-marine carbonate deposition, and the end of the Adriatic Carbonate Platform.

The stratigraphic hiatus between the Cretaceous (or Palaeocene in the aforementioned areas with a continuous K/Pc transition) and the Eocene was of very different duration, due to the formation of complex foreland basins in front of the uplifting Dinarides (see also Field trip C2, this vol.). The marginal parts of the mostly asymmetric foreland basins were characterized by the deposition of Foraminiferal limestones, a typical succession of different species indicating a gradual deepening of the carbonate ramp environments, followed by the so-called Transitional beds – deposits of marls with glauconite. The deeper parts of foreland basins were filled with thick turbidite deposits, which in some places are almost exclusively carbonate in composition. Parts with a higher input of material from the uplifted areas of the Alps and the Dinarides include a significant proportion of siliciclastic components. The top parts of the turbidite succession are mostly missing due to erosion or subsequent tectonic deformation (folding, reverse faulting and thrust tectonics) related to the final uplift of the Dinarides, and only in some areas is a regressive sequence from deeper marine to continental deposits preserved, usually referred to as the Promina Deposits (for more information see Field trip C2, this vol.). In some areas of Velebit Mt., Lika and some northern Adriatic islands a specific massive carbonate breccia referred to as the Jelar Deposits (Bahun, 1963, 1974), Jelar Formation (Herak & Bahun, 1979) or Velebit Breccia (Vlahović *et al.*, 2012) crops out, approximately determined as Oligocene to Miocene in age.

During the Neogene, spatially limited intramountain basins characterized by lacustrine sedimentation were formed within the Dinarides area, in some places characterized by very thick deposits (for more information see Field trip A3, this vol.).

## Geology of Konavle

A large part of the entire External Dinarides sedimentary succession can be seen in Konavle (with a total thickness of more than 4500 m – Prtoljan *et al.*, 2015), part of which will be seen on this field trip. Konavle consists of two geologically and geomorphologically different parts that are in tectonic contact, locally called the Donja Banda and Gornja Banda (which could be translated as Lower Part / Upper Part or Lower Side / Upper Side; Figs. 1–3). The Donja Banda covers the area from the Adriatic Sea in the southwest to the northeastern edge of the Konavosko polje, and is composed of Upper Cretaceous carbonates and Palaeogene carbonate and clastic deposits. The Gornja Banda represents a thick succession of Upper Triassic, Jurassic and Lower Cretaceous carbonate deposits monoclinally inclined towards the SE, passing into Bosnia and Herzegovina where the younger Cretaceous and Paleogene deposits crop out.

The contact between the Donja Banda and Gornja Banda represents one of the most significant faults

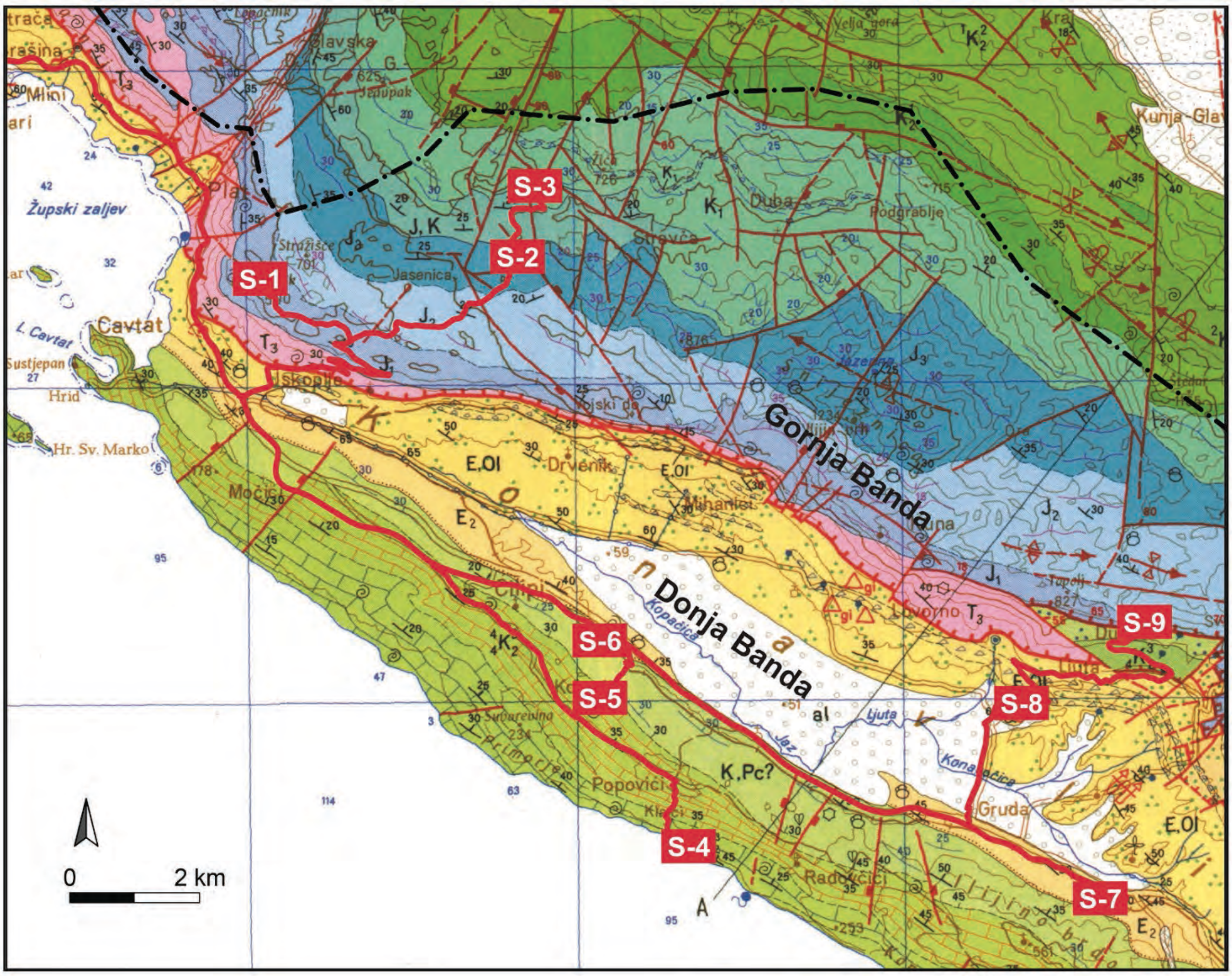



**Fig. 3.** Part of the old Basic Geological Map of SFRY in 1:100,000 scale, Dubrovnik sheet (Inst. geol. istraž. Beograd, 1971) showing the itinerary of Field Trip A1, location of Stops 1–3 in the Gornja Banda area and Stops 4–9 in the Donja Banda area.

in the Dinarides, the so-called High Karst Nappe, which divides two regional tectonic units: the less disturbed Adriatic or Dalmatian Zone to the SW and the intensely deformed High Karst Unit to the NE (Auboin *et al.*, 1970; Cadet, 1978). Although this fault is usually supposed to exist along the entire External Dinarides range, it is clearly documented only from southern Montenegro to the vicinity of Split (a length of about 275 km).

The first part of our field trip will include three stops on the Gornja Banda (Figs. 1–3), where we will focus on the deposition of the deeper subtidal to supratidal deposits and discuss the sequence stratigraphic framework of the older part of the Adriatic Carbonate Platform: one stop in the Lower–Middle Jurassic and two in the Upper Jurassic section.

In the second part of the field trip, we will briefly visit six stops representing some typical parts of the Upper Cretaceous carbonates and Palaeogene carbonate and clastic deposits of the Konavle region, in order to place them in the regional context of the evolution of the AdCP and External Dinarides (Figs. 2 and 3). As part of this, we will also briefly discuss present day seismotectonic activity in the SE part of the Dinarides. The field trip will conclude with a visit to the medieval fortress of Sokol Grad located on top of the huge olistolith, which will both complete and unite our trip: it is built on a disintegrated part of the Gornja Banda located within the Donja Banda.

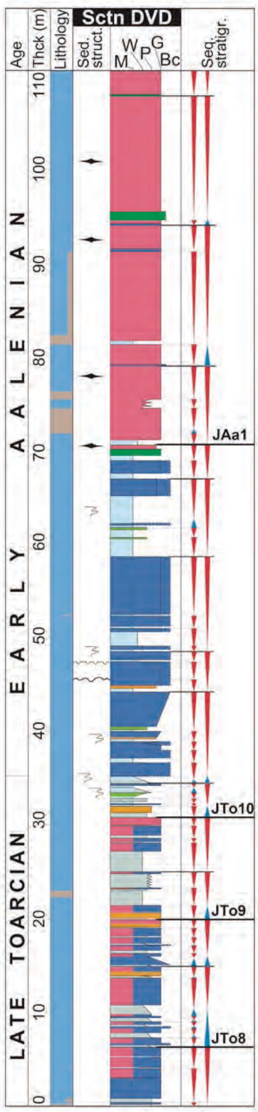
## Description of field stops

## Gornja Banda

### Stop 1: Upper Toarcian–lower Aalenian coated-grain dominated carbonates: upward shallowing from deeper subtidal/outer ramp to oolitic-peloidal sand sheets

The Jurassic succession of the Adriatic Carbonate Platform contains abundant non-skeletal coated grains that formed in a range of settings, from normal-marine, outer-ramp deeper subtidal to hypersaline shallow subtidal environments (Tišljar, 1985; Tišljar *et al.*, 2002; Vlahović *et al.*, 2005; Husinec & Read, 2006, Sabatino *et al.*, 2013; Husinec *et al.*, 2022). The most abundant coated grains are sand- to granule-size oncoids that are ubiquitous in varied subtidal settings, from high-energy shoals to low-energy deeper subtidal, where filamentous microbes trapped and bound fine sediment around a range of nuclei. Also common are sand-size tangential ooids that are similar to modern concentrically-coated ooids found in shallow-water (<3 m), high tidal-energy areas inward from isolated platform margins (e.g., Harris *et al.*, 2019). The least common but perhaps

**Fig. 4.** Adriatic Sea vista from Stop 1 with Cavtat (left) built on the Upper Cretaceous limestone, and the city of Dubrovnik in the distance (right).



