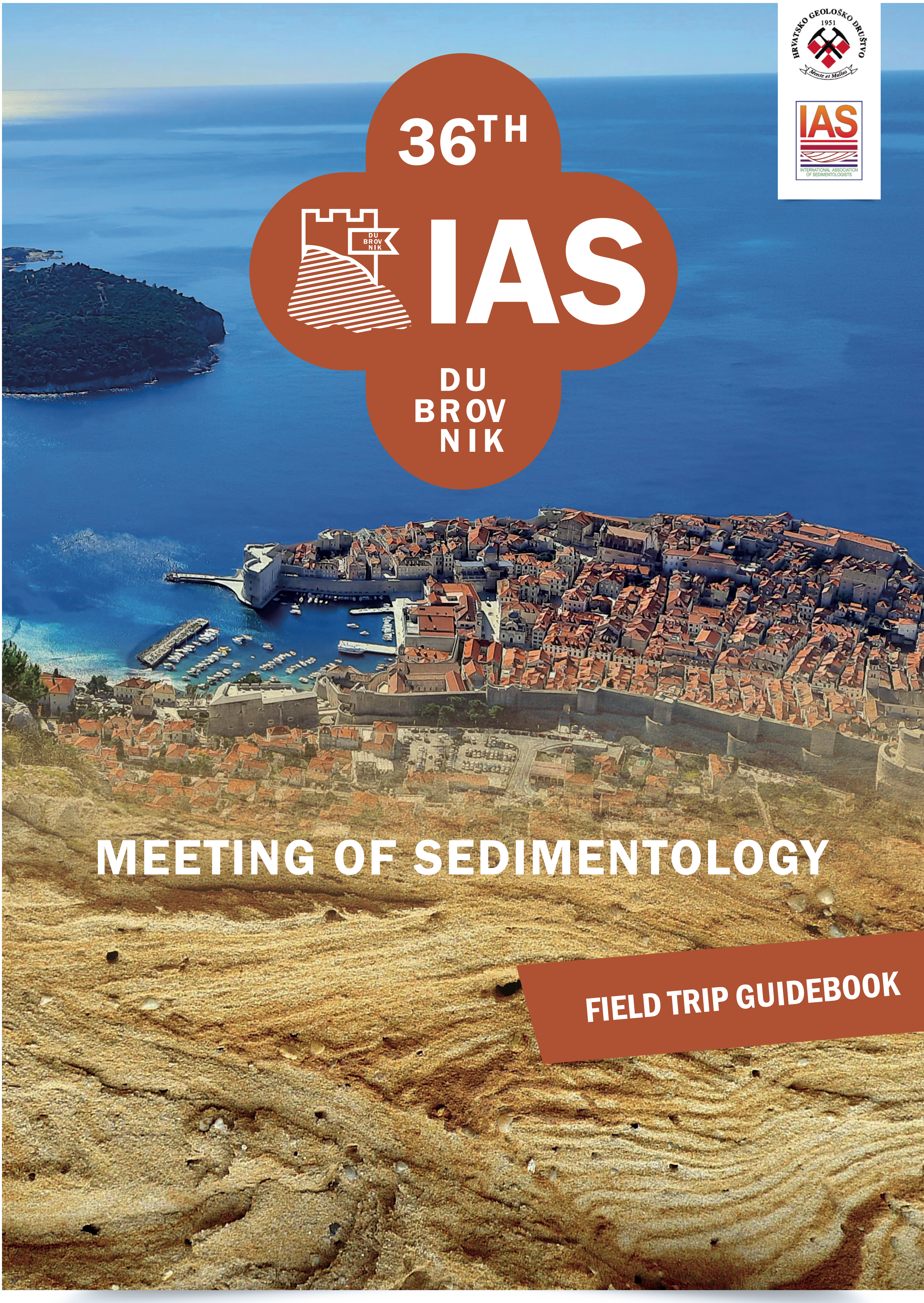


12–16 June 2023, DUBROVNIK, **CROATIA**

Organized by:
Croatian Geological Society (HGD) and International Association of Sedimentologists (IAS)

Publisher: Croatian Geological Society (HGD)
For the publisher: Slobodan Miko
Editors: Tvrtko Korbar, Marijan Kovačić and Igor Vlahović
Language Editor: Julie Robson (Scotland, United Kingdom)
Digital layout: Laser Plus d.o.o
Cover design: Ana Badrić
eISBN: 978-953-6907-80-9

Reference to any paper in this publication should be followed by:
...In: Korbar, T., Kovačić, M. & Vlahović, I. (eds.): Sedimentary cover of the Adria and its surroundings: from aborted rifting in the central Adriatic to the post-collisional deposition in the Dinarides, the Southern Alps, and the Pannonian basin. 36th IAS Meeting of Sedimentology, Dubrovnik (Croatia), June 12–16, 2023, Field Trip Guidebook, pp-pp, Zagreb.

36th International Meeting of Sedimentology
June 12–16, 2023, Dubrovnik, Croatia

FIELD TRIP GUIDEBOOK

Sedimentary cover of the Adria and its surroundings

from aborted rifting in the central Adriatic to the post-collisional deposition in the Dinarides, the Southern Alps, and the Pannonian basin

Edited by: Tvrtko Korbar, Marijan Kovačić and Igor Vlahović

Contents

Foreword

Dear colleagues,

Forty years after the 4th IAS Regional Meeting that was held in Split (1983), and twenty years after the 22nd IAS Meeting of Sedimentology that was held in Opatija (2003), the international sedimentological community decided to gather again in Croatia for the 36th IAS Meeting of Sedimentology in Dubrovnik.

Field trips are an integral and very important part of every IAS meeting, and we are proud to highlight the guidebooks of the meetings held in Croatia:

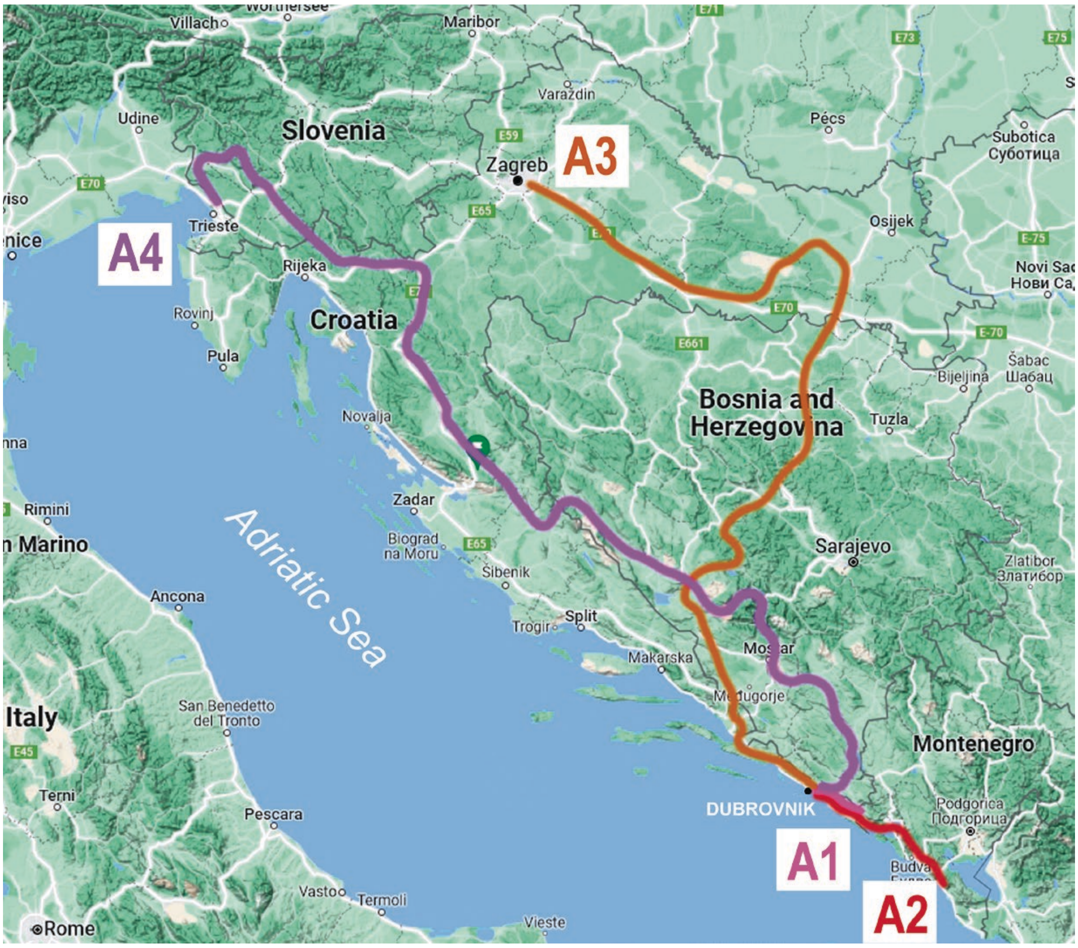
In 1983, **Ljubomir Babić** and **Vladimir Jelaska** edited a guidebook with field trips from Istria to Dalmatia and thus enabled the authors to somehow break the ice for international cooperation in these areas but also to chart the path for numerous sedimentological successors in Croatia and Slovenia that contributed and are still contributing to the completion of knowledge about the geological evolution of the region;