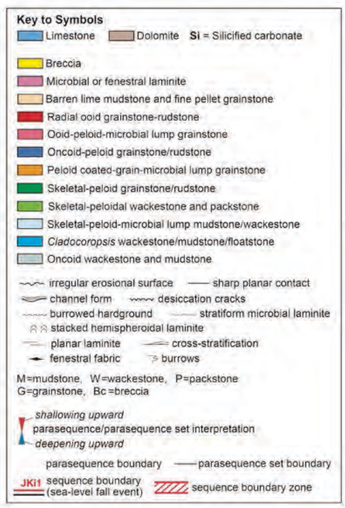




**Fig. 5.** Stratigraphic column DVD showing gross lithology, sedimentary structures, facies stacking, and sequence stratigraphy at Stop 1 (modified from Husinec & Read, 2022). For location, see Figures 1 and 3.

the most interesting are granule-size, dark, commonly broken and re-coated radial ooids with superimposed vadose fabrics that formed along the shores of shallow hypersaline ponds and restricted lagoons, similar to modern low-energy lake and marginal-marine pond ooids (e.g., Loreau & Purser, 1973).

Stop 1 (Figs. 1–3) comprises a short walk with a nice Adriatic Sea view (Fig. 5) to the ~110 m thick Velji Do road-cut section (Fig. 5), observation of the outcropping Upper Toarcian–Lower Aalenian oncolitic and oolitic grain-supported limestones (Figs. 6–8), and a short walk to rejoin the bus. The lower

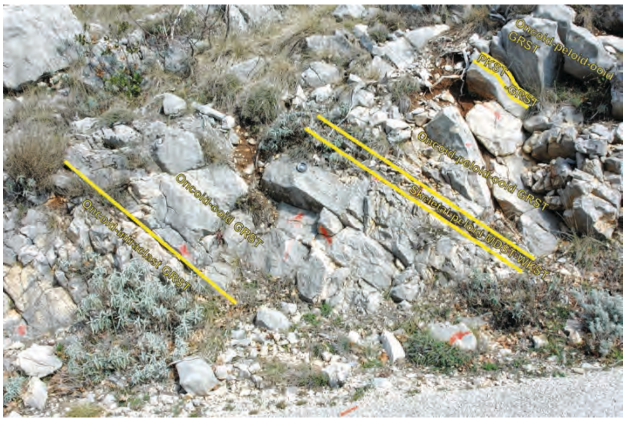



**Fig. 6.** Outcrop photograph of Upper Toarcian thin- to medium-bedded orange-brownish carbonates with coated grains; Dunham rock types are indicated (modified from Moynihan *et al*., 2016). Lens cap for scale is 5 cm.

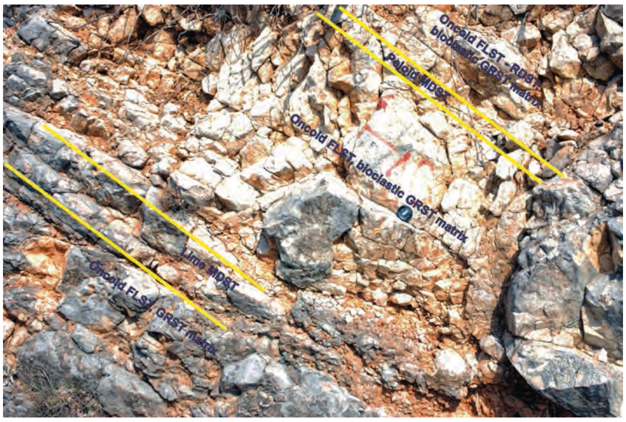



**Fig. 7.** Outcrop photograph of Lower Aalenian coated grain-rich, predominantly grainy carbonates; Dunham rock types are indicated (modified from Moynihan *et al*., 2016). Lens cap for scale is 5 cm.

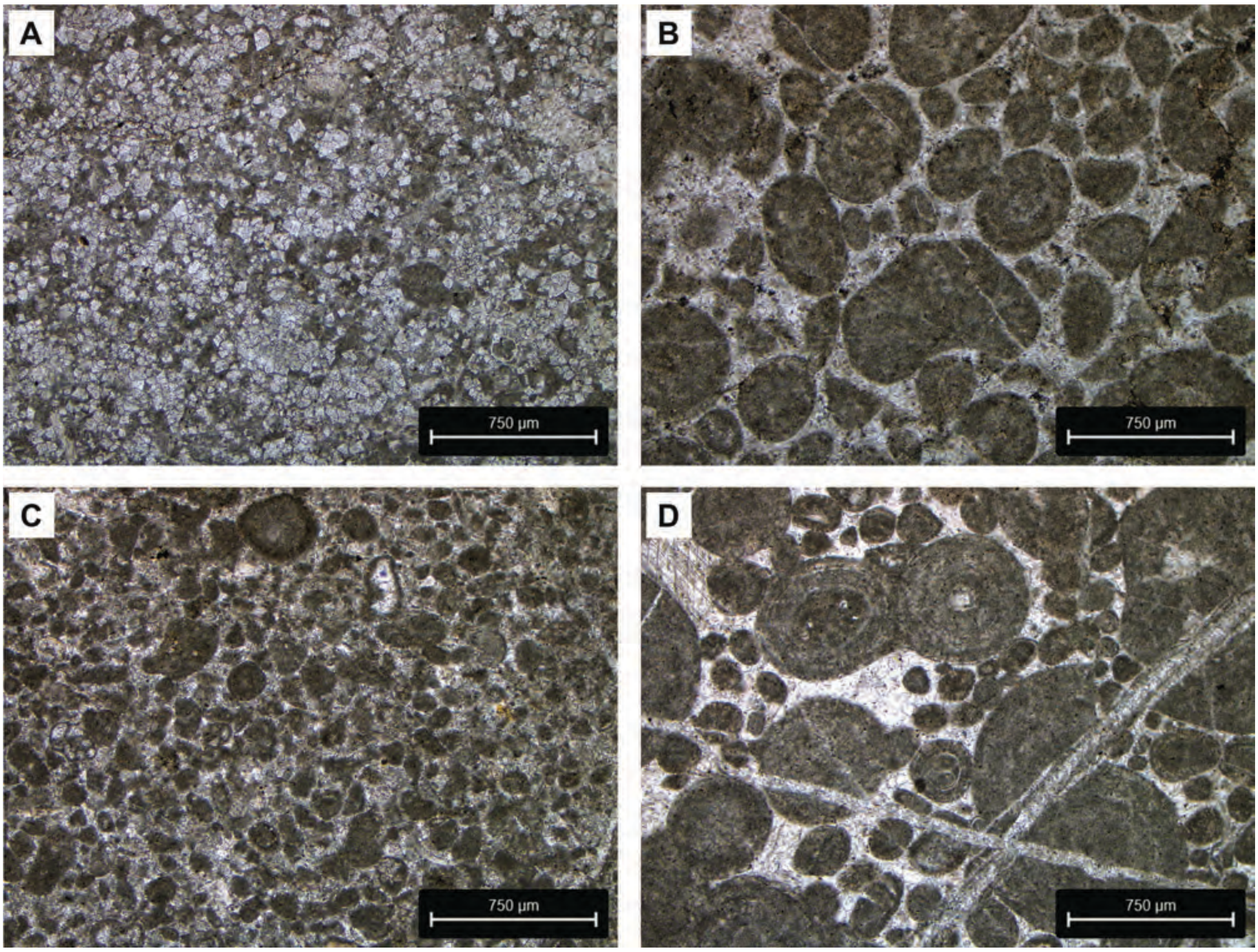



**Fig. 8.** Thin-section photomicrographs of selected microfacies. (A) Dolomitized fine peloid mudstone-wackestone (foreshoal/outer ramp), upper Toarcian. (B) Peloid-intraclast-ooid grainstone (foreshoal), upper Toarcian. (C) Fine peloid packstone-grainstone (foreshoal), upper Toarcian. (D) Ooid-peloid grainstone (ooid-peloid sand sheet), lower Aalenian.

~35 m of the section consists of dark gray to orange-brown, thin-bedded, predominantly deeper subtidal limestones regionally known as densely burrowed *Fleckenkalk* facies, with the German name marking its characteristic appearance with spots or blotches due to bioturbation and associated burrow-facilitated dolomitization. In the absence of index fossils, the Late Toarcian age is suggested based on the stratigraphic position between the underlying upper Pliensbachian–lower Toarcian lithiotid limestones, and the overlying lower Aalenian medium- to thick-bedded limestones. The latter comprise the upper ~75 m of the section and indicate a general shallowing-upward trend into the lower Aalenian.

The poorly cyclic subtidal cycles that characterize the upper Toarcian–lower Aalenian interval in this area have recently been described by Husinec *et al.* (2022) and are summarized here. An ideal shallowing-upward parasequence (cycle) in the upper Toarcian part of the section consists of a basal dark-gray, weakly burrowed oncoid-peloid wackestone–packstone that grades up into fine peloid packstone–grainstone, which is in turn overlain by dark gray to orange-brown oncoid packstone, grainstone, and rudstone. These, on average 1.5 m-thick cycles, exhibit shallowing upward from deeper subtidal/outer ramp to foreshoal and oolitic-peloidal sand sheet settings. The basal Aalenian has thicker cycles (mean ~2 m) commonly with burrowed mudstone–wackestone (outer ramp) overlain by thick oncoid grainstone–rudstone (foreshoal). The remaining lower Aalenian succession is made up of thick units of white to tan ooid-peloid-oncoid grainstone (ooid-peloidal sand sheets) with rare fenestrae and burrows. These form caps to thick parasequences (mean thickness of ~4 m) with thin basal skeletal mudstone to grainstone (shallow subtidal), or oncoid-peloid grainstone (high-energy shallow subtidal).

Oncoids are the major rock-forming grains in the lower 2/3 of the Velji Do road-cut section. Their shape commonly reflects the type of nucleus, with spherical/subspherical oncoids having laminated coats around peloid cores, whereas ellipsoidal oncoids tend to have bioclastic cores (commonly bivalve or gastropod fragments). The occurrence of oncoids in a range of facies/environments around the Toarcian–Aalenian boundary, coupled with their morphological variability, suggests that microbes and bottom-water oxygenation likely played an important role in their formation (cf., Zhang *et al.*, 2015). The early Toarcian global warming and the associated anoxic event (T-OAE) with worldwide deposition of organic-rich black shale in oceanic basins (e.g., Jenkyns, 1988; Bailey *et al.*, 2003; McElwain *et al.*, 2005) has also resulted in lowered bottom-water oxygen levels on the platform (e.g., Velić *et al.*, 2002). This likely resulted in reduced grazing metazoan populations, allowing for a microbial bloom and increased oncoid production at that stage. The earliest Aalenian abrupt cooling (Korte *et al.*, 2015) and the associated eustatic sea-level fall (Haq, 2018) marked the beginning of the Middle Jurassic cold interval (Gómez *et al.*, 2009; Price, 2010). In the study area, this corresponds to a major shallowing of the platform from deeper subtidal Toarcian facies upwards into basal Aalenian oncoid-skeletal and thick ooid grainstone facies.

## Stop 2: Upper Kimmeridgian shallow subtidal and peritidal facies with subaerial exposure breccias

The greenhouse Kimmeridgian climate was characterized by the highest reconstructed seawater temperatures during the Middle and Late Jurassic, which then decreased into the latest Kimmeridgian–early Tithonian (Dera *et al.*, 2011). During the Kimmeridgian, varied shallow-marine environments flourished on the AdCP, with several larger emergent areas characterized by extensive karstification and bauxite deposition, and smaller intraplatform troughs with deep-water, organic-rich, and cherty limestones with radiolarians and ammonites (e.g., Tišljar *et al.*, 2002; Velić *et al.*, 2002; Vlahović *et al.*, 2005). In the study area, the Kimmeridgian deposits are disconformity prone and comprise the highstand systems tract of the regional Callovian–basal Tithonian supersequence JSS3 (Husinec & Read, 2022; Husinec *et al.*, 2022).

**Fig. 9.** Panorama showing Brotnice village (front) and gently sloping Kimmeridgian–basal Tithonian strata (centre). The lower part of the BK section visited at Stop 2 is above the bend in the road (centre-left).

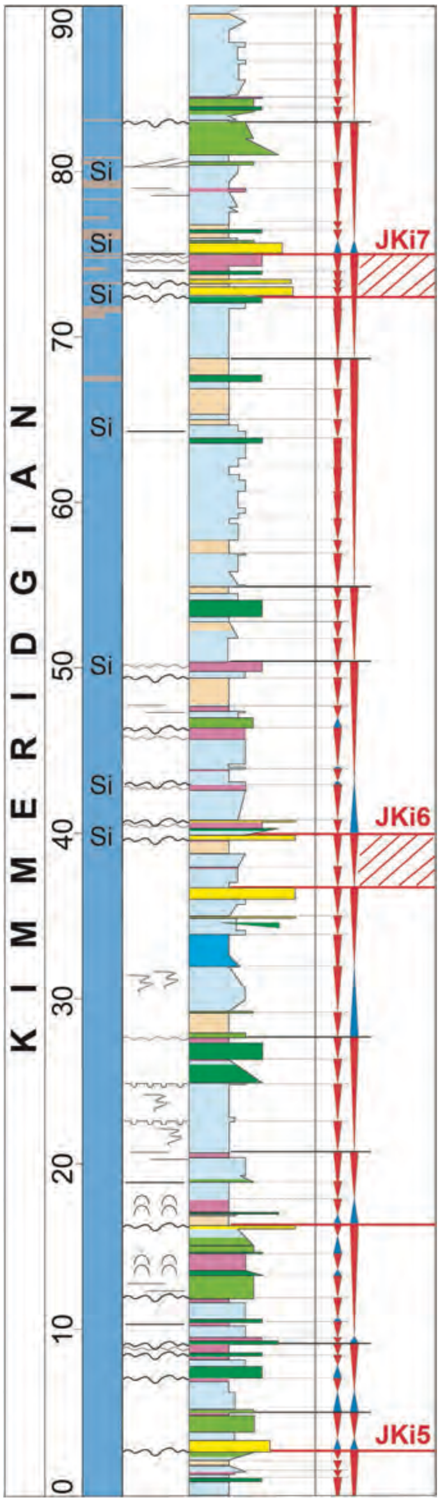



**Fig. 10.** Stratigraphic column BK (lower part) showing gross lithology, sedimentary structures, facies stacking, and sequence stratigraphy at Stop 2 (modified from Husinec & Read, 2022). For location, see Figures 1 and 3.

**Fig. 11.** Oncoid-microbial lump floatstone capped by microbial laminite. Coin for scale is 26.5 mm in diameter.

**Fig. 12.** Mud-clast breccia with greenish micrite matrix. Coin for scale is 26.5 mm in diameter.

**Fig. 13.** Major erosion surface (sequence boundary) with silicified intraclast rudstone (breccia) with brown clayey matrix overlying karstified microbial laminite.

At Stop 2 near the village of Brotnice (Fig. 9), an Upper Jurassic, upper Kimmeridgian road-cut section is well exposed (Figs. 10–14). The age was biostratigraphically constrained based on benthic foraminifera and calcareous green algae (Nikler & Sokač, 1968; Velić, 2007), tied to $\delta^{13}C$ stratigraphy (Husinec *et al.*, 2022), and fine-tuned to the coastal onlap curve of Haq (2018). Carbonate facies exposed at this stop were described by Husinec & Read (2022) and include, from deepest to shallowest: *Cladocoropsis* floatstone/wackestone (open-marine, shallow subtidal lagoon; rare); oncoid-microbial lump wackestone–mudstone/

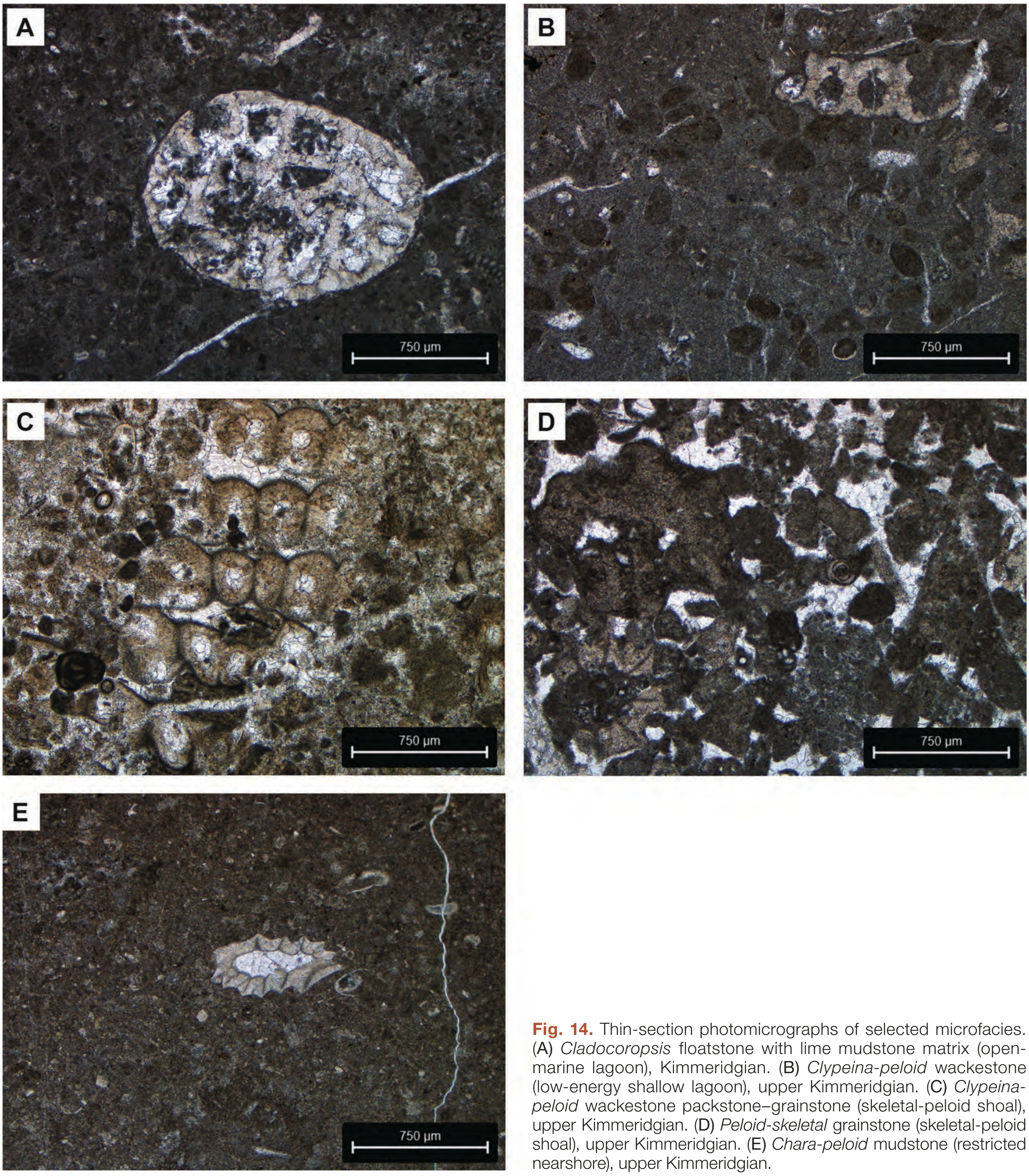



**Fig. 14.** Thin-section photomicrographs of selected microfacies. (A) *Cladocoropsis* floatstone with lime mudstone matrix (open-marine lagoon), Kimmeridgian. (B) *Clypeina-peloid* wackestone (low-energy shallow lagoon), upper Kimmeridgian. (C) *Clypeina-peloid* wackestone packstone–grainstone (skeletal-peloid shoal), upper Kimmeridgian. (D) *Peloid-skeletal* grainstone (skeletal-peloid shoal), upper Kimmeridgian. (E) *Chara-peloid* mudstone (restricted nearshore), upper Kimmeridgian.

floatstone with calcareous algae (*Clypeina jurassica, Salpingoporella annulata*) and benthic foraminifera (*Parurgonina caelinensis, Kurnubia palastiniensis, K. wellingsi*) (shallow subtidal); peloid packstone–grainstone and minor wackestone (lower intertidal lime flats); barren carbonate mudstone locally with fresh to brackish water calcareous alga *Chara* (intertidal–restricted very shallow subtidal); microbialite (wavy or horizontally laminated, rare stacked hemispheroids), rarely mud-cracked or with small teepee structures (tidal flat); and intraclast rudstone and floatstone (breccia) with mudstone clasts and greenish-gray argillaceous carbonate matrix.