In 2003, **Igor Vlahović** and the late **Josip Tišljar**, edited a guidebook with field trips focused on more stratigraphical and sedimentological details and extended sedimentological interests all the way to the Alps (Slovenia) and the Pannonian Basin (northern Croatia), holding the door wide open for international cooperation.

Given the fact that in the eastern Adriatic region and its wider hinterland, Phanerozoic sedimentary rocks cover the vast majority of the territory, the region is still underexplored. That is why we also invited authors that traditionally deal with Mesozoic basinal deposits that crop out in Montenegro, as well as authors working on mass wasting deposits and Quaternary glacial, colluvial, lacustrine and aeolian sediments. Thus, even after 40 years of presenting the sedimentology in the region, we manage to offer new sedimentological delicacies that the authors have packaged into nine field trips through Croatia, Montenegro, Bosnia and Herzegovina and Slovenia, all ending or starting in Dubrovnik – the pearl of the eastern Adriatic in the south of the Republic of Croatia.

We are proud to present the Field Trip Guidebook of the third, now already traditional IAS Regional Meeting in Croatia that is organized every 20 years (1983, 2003, 2023, ...). We hope that you will enjoy the regional sedimentary geology, and that many of us will meet again somewhere in Croatia in 2043...

The Editors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Volcano-sedimentary-evaporitic rocks from an aborted Triassic rift and Cretaceous to Palaeogene Adriatic Carbonate Platform successions: OAEs, K–Pg boundary and the Palaeocene platform top (central Dalmatian islands, Croatia)

Tvrtko Korbar, Mirko Belak, Ladislav Fuček, Jelena Španiček, Thomas Steuber

FIELD TRIP C1

Volcano-sedimentary-evaporitic rocks from an aborted Triassic rift and Cretaceous to Palaeogene Adriatic Carbonate Platform successions: OAEs, K–Pg boundary and the Palaeocene platform top (central Dalmatian islands, Croatia)

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Abstract

The central Adriatic Vis archipelago was in 2019 recognized as a UNESCO Global Geopark. The islands are characterized by the oldest and the youngest rocks in the Adriatic, owing to salt tectonics that characterize the area. Salt diapirs are the most prominent subsurface tectonic structures in the central part of the Adriatic, built of once deeply buried volcano-sedimentary-evaporitic rocks deposited during the middle Triassic rifting stage of the Adriatic microplate (Adria). The subtropical Adriatic Carbonate Platform (AdCP) existed during most of the Mesozoic in the central part of the then more spacious Adria. The NE part of the AdCP has been incorporated into the Dinarides fold-and-thrust belt during the Palaeogene while the SW part remained relatively undeformed within the Adriatic foreland, which is mostly covered by the Neogene clastic deposits and by the sea since the Holocene. The diapirs include complexes of various Triassic rocks, which in places uplifted, and even pierced, a few kilometres thick AdCP succession, e.g., Komiža Bay on the island of Vis. As a consequence, an up to 1500 m-thick succession of the Cretaceous shallow-water carbonates is exposed on the flanks of the Komiža diapir. While pre- and post-Aptian successions are characterized by monotonous peritidal cycles, the Lower Aptian is marked by prominent facies diversification because of the perturbations related to the onset of the Ocean Anoxic Event 1a (OAE 1a), and the upper part is characterized by a regional subaerial exposure. OAE 2 is only incompletely recorded within the Cenomanian–Turonian succession on the islands of Vis and Biševo, as a consequence of local emergence of the platform top during the event, that is followed by a relatively short period of deposition until the Coniacian, when the SW part of the AdCP emerged. In the NE part of the platform the deposition continued until the Maastrichtian, and in places even into the Palaeocene. Thus, the Cretaceous–Palaeogene (K–Pg) boundary event is recorded within rare successions deposited on tidal flats (Hvar island) or in inner-platform lagoons (Brač island), but there is still debate on the origin of the specific boundary layer. The AdCP top is characterized by a major subaerial exposure, during which distinct discontinuity surfaces have been formed, and it is unconformably overlain by diachronous Eocene Foraminiferal Limestones that were deposited on a distal ramp of the once migrating Dinaric foreland basin.

Introduction and geological setting

The central Adriatic is a common foreland of two orogenic systems (Fig. 1A) – Dinarides in the northeast (Korbar, 2009) and Apennines in the southwest (Scisciani & Calamita, 2009). The Mesozoic Adriatic Carbonate Platform (AdCP) successions (Vlahović *et al.*, 2005, see also field trip A1, this volume) are mostly buried within the central Adriatic below Cenozoic deposits, but also crop out along the eastern Adriatic islands (Dalmatia, Croatia). The NE part of the AdCP has been incorporated into the Dinarides fold-and-thrust belt during the Palaeogene while the SW part remained relatively undeformed within the Adriatic foreland (Korbar, 2009), which is mostly covered by the Neogene clastic deposits, and by the sea since the Holocene.