The above facies are stacked into m-scale subtidal and peritidal parasequences, the latter with subaerial exposure breccias near sequence boundaries. The latter are commonly marked either by a single breccia or by several closely spaced breccias. At Stop 2, a typical shallowing-upward sequence has a basal skeletal mudstone–wackestone that grades up into peloid-skeletal packstone–grainstone, which is in turn capped by microbial laminite or barren lime mudstone. Some parasequences contain only mud-supported facies, whereas locally silicified carbonates underlie disconformities. On average, Kimmeridgian parasequences are 1.5 m thick, and form eight third-order sequences that were influenced both by eustasy and regional tectonics (Husinec & Read, 2022). The former is suggested based on a fair match between the relative positions of the sequence boundaries and those on Haq's (2018) global chart. Alternatively, tectonic control is suggested by the pronounced thickness variation of the Upper Jurassic units along the strike (Tišljar *et al.*, 2002) likely associated with differential movement on basement fault blocks (cf., Bosellini *et al.*, 1981), coupled with an increase in the subsidence rates with the highest rates in the Tithonian (Husinec & Jelaska, 2006).

## Stop 3: Uppermost Tithonian peritidal, laminite-capped cycles with dasyclads and faecal pellets

The stratigraphic placement of the Jurassic–Cretaceous boundary remains a controversial issue and its GSSP (Global Stratotype Section and Point) has yet to be defined (e.g., Wimbledon *et al.*, 2020; Granier, 2020). On the Adriatic Carbonate Platform, the upper Tithonian is characterized by an impoverished foraminiferal association with the last appearance data of several foraminiferal taxa (e.g., *Parurgonina caelinensis*, *Anchyspirocyclina lusitanica/neumannae*), and an abundance of calcareous alga *Campbelliella* (Velić, 2007). The basal Cretaceous Berriasian strata record the first appearance of several algal taxa, including *Clypeina isabelae, C. parasolkani, C. catinula, Humiella sardiniensis, H. catenaeformis,* and *Salpingoporella katzeri?* (Husinec & Sokač, 2006).

At Stop 3 near the hamlet of Obić (for location see Figs. 1 and 3), we will examine a road-cut section that exposes the topmost Jurassic end-Tithonian section of the AdCP (Figs. 15–19). The thin- to medium-bedded succession contains several distinct facies, from deepest to shallowest: skeletal-peloid mudstone and wackestone (low-energy shallow lagoon; euphotic, <10 m water depth); skeletal-peloid wackestone–packstone (moderate-energy shallow lagoon with some current winnowing); skeletal-peloid packstone and grainstone locally with nicely developed ripple cross-lamination (subtidal tide- and wave-influenced sand sheets); barren (unfossiliferous) lime mudstone with rare peloids, gastropods, and ostracods (restricted nearshore seaward of tidal flats); and microbial, planar, and fenestral laminite with intraclasts (tidal flat). The most common skeletal components include calcareous green

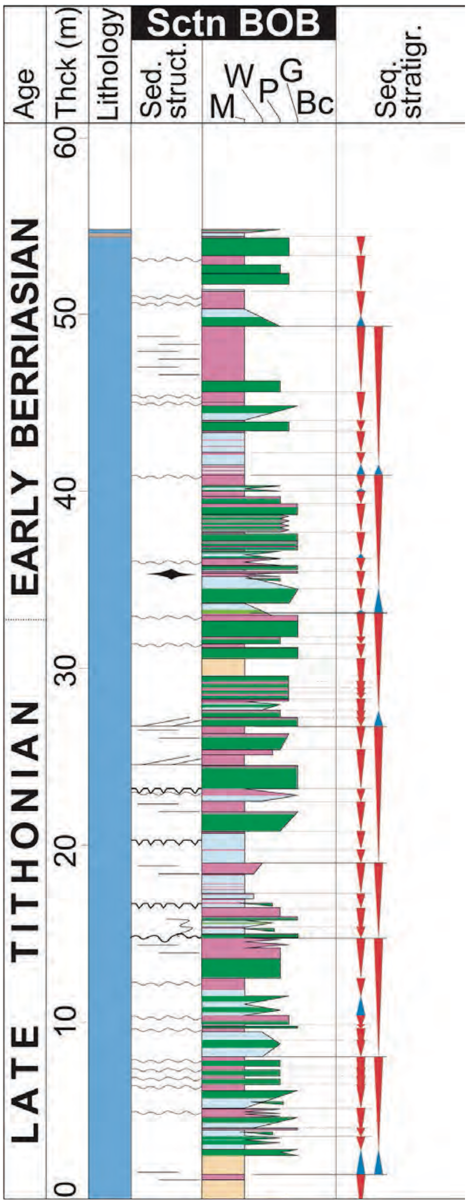



**Fig. 15.** Stratigraphic column BOB (lower part) showing gross lithology, sedimentary structures, facies stacking, and sequence stratigraphy at Stop 3 (modified from Husinec & Read, 2022). For location, see Figures 1 and 2.

**Fig. 16.** Wavy to LLH microbial laminite on scalloped top of algal (*Campbelliella*) wackestone. Scale in cm.

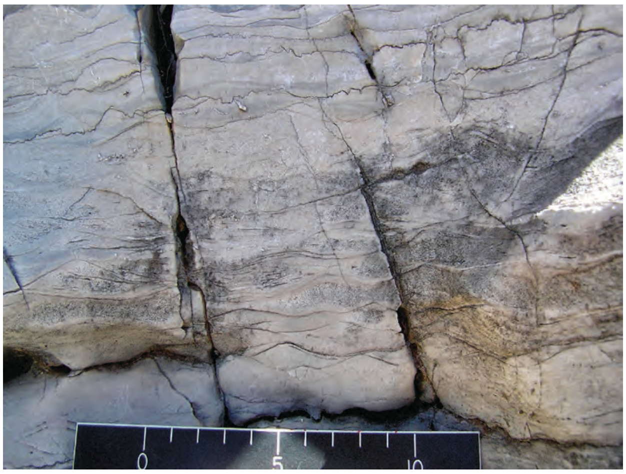



**Fig. 17.** Wave ripple cross-laminated peloid grainstone. Scale in cm.

**Fig. 18.** Mud drapes (pale gray) on top of wave ripple cross-laminated peloid grainstone (dark gray). Note thin flat-pebble floatstone at the bottom (below coin, 26.5 mm in diameter), and microbial laminite on top.

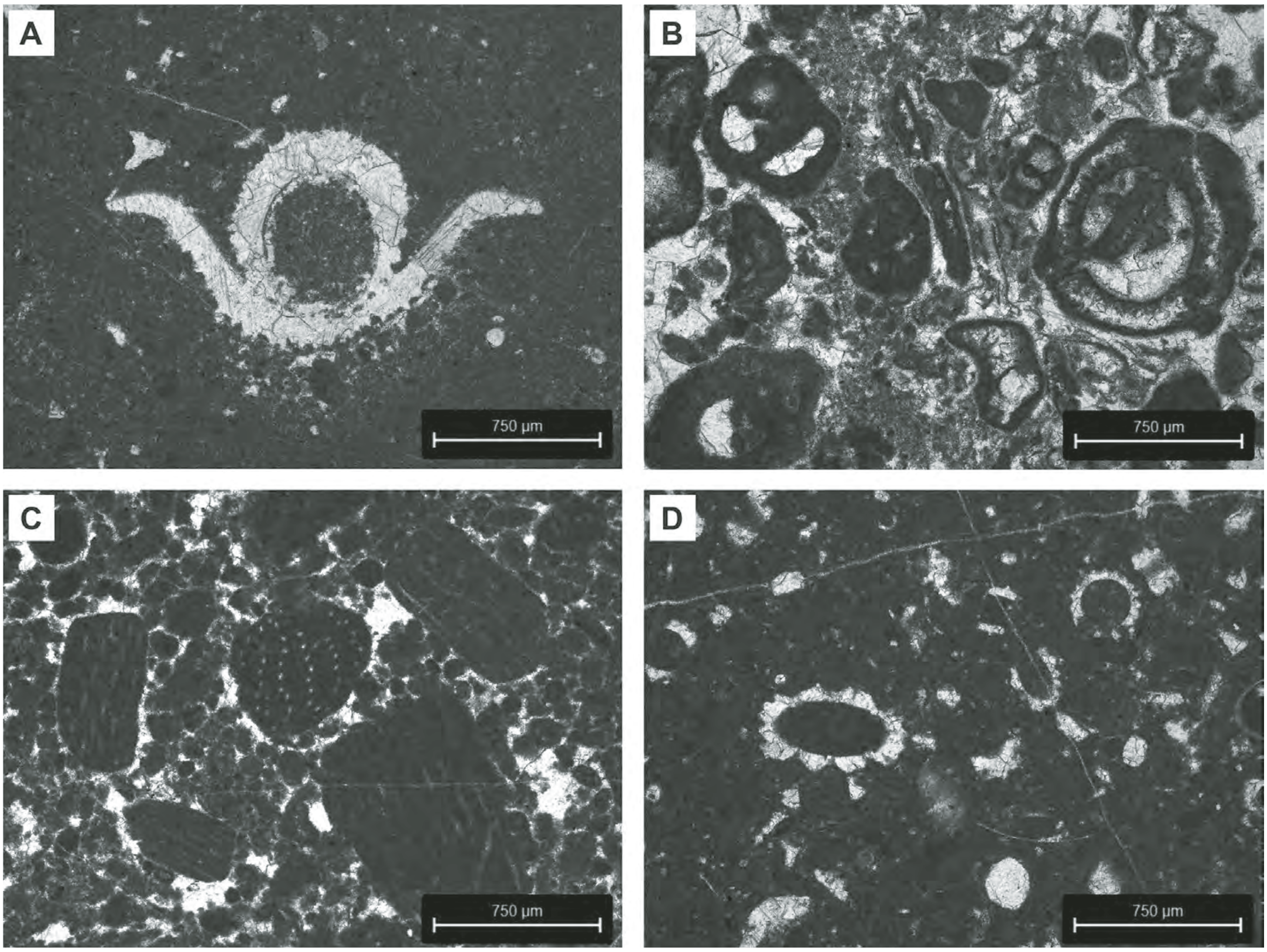



**Fig. 19.** Thin-section photomicrographs of selected microfacies. (A) *Campbelliella*-peloid mudstone–wackestone (low-energy shallow lagoon), upper Tithonian. (B) *Skeletal*-peloid grainstone with benthic foraminifera and green algae (high-energy subtidal), upper Tithonian. (C) *Favreina*-peloid packstone–grainstone (skeletal-peloid shoal), lower Berriasian. (D) Algal wackestone (low-energy shallow lagoon), lower Berriasian.

algae (*Salpingoporella*, *Campbelliella*), small benthic foraminifera, faecal pellets (*Favreina*), and fragments of bivalves and gastropods.