Central Adriatic is characterized by huge masses of Triassic salt and associated rocks (Fig. 1B) that are buried under a few kilometres thick successions of carbonates and clastic deposits (Grandić *et al.*, 2001, 2010; Velić *et al.*, 2015; Saftić *et al.*, 2019). The salt diapirs of the central Adriatic are distinct subsurface tectonic structures recognized on deep seismic images that only in places pierced the overlying successions and appear as the offshore islands or seamounts. The shallow parts of the salt structures have been confirmed also by shallow geoacoustic surveys (Gelletti *et al.*, 2008), and by geological mapping (Korbar *et al.*, 2012). It is assumed that the onset of salt movement is related to a neotectonic reactivation of Mesozoic extensional faults (Grandić *et al.*, 2002), while the evacuated salt could be protruded

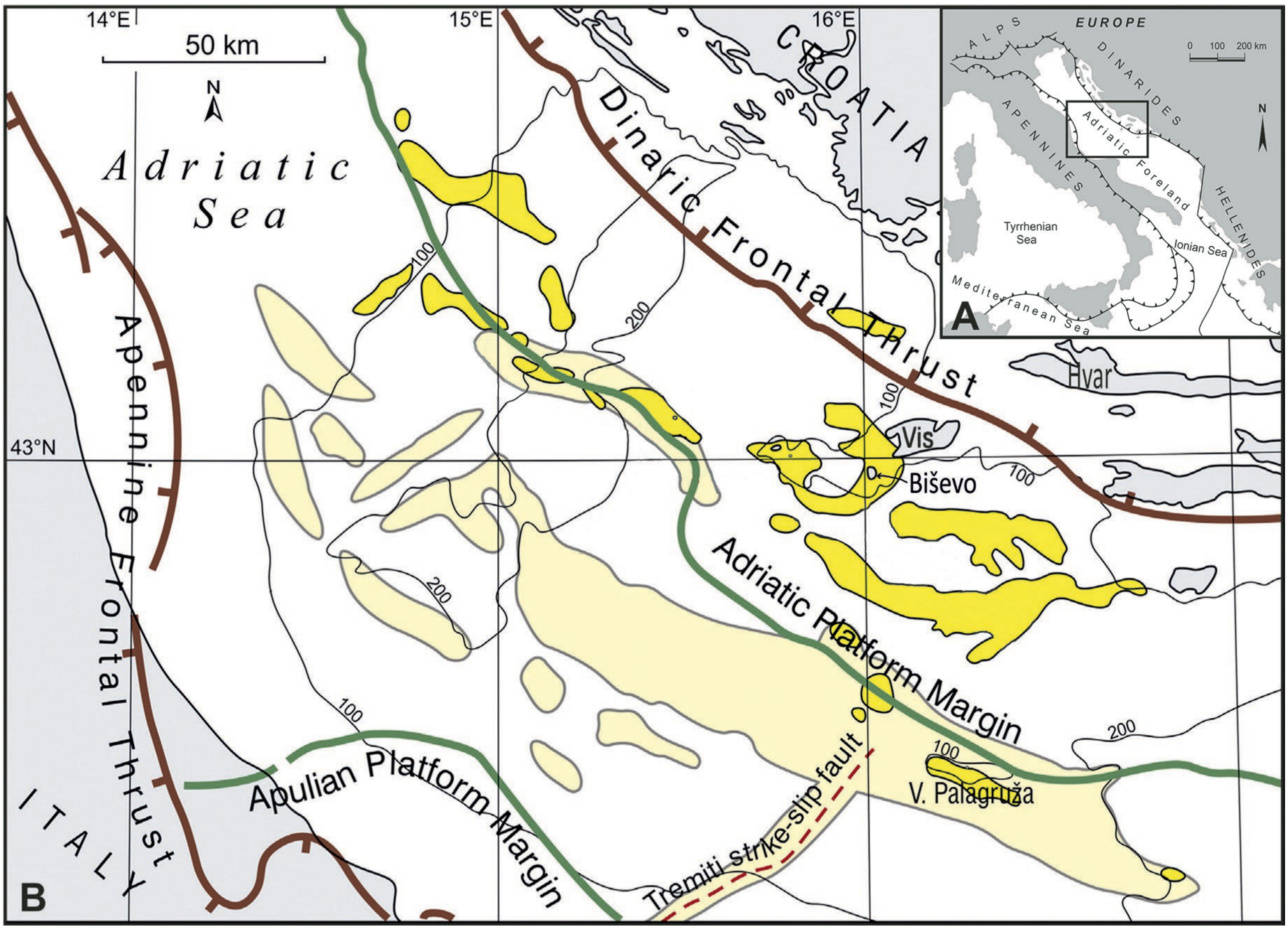

Fig. 1. A) Location map of the central Adriatic (rectangle is location of Fig. 1B) within the central-northern Mediterranean tectonic sketch (modified after Korbar, 2009). B) Bathymetric map of the Central Adriatic (isobaths in metres) with highlighted salt structures (yellow=salt diapirs, ocher=salt domes), and the main paleogeographic and tectonic lineaments (map modified after Geletti *et al.* (2008) and Pikelj *et al.* (2015), and references therein). Green lines: platforms margin; brown lines: thrust fronts.

through the seabed since the Miocene (Pikelj *et al.*, 2015). Some salt structures are still active today, as evidenced by seismicity (Herak *et al.*, 1996, 2005) and by the uplift of some offshore islands (Babić *et al.*, 2012).

The Early Aptian (Early Cretaceous) was a time of significant environmental change affecting low-latitude Tethyan carbonate platforms (Huck *et al.*, 2010), many of which are characterized by incomplete successions related to emergence and/or drowning, and only a few have preserved a more complete record of the OAE 1a (Steuber *et al.*, 2022). While pre- and post-Aptian successions of the AdCP are dominated by peritidal environments, the beginning of the Aptian is marked by the onset of subtidal, more open-platform environments, characterized either by *Lithocodium–Bacinella* or skeletal, rudist-rich facies. Apart from the northern (marginal) part of the AdCP that is characterized by rudist-coral-stromatoporoid communities, which flourished within a high-energy belt, other areas of the platform are characterized by oligospecific associations of *Toucasia* and *Requienia*. More diverse, *Offneria*-bearing deposits are to date reported from only a few localities (Masse *et al.*, 2004).

A prominent stratigraphic package within the AdCP succession is the Cenomanian–Turonian (Ce–Tu) succession, related to the onset of OAE 2 that strongly influenced shallow-water deposition and caused flooding of large parts of the AdCP (Gušić & Jelaska, 1990, 1993; Jenkins, 1991). The succession was reported in detail from the neighbouring islands of Hvar (Davey & Jenkyns, 1999) and Brač (Korbar *et al.*, 2012). Although the record of the OAE 2 on the island of Vis and Biševo is incomplete because of the local emergence of the platform top, and a local hiatus that is probably related to synsedimentary tectonics, the Ce–Tu package is a good stratigraphical marker since it is more massive than the underlying and overlying well-bedded peritidal carbonates, and characterized by prominent lithological and biostratigraphical changes.

Late Cretaceous synsedimentary tectonics strongly influenced the significant differentiation of the depositional environments within the AdCP (Vlahović *et al.*, 2005), visible in various Cretaceous-to-Palaeogene depositional records (Korbar, 2009). A continuous Cretaceous–Palaeogene (K–Pg) shallow-water succession is reported from the island of Hvar (Korbar *et al.*, 2015), and the deeper water equivalent from the island of Svetac (Korbar *et al.*, 2020). However, the Cretaceous–Palaeogene (K–Pg) boundary event is only recorded in two localities, one succession deposited on a tidal flat (Hvar island, Korbar et al., 2015) and another in a lagoon (Brač island, Korbar *et al.*, 2017a). However, there is still debate on the origin of the specific boundary layer (Font *et al.*, 2017; Korbar *et al.*, 2017b; Korbar, 2019; Cvetko Tešović *et al.*, 2020). Peritidal deposition continued during the Early Palaeocene (Danian), and the AdCP top is characterized by a major subaerial exposure during which distinct discontinuity surfaces formed (Brlek *et al.*, 2014). Subaerial exposure corresponds to a hiatus representing at least 10 million years of platform emergence. The palaeokarstified Palaeocene platform top is unconformably overlain by diachronous Eocene Foraminiferal Limestones (Marjanac *et al.*, 1998) that were deposited during the Eocene transgression on a distal ramp of the once migrating Dinaric foreland basin (Korbar, 2009).