The above facies form highly cyclic peritidal units with distinctive microbial laminite caps on parasequences. The latter are on average ~1 m thick and are typically composed of basal skeletal-peloid mudstone–wackestone up into wackestone–packstone (rare), overlain by skeletal (*Campbelliella*)-intraclast-peloid packstone–grainstone with faecal pellets, and capped by barren lime mudstone and microbial laminite (Husinec *et al.*, 2022). Note that further seaward towards the western AdCP margin, at Lastovo Island, much of the uppermost Tithonian succession is oolitic and suggestive of hypersaline settings, with upward-fining parasequences typically composed of thick basal radial-ooid grainstone with intraclast lag, that grades up into skeletal-peloid wackestone–packstone to grainstone, and is capped by barren lime mudstone (rare) and microbial or fenestral laminite (Husinec & Read, 2006, 2007); it resembles coeval facies from the Jura Mountains (Strasser, 1994). The cyclic peritidal facies at Stop 3 and oolitic facies of Lastovo Island formed during a global cooling trend and increasing aridity (Föllmi, 2012), as well as a long-term sea-level fall (Haq, 2018). They form the highstand part of the Tithonian Adriatic supersequence JSS4 that is capped by the basal Berriasian breccias (Husinec *et al.*, 2022).

## Donja Banda

### Stop 4: Oldest Upper Cretaceous deposits in Konavle: Santonian–Campanian Gornji Humac fm. and brief overview of the recent seismicity of the Dubrovnik region

At the first stop in the area of the Donja Banda, the oldest Upper Cretaceous deposits in the Konavle area can be observed as the tour will follow the stratigraphic order from older to younger deposits.

Stop 4 is reached via a 1 km walk along an asphalt road and then a 300 m descent along a pedestrian path cut into Konavle cliffs (Fig. 20) to Pasjača beach.

Pasjača Beach (Fig. 21) was created by an interesting cooperation between nature and humans: in 1955, for the purpose of the reclamation of Konavosko Polje, a 2000 m long tunnel was drilled in order to prevent constant flooding of the field during high water. Part of the crushed rocks was dumped down the cliff from the end of the tunnel, where the sea rounded it and formed a beach in a place where there was none before. However, the entire material was blown away by the action of currents and waves over several years, so the locals brought new quantities of stone material, and this is repeated every few years since. The first visit to the beach after winter storms can therefore bring a big surprise, because often a large part of the beach is shifted or gone.

The oldest rocks in Konavle belong to the Gornji Humac fm., first described on the island of Brač (Gušić & Jelaska, 1990), but it is clearly recognizable in almost all parts of the AdCP, with a typical stratigraphic range from middle Turonian to Campanian.

**Fig. 20.** The Konavle Rocks, steep cliffs which are subject to ongoing protection as a special landscape. Their average height is 100–200 m, and the highest is up to 300 meters. Along the ecological educational path, signs have been placed showing numerous rare species of flora and fauna of the area (with a few endemics, such as the Dubrovnik hares).

**Fig. 21.** Pasjača beach at the foot of the Konavle Rocks, chosen as being among the most beautiful beaches in Europe and the world in the last few years.

In Konavle the stratigraphic range of this unit is from the middle Santonian to the upper Campanian (approx. 85 to 75 million years ago), because the lower part of this unit is covered by the sea. It can be assumed that the missing part has a stratigraphic range from mid-Turonian to lower Santonian, because in almost all parts of the AdCP, these deposits overlie the late Cenomanian to early Turonian drowned platform succession formed during the oceanic anoxic event (OAE-2; Jenkyns, 1991, Korbar *et al.*, 2012, Brčić *et al.*, 2021).

The Gornji Humac fm. in Konavle are well-bedded light brown to brown limestones, less often dolomites, in which there is an alternation of four typical lithofacies.

The most common beds are mudstones to wackestones with a variable proportion of *Decastronema kotori* (in places very numerous fossil remains of a large filamentous microorganism, which produced and dwelled in tubular sheaths similar to some present-day organisms from the group of cyanobacteria – Golubic *et al.*, 2006; Fig. 22) and common sections of the green alga *Thaumatoporella parvovesiculifera*.

Foraminiferal-peloid wackestones to packstones (Fig. 23) are common with numerous sections of *Cuneolina* gr. *pavonia*, *Scandonea samnitica*, *Pseudorhapydionina mediterranea*, *Moncharmontia apenninica*, *Dicyclina schlumbergeri*, *Calveziconus lecalvezae*, *Murgella lata*, and other benthic foraminifera.

The third lithotype in the succession of the Gornji Humac fm. deposits is represented by rudist floatstones (Fig. 24) with different proportions of fragments and whole sections of radiolitid and less often hippuritid rudists. Remains of beds in which rudists are preserved in their primary position are rarely found, and they are mostly oligospecific, one-generation biostromes.

The fourth lithotype is represented by usually thin interbeds of laminites composed of the alternation of thin micritic, pelmicritic, pelsparitic and cyanobacterial laminae.

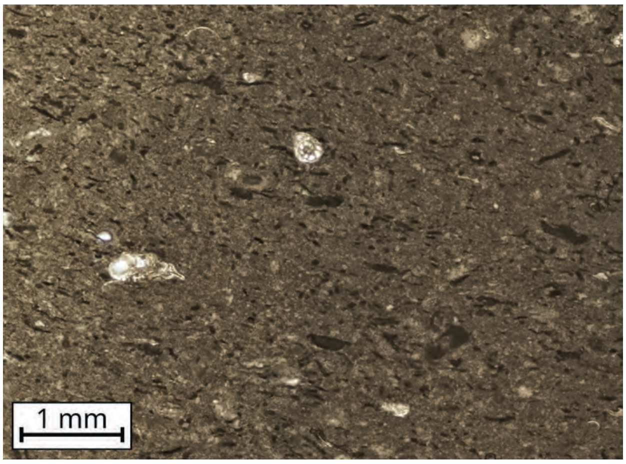



**Fig. 22.** Thin-section photomicrograph of wackestone with numerous sections of *Decastronema kotori* and rare foraminifera, typical microfacies of the Gornji Humac fm.

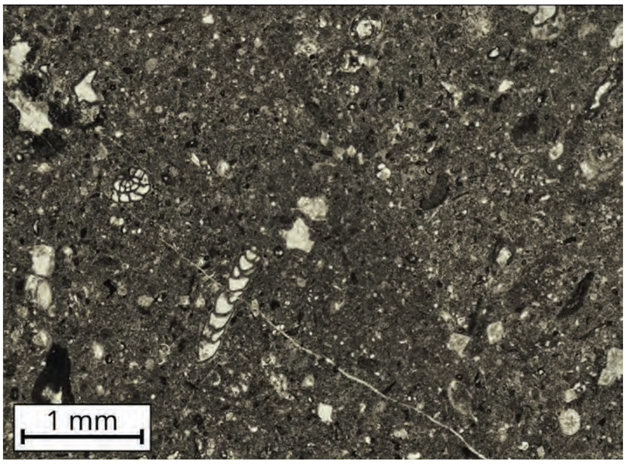



**Fig. 23.** Thin-section photomicrograph of foraminiferal-peloid wackestones to packstones with *Decastronema kotori* and *Thaumatoporella parvovesiculifera*.

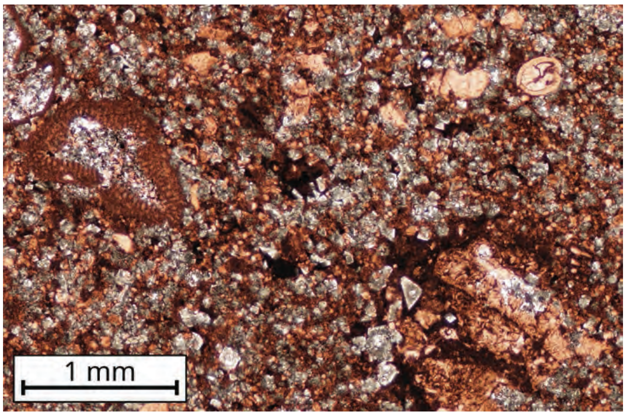



**Fig. 24.** Thin-section photomicrograph of dolomitized limestone stained by Alizarin Red S in which unstained dolomite rhombohedrons and red-stained limestone remains are visible.


**Fig. 25.** Rudist floatstones composed of numerous small radiolitid rudist fragments, typical facies of the Gornji Humac fm.; path to Pasjača beach, Konavle.

The rocks are late-diagenetically dolomitized in places, somewhere only in the form of small rhombohedral dolomite crystals within the limestone (Fig. 25), and in some places the dolomitization was very intense, and dolomite packages several metres thick can be observed, especially in the younger part of the unit.

If we look from Pasjača beach, we will enjoy the view of the open sea, but we will not see what is hidden at the sea bed: at a distance of approximately 3 km from the shore there is a regional fault along which the epicenters of the strongest earthquakes recorded in the territory of the present day Republic of Croatia are located.

The southernmost part of the Republic of Croatia, Dubrovnik–Neretva County, represents the seismotectonically most threatened area of Croatia, with potential earthquakes of a magnitude +7.