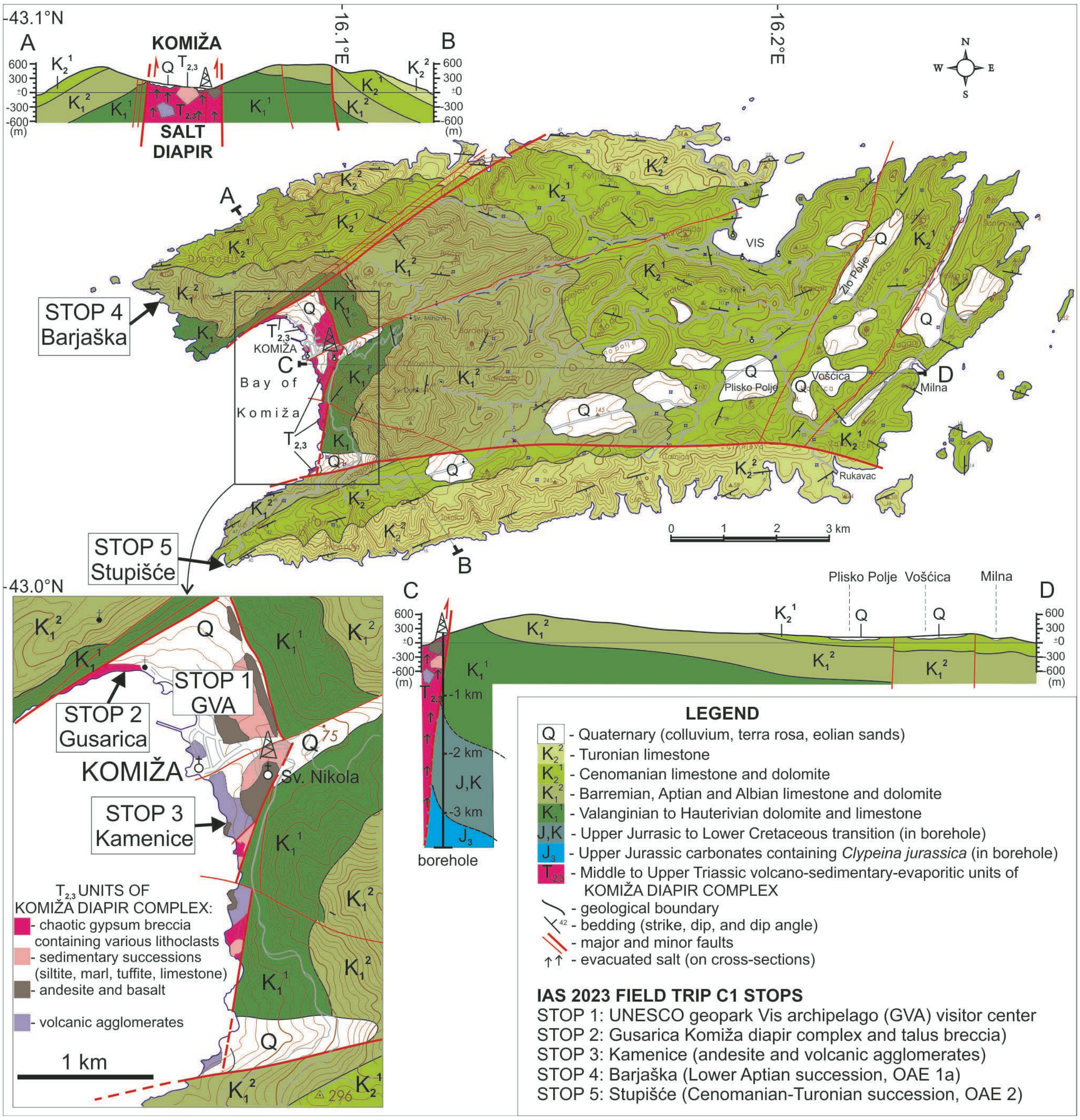

Fig. 2. Geological maps and cross-sections of the island of Vis and the Bay of Komiža (simplified from Korbar *et al.*, 2012a).

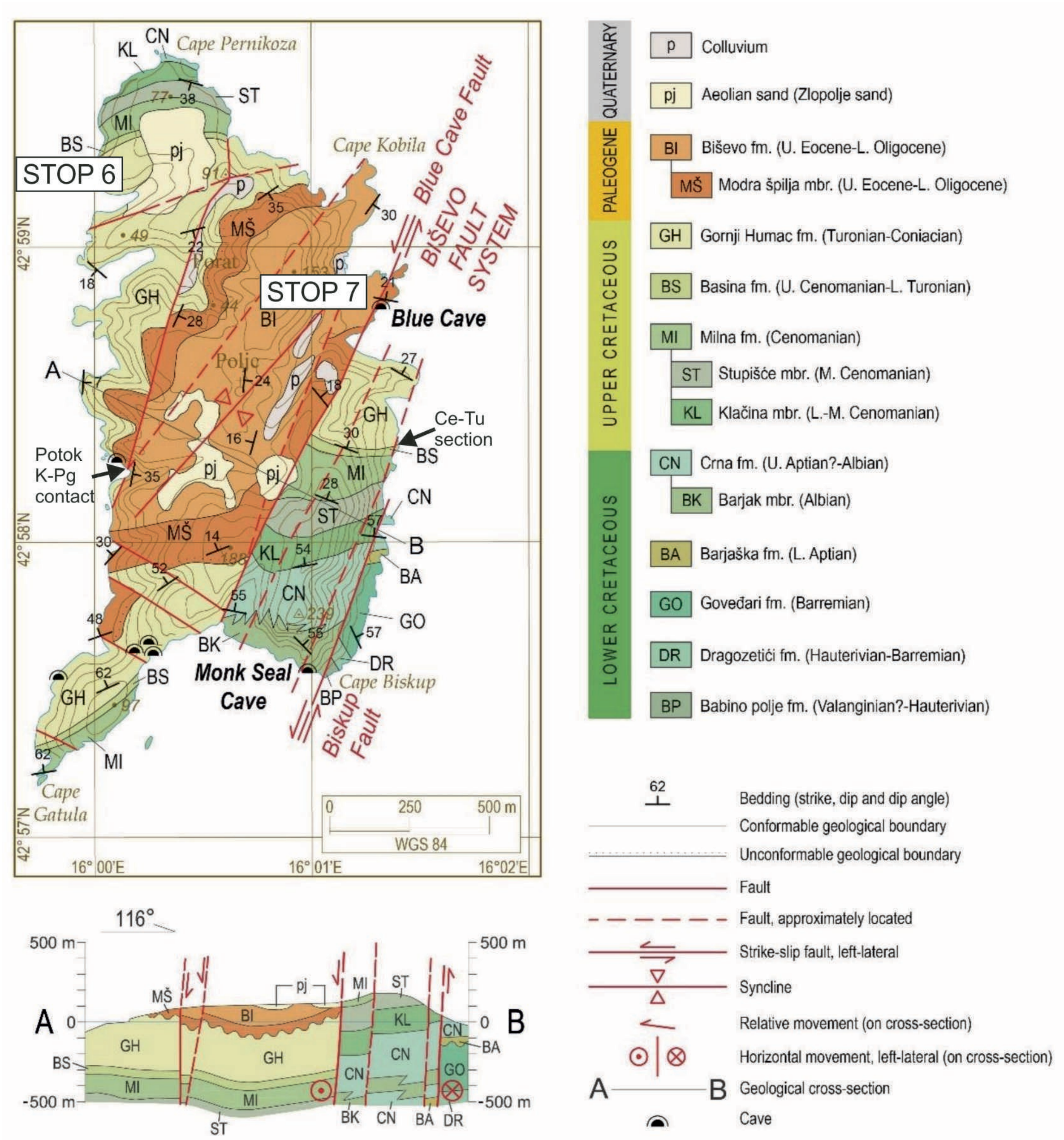

Fig. 3. Geological map and geological sections of the island of Biševo (after Korbar *et al.*, 2012a).

Description of the stops

The island of Vis is a generally E-W trending antiform plunging to the east (Korbar *et al.*, 2012). The oldest deposits are exposed in the western part of the island, in the Bay of Komiža (STOPS 1–3), which represents the eroded head of a salt diapir (Fig. 2). The Komiža diapir complex is built of volcano-sedimentary-evaporitic rocks deposited during the middle Triassic rifting stage (Belak & Koch, 2009) and break-up of Pangea, that led to the separation of the Adriatic microplate – the Adria (van Hinsbergen *et al.*, 2020). Micropalaeontological analyzes indicate Ladinian sedimentation and contemporaneous volcanism (Koch & Belak, 2003; Belak *et al*, 2005), while the results of geochronological analysis indicates Carnian intrusions in the area (De Min *et al.*, 2009).

Owing to the specific tectonic style in the area of the Bay of Komiža that is related to a diapir piercement, relatively undisturbed successions of Cretaceous platform carbonates are exposed on the western part of the island. A succession more than 1500 m thick is exposed along the NW and SW coasts (STOPS 4 and 5), while the contact of Cretaceous and Palaeogene carbonates, characterized by an approx. 50 million years hiatus, is exposed only on the neighbouring island of Biševo, (between STOPS 6 and 7 on Fig. 3; Korbar *et al.*, 2012a).

Stop 1. Komiža (Vis island): UNESCO Geopark Vis Archipelago (GVA) visitor center

Owing to the variety of exposed rocks and significant geomorphological features, many of which are protected as monuments of nature and significant landscapes, the Vis archipelago was declared by UNESCO as a Global Geopark in 2019 [https://www.geopark-vis.com/]. Most of the rocks and sediments that appear all around the archipelago are exhibited in the visitor center.

Stop 2. Gusarica: Komiža diapir complex and talus breccia

The western coast of the city beach of Gusarica is composed of a chaotic mélange that consists of various Triassic rocks, predominantly gypsum breccia which is partially covered by quaternary colluvium and eluvium (Fig. 4). The gypsum breccia is clast to matrix-supported, poorly sorted, with clasts ranging in size from one to tens of centimetres. The polymictic breccia consists of various Triassic lithoclasts (Belak *et al.*, 2005) among which are laminated evaporites, nodular evaporites, dolostones, limestones, bituminous laminated carbonates and clasts of volcanic rocks. The matrix is clay and gypsum. A nodular evaporite with a dolomite matrix indicates a primary sabkha environment. The breccia was formed by diapiric uplift, enterolithic folding and hydration of anhydrite within the Komiža diapir complex. The process of anhydrite hydration in the subsoil is recent, which in combination with rapid surface weathering results in rapid geomorphological changes on outcrops of the gypsum breccia.

The Quaternary talus (colluvial) breccia of the Gusarica locality is related to the steep relief of Komiža Bay, formed by intense erosion of the diapiric salt complex. The talus breccia is composed of unsorted greyish angular fragments of the sur-

Fig. 4. Stop 2. Gusarica. Komiža diapir complex and talus breccia. A) Outcrop of chaotic gypsum breccia and collapsed blocks on the beach. B) Close-up view of gypsum breccia with various Triassic lithoclasts (andesite, sedimentary rocks, strongly deformed gypsum, etc.). C) Erosional remnants of talus (colluvial) breccia with Gusarica beach and church in the background. E) Close up view of talus breccia showing abundant reddish matrix.

rounding carbonate rocks (Lower Cretaceous) and various amounts of reddish matrix. The material is widely used as local cheap building stone for traditional houses in Komiža.

Stop 3. Kamenice: volcanic and volcaniclastic rocks – andesite and agglomerates

In the bay (beach) of Kamenice there is a unique succession of Triassic volcanic and volcaniclastic rocks (Fig. 5). Autoclastic andesite breccia is overlain by coherent andesite lava, on which a thick sequence of volcanic agglomerates was deposited – the primary eruptive pyroclastic deposit.

The autoclastic breccia was formed as a result of the non-explosive fragmentation of lava (McPhie *et al.*, 1993), and consists of monomictic blocks of andesite lava with some hyaloclastic matrix. Towards the northwest, the breccia gradually changes into a coherent andesite lava. Autobreccia is a common product of subaerial effusions (McPhie *et al.*, 1993), but has also been identified in submarine basalt effusions (Ballard *et al.*, 1979). The autobreccia and coherent lava are overlain by volcanic agglomerates, as primary volcaniclastic deposits formed by explosive eruptions and deposited by syn-eruptive volcanic processes. Agglomerates are built from blocks of volcanic rocks and volcanic bombs up to 50 cm in size, supported by matrix, and poorly sorted. The matrix comprises fine pyroclastic material, crystaloclasts and volcanic ash. Along with andesite blocks, there are also blocks of basalt and trachyandesite. The primary magmatic minerals of the volcanic rocks are plagioclase phenocrysts (andesine core, albite rim) and altered clinopyroxene. The major minerals includes plagioclase microlites with secondary content of quartz, K-feldspar, magnetite, sphene and apatite. In basaltic rocks, plagioclases are albites and do not contain K-feldspar. The vesicles are filled with prehnite, quartz and chlorite.

Chemical analyses of all rock varieties (unpublished data) indicate middle Triassic calc-alkaline volcanism related to crustal extension. According to the data, there is a logical genetic link between the lava and intrusive, sub-volcanic counterparts of the magma that originated from older pre-Mesozoic subduction processes (De Min *et al.*, 2009).

Stop 4. Barjaška: Lower Aptian succession and OAE 1a

An excellent exposure of various Lower Aptian shallow-water carbonate facies at the Barjaška locality on the island of Vis (Dalmatia, Croatia, Fig. 6). The Lower Aptian facies stacking within a ca. 90 m thick succession is probably the most lithologically diverse intra-platform succession in the peri-Adriatic region. It is characterized by thick-bedded dolostones with remnants of *Lithocodium–Bacinella* oncoids, thin-bedded marly limestones, (dolomitized) slump?-mounds, rudist- and chondrodontid-rich sedimentary bodies including *Offneria* floatstones, *Chondrodonta* and *Palorbitolina* tempestites, chert horizons, and algal-rich subtidal facies. Transitions between the facies are mostly sharp.

A thick-bedded dolostone unit comprises the lowermost 30 m of the Lower Aptian succession. *Lithocodium–Bacinella* and *Palorbitolina* are observed in limestone lenses that escaped dolomitization. The dolomitized unit is recognized as being equivalent to the Lower Aptian Kanfanar unit reported from Istria (Vlahović *et al.*, 2003; Huck *et al.*, 2010). Above the dolostone unit, ca. 60 m of limestone with diverse facies characterizes the rest of the Lower Aptian succession at Barjaška. Integrated biostratigraphy and isotope chemostratigraphy (carbon, strontium) reveal the Lower Aptian age of the strata deposited during OAE 1a. Sr-isotope ratios of requieniid shells from 15 horizons within the limestone unit, indicate similar Early Aptian numerical ages (Bedoulian, 123–124 Ma, timescale of Gradstein et al., 2004; unpublished data). This is slightly younger than the recently improved age of the *Lithocodium–Bacinella* unit of the Istrian reference sections at Kanfanar (124–125 Ma; Huck *et al.*, 2010), implying greater accommodation space (approx. 70 m) during the Early Aptian at the Vis locality, or less erosion during the subsequent Aptian–Albian subaerial exposure.