The strongest instrumentally recorded earthquake in the wider area of Dubrovnik was the April 15, 1979 earthquake in southern Montenegro, magnitude 6.9, in which 136 people died; another significant earthquake that hit the immediate surroundings of Dubrovnik was the Slano–Ston earthquake on September 5, 1996, magnitude 6.0, with no casualties (Govorčin *et al.*, 2020). Ongoing tectonic activity is indicated by the earthquake of magnitude 5.7 recorded on April 22, 2022 near the town of Stolac in Bosnia and Herzegovina, only 90 km NW of Dubrovnik.

However, historical records indicate numerous strong earthquakes, with especially significant seismotectonic activity from the 15th to the 17th centuries (Herak & Herak, 2022), with devastating earthquakes (estimated intensity VIII to IX° MCS scale) and epicenters c. 10 km offshore from Dubrovnik in the years 1351, 1471, 1481, 1482, 1496, 1504, 1516, 1520, two strong earthquakes in front of Konavle in 1631 and 1639, followed by the so-called "Big Shaking" that happened on April 6, 1667 offshore from Dubrovnik (Fig. 26).

In that earthquake, the intensity of which in Dubrovnik was IX–X° MCS, and the estimated magnitude 7.1, the city was completely destroyed, with the only two buildings that remained intact being the

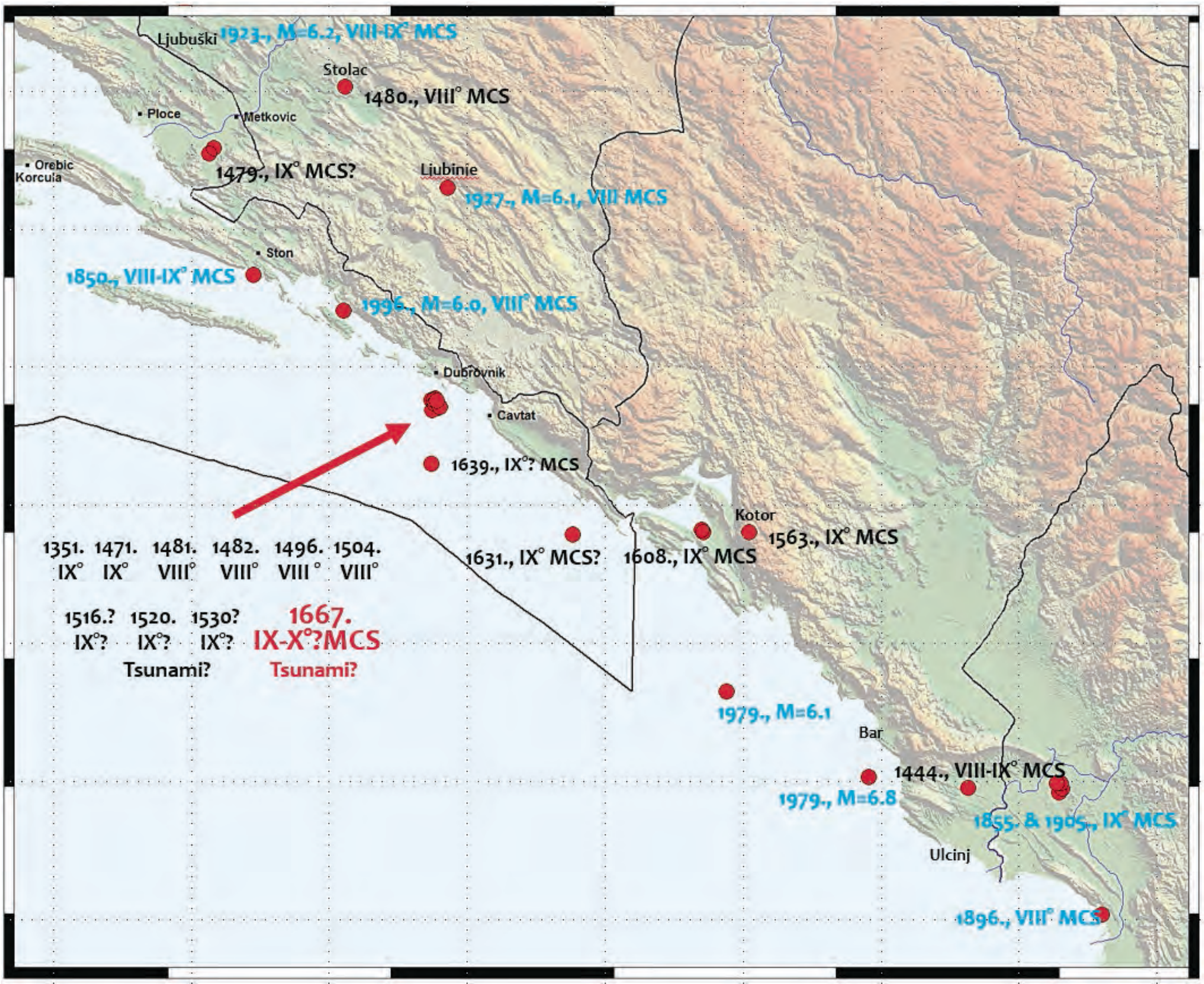



**Fig. 26.** Strong historic and recent earthquakes in the vicinity of Dubrovnik from the Croatian Earthquake Catalog for the period BCE–2020 (Herak & Herak, 2022).

Sponza Palace and the Rector's Palace. The earthquake produced a tsunami that caused the sea in the city's harbor to recede three times, and numerous ships on the Italian side of the Adriatic were washed ashore. The damage was increased by the large number of huge boulders that fell from Srđ hill in the hinterland, and especially the fire that broke out, which was not extinguished for the next 20 days. It is believed that less than half of the total population of 5,000 survived the earthquake.

What worries us today is that the tectonic activity around the city of Dubrovnik has been very low since then, relatively strong inter-seismic subsidence is clear (see field trip B1, this vol.), and the time since then roughly corresponds to the return period of the strongest earthquakes historically recorded in the region in the last 2.400 years.

## Stop 5: Top of the Cretaceous – Maastrichtian

Deposits of Maastrichtian age are not very common on the Adriatic Carbonate Platform, since the entire area of the platform was affected by synsedimentary tectonics during the Late Cretaceous. Thus, individual blocks were gradually deformed or uplifted and became emergent at different times, mainly from the Late Cenomanian to the Coniacian and Santonian. However, in the NW part of the AdCP, Maastrichtian and Palaeocene deposits are described near the Italian–Slovenian border north of Trieste (Drobne *et al*, 1989), while in the SE part of the platform, the shallow-marine transition between the Cretaceous and the Palaeocene including Maastrichtian deposits is described at several localities on the islands of Hvar (Korbar *et al.*, 2015) and Brač (Steuber *et al.*, 2005; Cvetko Tešović *et al.*, 2020), in the hinterland of Dalmatia and in the Konavle region.

The Maastrichtian deposits are usually described as the Sumartin fm. according to the typical informal lithostratigraphic unit described on the island of Brač (Gušić & Jelaska, 1990). Their lower boundary represents a significant discontinuity (so-called Lovrečina emergence), and in the lower part they contain a package of late diagenetic dolomites (see field trip B1, this vol.) followed by a thick package composed of radiolitid rudist debris. These are overlain by an alternation of bioclastic wackestones to floatstones and laminites, whereby the proportion of layers with radiolitid shells and debris gradually decreases upwards, and the proportion of foraminifera-peloid packstones increases. In general, the entire succession of deposits of the Sumartin fm. is marked by shallowing-upward cycles, with common emerged intervals composed of carbonate breccia, but also by a significant proportion of late diagenetic dolomites, which in some places form layers several metres thick, and dark intervals rich in organic matter in the younger part.

Maastrichtian deposits in the Konavle area, referred to as the Komaji fm., have similar features, but in contrast to the typical deposits of the Sumartin fm., the typical shallowing-upward cycles are less common, and they contain much less evidence of subaerial exposure. They are underlain by a thick upper Campanian dolomite succession called the Klaići fm., without a long-lasting emergence level described on Brač island as the Lovrečina emergence. The lithological transition from the Klaići fm. to Maastrichtian Komaji fm. is marked by a massive, 1–2 metre thick bioclastic wackestone–packstone with numerous bioclasts of requieniid-type rudists, gastropods, bivalves and the common large foraminifera *Rhapydionina liburnica*. In the central

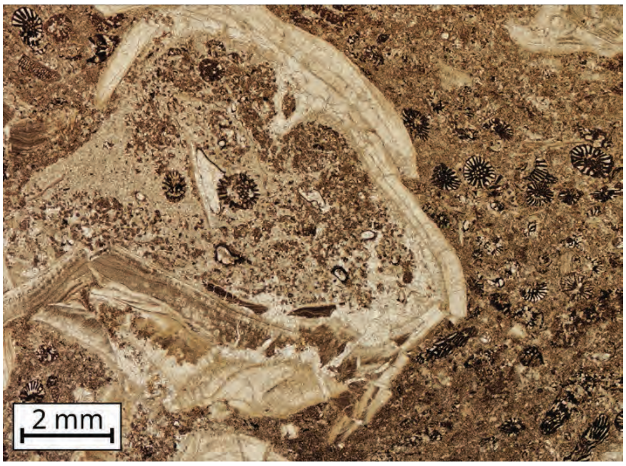



**Fig. 27.** Thin-section photomicrograph of Maastrichtian bioclastic packstone with numerous sections of *Rhapydionina liburnica*, rare sections of *Dicyclina schlumbergeri* and abundant debris of rudist bivalves; Komaji village.


**Fig. 28.** Outcrop of Maastrichtian bioclastic packstone with small bivalve molluscs and numerous *Rhapydionina liburnica* sections in Komaji village.

**Fig. 29.** Outcrop of organic matter-enriched laminites from the upper part of the Maastrichtian Komaji fm in Komaji village.

part of the unit, laminated early diagenetic and late diagenetic dolomites alternate with peloid wackestone–packstone and decimetre-thick beds of bioclastic packstone. Among the bioclasts, numerous large foraminifera *Dicyclina schlumbergeri*, *Moncharmontia apenninica* and especially *Rhapydionina liburnica* predominate (Fig. 27), which in places build up to 10 cm-thick foraminiferal packstones, less often grainstones. Fragments of bivalve molluscs with brown shells are common (Fig. 28), which in places form decimetre thick interbeds. Within the central and upper part of the Komaji fm. 10–30 cm thick beds of organic matter-enriched laminites can be observed (Fig. 29), some being almost black in colour.