The carbon and oxygen isotopic composition of bulk-rock samples (unpublished data) indicates a significant diagenetic overprint. The compact calcite of rudist shells that has also been used for Sr-isotope stratigraphy, yielded more reasonable 'normal-marine' values. These, however, show no obvious trends. Thus, the carbon-isotope stratigraphy does not allow for a confident recognition of C-segments that are typically used for a detailed subdivision of the Early Aptian. Chondrontid accumulations on top of rudist limestones, as observed at Barjaška, are remarkably similar to the succession observed at the Cenomanian/Turonian boundary of the AdCP (Gušić & Jelaska, 1990, 1993; Vlahović *et al.*, 2005), and may be an indication of increased nutrient fluxes. Coupled with an increase in accommodation space, this may also be expressed in the following, thin bedded chert unit. The depositional environment subsequently shallowed in the overlying *Salpingoporella* unit.

Fig. 5. Stop 3. Kamenice: Triassic volcanic and volcaniclastic rocks. A) Panoramic photograph of Kamenice beach from the west, and indication of the section. B) Stratigraphic column Kamenice. C) Agglomerates and volcanic bombs. D) Prehnite close up. E) Andesite and info-table showing prehnite photomicrograph. F) Autoclastic andesite breccia.

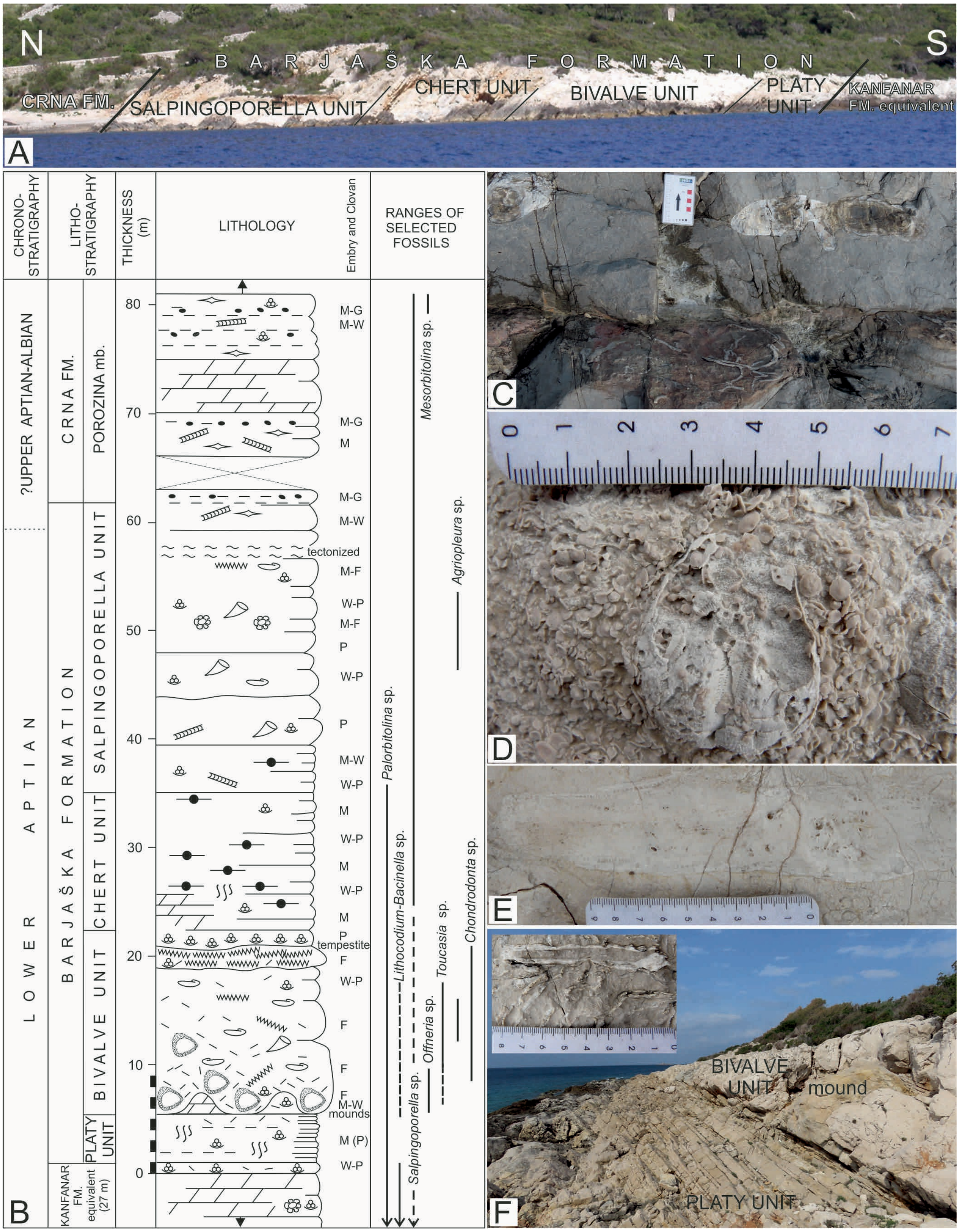

Fig. 6. Stop 4. Barjaška. Lower Aptian and OAE 1a. A) Panoramic photograph of the section from the west. B) Stratigraphic column Barjaška. C) Ichnofossils and chert nodules. D) Echinoid in orbitolinid tempestite. E) Longitudinal section of rudist shell Offneria sp. F) Lower part of the section. The Legend for the Vis and Biševo sections is shown on Fig. 7C).

Although the AdCP obviously experienced a prominent relative sea-level rise at the beginning of the Early Aptian, intraplatform thickness variations of up to 70 m are probably the result of synsedimentary tectonics. Our data from the island of Vis show that significant facies diversification is related to the onset of the OAE 1a, while the facies-stacking pattern was driven by coeval sea-level changes. Subsequent shallow-water carbonate deposition is marked by multiple marl horizons that are generally recognized as the regional Aptian–Albian emergence (Vlahović *et al.*, 2005; Huck *et al.*, 2010).

The depositional units observed at Barjaška thus include typical Lower Aptian biofacies observed elsewhere in southern Tethys, but a detailed correlation with other sections and sequences of events related to OAE 1a requires additional studies.