The share of late diagenetic dolomites increases towards the upper part of the Komaji fm., so unlike the well-known Likva locality on the island of Brač (Steuber *et al.*, 2005; Cvetko Tešović *et al.*, 2020) where the Cretaceous/Palaeocene transition is located within limestones, this important level is everywhere in the Konavle area marked by the dolomites. In the area of the Komaji village the interval of dolomite with rare relics of more or less recrystallized limestones is several tens of metres thick, while it is the thinnest on the slopes of Sv. Ilija hill c. 9 km NE of Komaji, where between the last layers of Maastrichtian rudist limestones and the first layers with documented Palaeocene fossils there is only an interval of dolomite about 7 m thick, with relics of light brown mudstones with rare ostracods.

## Stop 6: Palaeocene(–lower Eocene?) deposits – the end of the Adriatic Carbonate Platform in Konavle

Palaeocene deposits are quite rare in the area of the former AdCP: due to the progressive deformations of the Adria Microplate uppermost crust (including the AdCP succession) driven by the subduction of the Adria beneath the Eurasian Plate, the largest part of the area of the former platform was uplifted and a significant regional emergence phase marked the end of deposition on the typical shallow-marine carbonate platform. The stratigraphic hiatus was of very different duration, and the continuity of deposition until the end of the Cretaceous and the transition to the Palaeocene was recorded only along the central axis of the AdCP (Korbar, 2009), in the farthest NW in the border area of Italy and Slovenia (Drobne *et al.*, 1989) and in a wider area in the SE part of the platform.

In the SE part, the K/Pg transition is best explored on the islands of Brač (Steuber *et al.*, 2005; Cvetko Tešović *et al.*, 2020) and Hvar (Korbar *et al.*, 2015), where after a more or less continuous K/Pg transition, a 16 m (Brač) or 27 m (Hvar) thick succession of Palaeocene deposits follows beneath a regional emergence overlain by the Foraminiferal limestones.

In the area of Konavle, this succession is considerably thicker, so between the K/Pg boundary and the disconformity with the Foraminiferal limestones there is more than a 300 m thick succession of predominantly limestones – the informal Čilipi fm (Fig. 30). These are mainly limestones deposited in protected shallows where mudstones, algal wackestones and peloidal wackestones–packstones alternate (Fig. 31), while stromatolites and dolomite intervals are scarce. Among the fossils, the most stratigraphically significant are the relatively rich communities of dasyclad algae, including several recently described species (Radoičić, 2004; Sokač & Grgasović, 2020) and benthic foraminifera. In the succession two or three levels with *Microcodium* aggregates occur locally, which are common in many calcretes and calcareous palaeosols in the Cretaceous and Palaeogene of the peri-Tethyan realm. These structures were formed

**Fig. 30.** Outcrop of the Palaeocene Čilipi fm. peloidal packstone north of Komaji village.

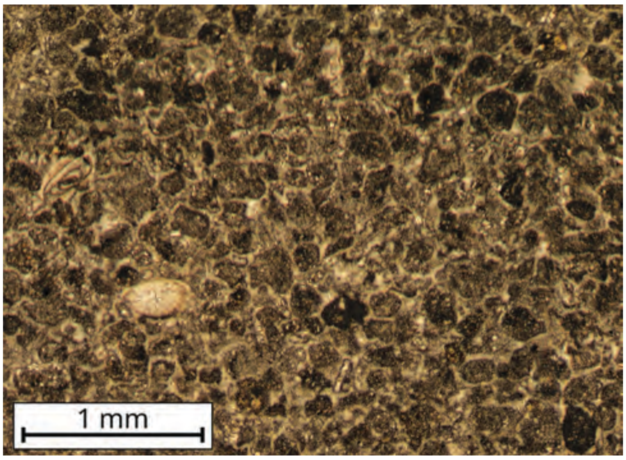



**Fig. 31.** Thin-section photomicrograph of Palaeocene peloidal packstone with rare benthic foraminifera sampled north of Komaji village.

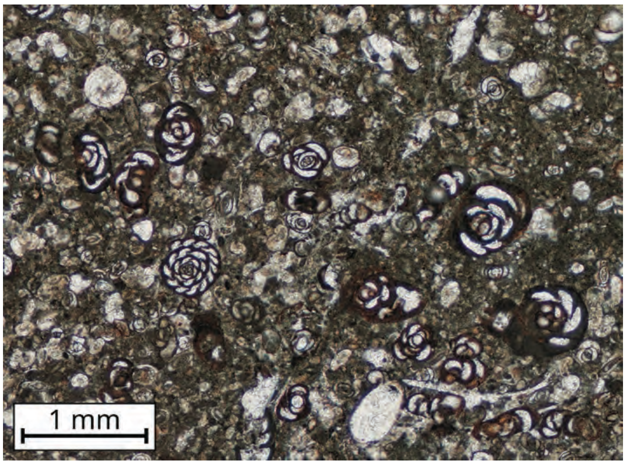



**Fig. 32.** Thin-section photomicrograph of Palaeocene foraminiferal packstone with predominant miliolids; sample KIL-19, Sv. Ilija profile, Konavle.

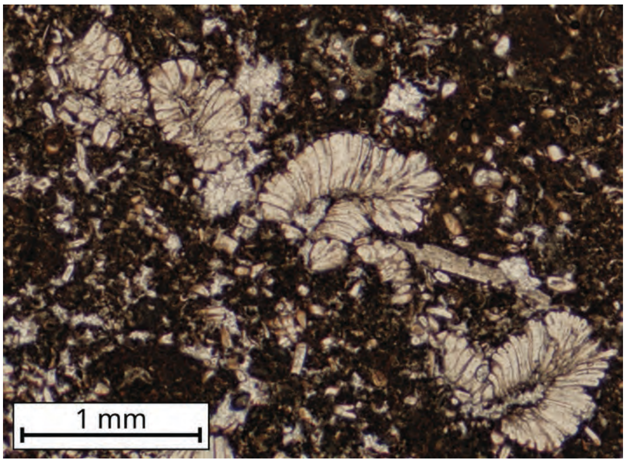



**Fig. 33.** Thin-section photomicrograph of Palaeocene bioclastic-peloid packstone with *Microcodium* sections; sample KIL-21, Sv. Ilija profile, Konavle.

by the calcification of roots of pioneering plants following subaerial exposure (Košir, 2004). The lower part of the succession is often bioturbated, while in the upper part of the succession c. 80 m below the main disconformity a package of intraformational breccia several m thick crops out. At the very top of the unit there is a disconformity, with bauxite occurrences in places.

Based on the dasyclad algae (Sokač & Grgasović, 2020) and benthic foraminiferal assemblages (Ćosović, pers. comm.), it could be estimated that the stratigraphic range of the Čilipi fm. in the Konavle area covers the entire Palaeocene, while the top part could even belong to the lowermost Eocene (approximately 11 Ma duration in total).

## Stop 7: Eocene Foraminiferal limestones

Foraminiferal limestones are, over most of the former AdCP area, deposited either continuously on top of the transgressive Kozina unit (fresh-water to brackish, organic-rich deposits containing coal occurrences and deposits), or transgressively over different levels of Upper Cretaceous limestones (in central Istria, even over the Lower Cretaceous deposits locally, Matičec *et al.*, 1996). Exceptions are the previously mentioned localities with continuation of shallow-marine platform deposition into the Palaeocene, where the emergence started later, in the Palaeocene (as on islands of Hvar and Brač) or even the latest Palaeocene or earliest Eocene as in here at Konavle.

Similar to other areas of the External Dinarides, the Foraminiferal limestones in Konavle can be divided into four conditionally defined lithostratigraphic units: miliolid, alveolinid, nummulitid and orthophragminid limestones. These lithotypes are predominantly arranged in a superpositional relationship, reflecting the more or less continuous deepening of depositional environments: over most of the External Dinarides these deposits are of lower Eocene to early middle Eocene age, while in the Konavle area deposition probably began at the end of the early Eocene and continued throughout the middle Eocene.

Foraminiferal limestones are mainly composed of whole and fragmented skeletons of benthic and less often planktonic foraminifera (mostly towards the top of the unit). Numerous miliolids (*Idalina*, *Periloculina*, *Spiroloculina*, etc.) and many forms of genera *Coskinolina*, *Alveolina*, *Nummulites*, *Operculina*, *Orbitolites*, *Assilina*, *Discocyclina*, etc. were determined. Among the planktonic foraminifera the most important genera are *Globigerina*, *Morozovella*, *Acarinina* and *Turborotalia*. Common allochems also include bivalve debris (ostreids, pectenids, etc.), ostracods, echinoderms, red algae, corals, hydrozoans, sponges, annelids and bryozoans. In the uppermost part, limestones contain both authigenic and detrital glauconite.