Stop 5. Stupišće and stop 6. Biševo: Ce–Tu succession and OAE 2

At the Stupišće (SW Vis, Figs. 2 and 7) and Biševo sections (Figs. 3 and 8) the OAE 2 influence on top of the Adriatic carbonate platform is reflected in facies variability. The Ce–Tu package is a good stratigraphical marker since it is more massive than both un-

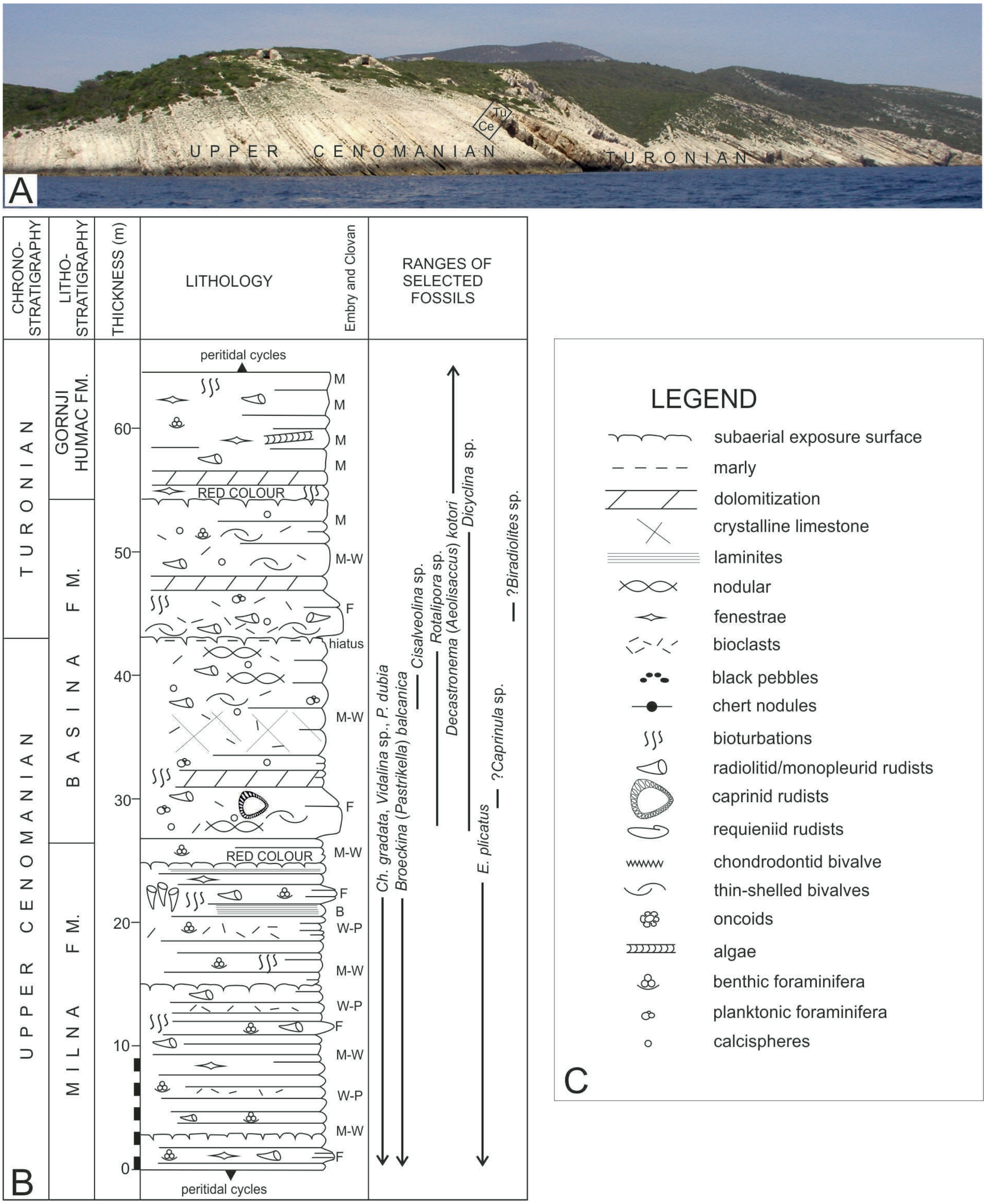

Fig. 7. Stop 5: Stupišće Ce–Tu section. A) Panoramic photograph of the section from the west. B) Stratigraphic column. C) Legend for all Cretaceous sections from Vis and Biševo (Figs. 6, 7, 8).

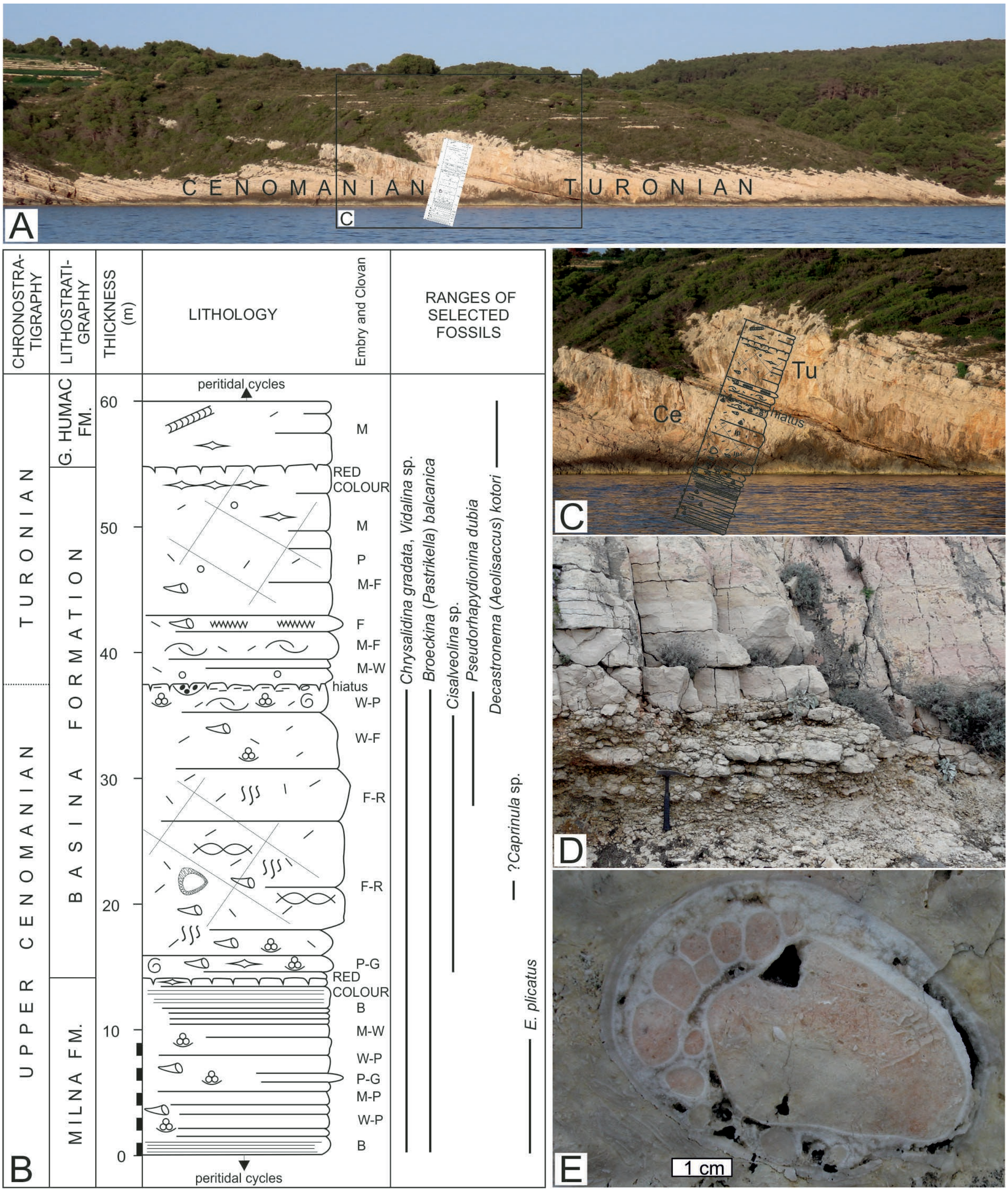

Fig. 8. Stop 6: Biševo Ce–Tu section. A) Panoramic photograph of the section from the west (originally recorded on the difficult-to-access eastern coast of the island, but is similar to that at stop 6). B) Stratigraphic column Biševo. C) Close-up of the Ce–Tu interval. D) Ce–Tu emergence horizon (hiatus). E) Transverse section of ?Caprinula sp. (Uppermost Cenomanian).

derlying and overlying well-bedded peritidal carbonates, and is morphologically expressed within the succession, especially along the coasts.