The whole succession of the Foraminiferal limestones represents a continuous change of different environments, from the protected inner environments formed on top of the submerged older platform deposits (miliolid limestones), through shallower and deeper shoreface environments (alveolinid and nummulitid limestones) to deeper environments of the carbonate ramp (orthophragminid limestones, in Croatia often colloquially known as the *Discocyclina* limestones). These formed along the margins of foreland basins caused by the intense synsedimentary compressional tectonics resulting in the final uplift of the Dinarides (see field trip C2, this vol.). Each individual succession may show variations due to the local palaeogeographic conditions, so lateral changes or repeated mixing of different varieties in vertical succession are common. The boundaries between

**Fig. 34.** Outcrop of Eocene Foraminiferal limestone on a former narrow-gauge railway track.

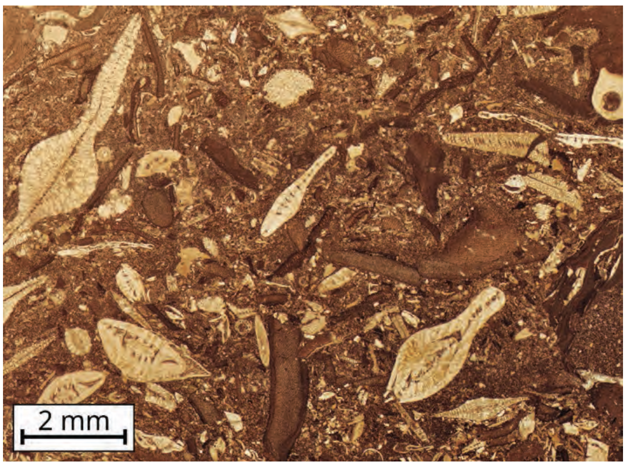



**Fig. 35.** Thin-section photomicrograph of Eocene Foraminiferal limestone with numerous sections of orthoprhragminid benthic foraminifera, nummulitids, red algae, peloids and echinoderms.

the aforementioned individual units are not sharp, since the division is based solely on the predominance of certain groups of benthic foraminifera (often even in the lowest miliolid limestone small nummulitids may be found, and miliolids and alveolinids are also common in the younger parts of the succession). A more or less continuous deepening-upward trend is visible everywhere, mostly due to the intense synsedimentary tectonics that ensured a huge accommodation space by creating foreland basins in front of the uplifting Dinarides mountain chains. The creation of a significant accommodation space was additionally emphasized by slower sedimentation due to increasingly unfavourable conditions for abundant carbonate production.

Stop 7 (Fig. 34) is located in the upper part of the Foraminiferal limestone fm., within the so-called orthophragminid limestones (Fig. 35).

From this stop we also have a good view of the fertile Konavosko polje with soil formed on Palaeogene clastic deposits, as the youngest deposits in the Donja Banda area, and the elevated area of the Gornja Banda which belongs to the High Karst Nappe. In this part of Gornja Banda the oldest deposits crop out, as the Upper Triassic Main Dolomite (Hauptdolomit) and limestones with megalodontids. A gently inclined regional thrust fault separating the Donja and Gornja Banda is covered by rockfall deposits and soil, but is locally marked by the occurrence of weathered gypsum outcrops, which probably represent the equivalent of the Burano Formation evaporites of Italy, similar to the evaporites on the island of Vis (see field-trip C1 in this vol.).

The Foraminiferal limestones are overlain by the Transitional Beds unit, several tens of metres thick, composed of clayey limestones, calcitic marls and marls with individual laminae containing bioclasts of benthic organisms and planktonic foraminifera. These were deposited in already significantly deepened environments during the Middle Eocene, representing a gradual transition to turbidite deposition in the area presented at Stop 8.

## Stop 8: Palaeogene clastic deposits

Clastic deposits form the core of the Konavosko polje syncline, the NW limb of which is isoclinally folded and overturned in the footwall of the regionally important reverse fault, the previously mentioned High Karst Nappe. The hanging-wall of this fault, i.e. the NE part of the study area, is composed of a thick monoclinal succession of uppermost Triassic, Jurassic and Cretaceous deposits, some of which we visited at Stops 1–3.

Description of this stop is based on the study by Prtoljan *et al.* (2009), according to which, clastic deposits in the easternmost part of Konavle area are about 400 m thick, consisting of the alternation of thin sandstone and mudstone beds (Fig. 36) with rare lenticular conglomerate beds in the upper part.

**Fig. 36.** Alternation of thin sandstone and mudstone turbidite beds in the central part of the upper Eocene clastic deposits of Konavle.

**Fig. 37.** Thicker bed of mixed calcareous–siliciclastic sandstone from the central part of the upper Eocene clastic deposits of Konavle.

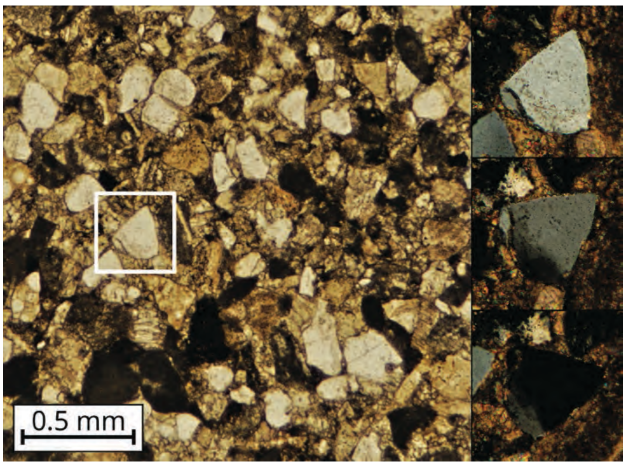



**Fig. 38.** Thin-section photomicrograph of mixed calcareous–siliciclastic sandstone from Fig. 37 with numerous quartz and calcite grains in a calcareous matrix.

The sandstones are mostly of a mixed siliciclastic–carbonate type (Fig. 37), while purely calcareous varieties are rare. Both types are grain-supported, well-sorted with subrounded to rounded grains and a small amount of predominantly micritic matrix.

**Mixed calcareous–siliciclastic sandstones** are composed of variable proportions of carbonate extraclasts, fossils and siliciclastic grains in a calcareous matrix (Fig. 38). **Carbonate detritus** is mainly composed of different types of Cretaceous and Palaeogene micritic and biomicritic limestone extraclasts, while the proportion of fossil material is variable (planktonic foraminiferal skeletons and bioclasts of corallinacea and benthic foraminifera are the most common). **Siliciclastic detritus** is mostly well sorted, ranging in size from fine- to coarse-grained sand. Rounded to semi-angular quartz grains, mostly characterized by uniform extinction (although rare undulatory extinction indicate metamorphic origin of some grains) predominate. In some samples, well-rounded chert grains dominate, probably originating from the ophiolitic complex of the Internal Dinarides in the hinterland (see Field trip C2, this vol.). Less common are quartzite, K-feldspars, plagioclase, muscovite, chlorite, chromites, zircon, opaque grains and fragments of possibly devitrified volcanic glass. Within the sandstone there are common laminae enriched in fine-grained plant remains.

**Calcareous sandstones** are sporadically observed within the succession of predominantly calcareous–siliciclastic sandstones, representing thicker (50–160 cm) beds built exclusively of carbonate detritus deposited from the head of high-density turbidity currents. The sandstones consist of subparallel oriented, sorted skeletons and fragments of large benthic foraminifera (mostly orthophragminids and nummulitids), clusters of corallinacean algae, and less frequent fragments of planktonic foraminifera, echinoderms, molluscs and bryozoans. Bioclasts vary from 1 to >10 mm in size. Matrix is scarce, micritic, with numerous small bioclasts. Biodetritus for the formation of calcareous sandstones originated from neighbouring shallow-marine carbonate factories producing large quantity of bioclastic material (foraminifera, algae, molluscs...).

The lower part of the succession of Konavle was probably deposited in the lower shoreface/off-shore transitional environments with common amalgamated hummocky cross-stratified beds, the middle part (Stop 8) contains thin turbidites deposited on a deeper part of a foreland basin slope, whereas the upper part with thin conglomerate bodies probably represents a prodeltaic facies within a regressive part of the succession (Cadet, 1978). Therefore, only the middle part of the studied clastic succession of the Konavle region may be referred to as actual turbidite deposits, commonly still referred to as 'flysch' in Croatian literature, while the lower and upper parts were probably deposited in shallower environments.

Turbidite deposits in the Dinaridic foreland basins are usually determined as Middle–Upper Eocene in age on the basis of their fossil content. Analyses of small benthic and planktonic foraminifera, as well as ostracods (Prtoljan *et al.*, 2009) indicate younger, Upper Eocene to Lower Oligocene ages for the studied succession. In addition, preliminary analyses of nannoplankton confirmed a partly Oligocene age, but samples contained numerous reworked older forms of Upper Cretaceous, Palaeocene and Eocene age.

Clastic deposits of the Konavle region have probably been deposited in a confined, narrow and relatively shallow piggyback sub-basin which has been in large part filled by resedimented deposits from the older foreland basins located in the NE hinterland, as indicated by the mixed sandstones and fine-grained deposits containing reworked older nannoplankton assemblages.

The presented results also indicate that the High Karst Nappe in this zone was probably thrusted no earlier than the Early to Middle Oligocene – in the traditional geodynamic framework the final uplift of the Dinarides was believed to have taken place several My earlier, during the Late Eocene or Early Oligocene.

## Stop 9: Sokol Grad

The last stop of the field trip is the small fortress of Sokol Grad (in translation, the fortress of the falcon). In the surrounding area there are traces of life that are 4000 years old.

Sokol Grad (Fig. 39) is a fortress in Dunava village in Konavle, mentioned for the first time in 1391, although it probably existed earlier as an Illyrian, Roman and Byzantine fortress. It was a fortress of the Bosnian nobles which came into the possession of the Republic of Dubrovnik in 1420, when they purchased the entire Konavle region. It survived the great earthquake of 1667, but after 1672 it is no longer mentioned in the archives, which leads to the conclusion that it has been abandoned since then. As was usual with abandoned fortifications, the surrounding inhabitants used its stones to build their houses and dry walls. The Society of Friends of Dubrovnik Antiquities bought the fortress from the Church in 1970, and in 2013 the fortress was completely renovated and became accessible to visitors.

From a geological point of view, the huge rock on which the fortress was built is particularly interesting. Namely, the surrounding area is covered by numerous large blocks and boulders (Fig. 40), mostly of Jurassic age, some of which are over 20 m in size, which were formed by breaking off from a thick suc-

**Fig. 39.** The medieval Sokol Grad fortress in Dunava village, Konavle.

**Fig. 40.** A large boulder of Jurassic rocks transported downhill from the Gornja Banda area in the hinterland.

**Fig. 41.** The Sokol Grad fortress built on top of a huge Middle Jurassic boulder.

cession of carbonates cropping out in the hanging wall of the High Karst Nappe, and today cover turbidite deposits of the Donja Banda. The fortress was built on a huge Middle Jurassic boulder (Fig. 41) about 50 m long, and due to the pronounced fracturing that was probably further accentuated during gravitational transport, the rocks had to be geotechnically additionally strengthened during reconstruction of the fortress by drilling large boreholes and connecting blocks with strong steel cables.

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