The Upper Cenomanian succession of shallow-water carbonates is characterized by peritidal cycles with monospecific radiolitid rudists and *Chondrodonta* biostromes. The succession passes upward into a massive deeper subtidal facies characterized by calcispheres, nodular bedding, and diversified neritic fossil association, since various foraminifera and rudists were determined within the Ce–Tu massive package. There is a prominent emersion horizon (hiatus) within the package at both sections that indicates local emergence of the platform top. According to the biostratigraphy, the horizon includes the Ce–Tu boundary. The overlying Turonian succession is characterized by monotonous fenestral mudstones with abundant but paucispecific shallow-water benthic microfossils.

Stop 7. Mezuporat (Biševo island): Modra špilja / Blue Cave

The island of Biševo has a long-standing tradition as a tourist destination and is also characterized by attractive geological sites. In 1884 Eugen Baron Ran-

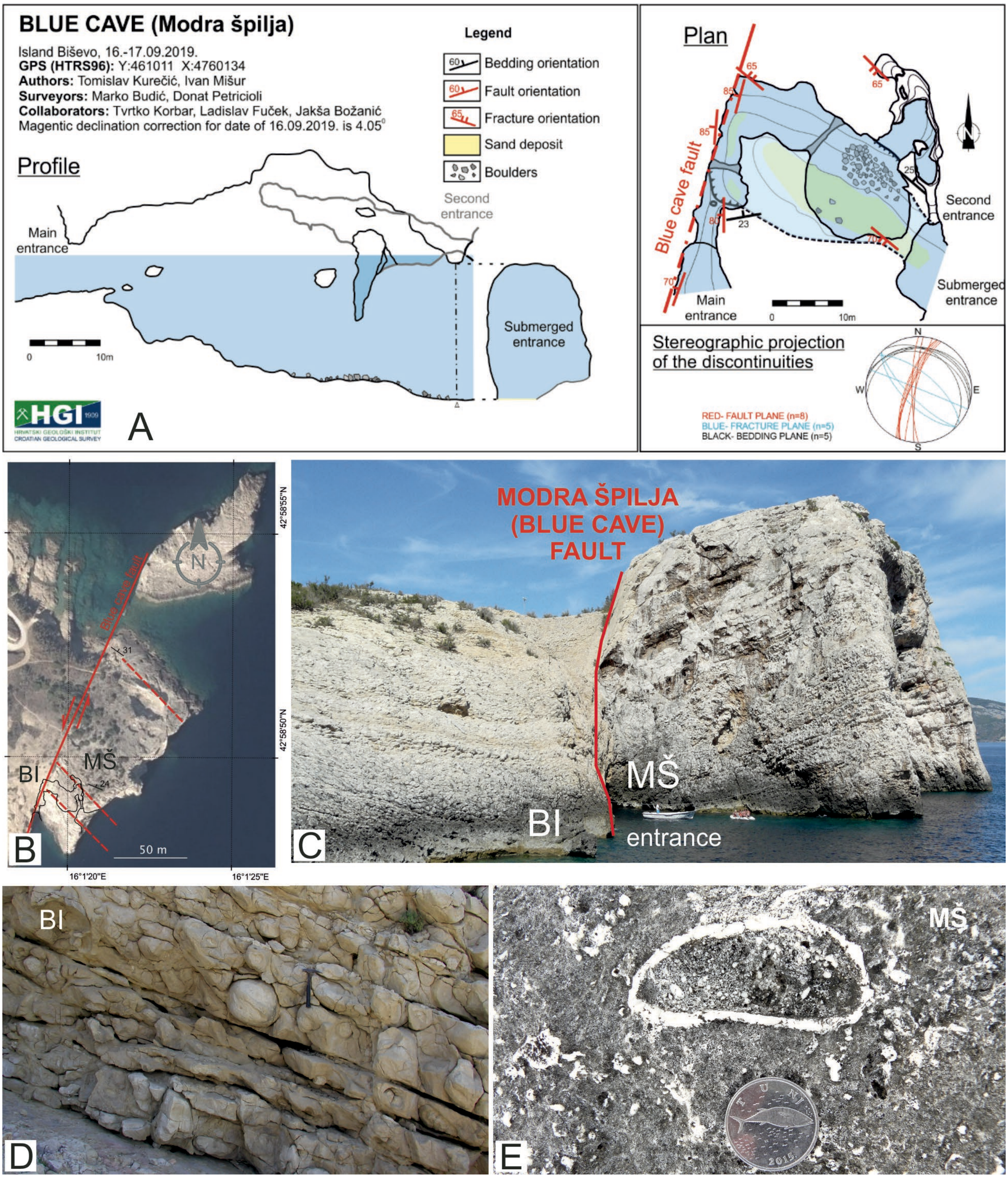

Fig. 9. Stop 7: Blue Cave (Modra špilja). A) Plan and profile of the Blue Cave (Mišur *et al.*, 2021). B) Interpreted satellite image of the Blue Cave (Mišur *et al.*, 2021). C) Panoramic photograph from the south to the entrance area of the cave and an indication of the main geological features (see map on Fig. 3). D) Typical nodular bedding of the younger (Lower Oligocene) part of the Biševo formation. E) Close view of the typical skeletal packstones to rudstones of the older (Late Eocene) Modra špilja member, with a transverse echinoid section. BI – Biševo formation; MB – Modra špilja member.

sonnet, a painter from Vienna, discovered a natural geomorphological luminous phenomenon on the island – the Blue Grotto (the Blue Cave, in English; Modra špilja, in Croatian). The Blue cave is famous for its blue light effect, which occurs when morning sunlight enters the cave through its submerged eastern entrance and reflects from the white sandy bottom creating a unique visual ambience (Mišur *et al.*, 2021 and references therein).

Rocks hosting the Blue Cave (Modra špilja) are referred to as the homonymous lithological unit (MŠ on Fig. 2). These are thick-bedded skeletal limestones inclined to the NNE, predominantly foraminiferal-bioclastic wackestones to rudstones. The Blue Cave Fault (Fig. 9) is the most prominent fault on the island, characterized by a left-lateral strike-slip shift of approximately 1 km (Fig. 3). The fault separates the Modra špilja member in the east from the Biševo formation in the west, and the fault plane is visible at the main cave entrance (Fig. 9). The fault plane borders the cave from the west, and delimits the older (Late Eocene) Modra špilja member (MŠ on Fig. 3) and the younger (Early Oligocene) nodular beds of the Biševo formation (BI on Fig. 3). In contrast to the thick-bedded skeletal limestones of the host rock of the cave (MŠ mb), the upper part of the Biševo formation (BI) is characterized by poorly cemented nodular bioclastic limestones, probably deposited on the steepening distal ramp in the latest phase of the Dinaric foreland basin formation (Korbar, 2009).

Stop 8. Hvar: K–Pg boundary and Palaeocene platform top

An exceptional 47-m-thick succession of Maastrichtian to Palaeocene inner-platform carbonates is exposed on the Dalmatian island of Hvar (Adriatic Sea, Croatia) in a seaside locality called Majerovica (Fig. 10).

The lower part of the succession (Fig. 11) is characterized by typical peritidal inner-platform carbonates of the Sumartin formation (Gušić & Jelaska, 1990) that in the town of Hvar overlies the regional Middle Campanian emersion (Korbar *et al.*, 2010). The upper part of the formation is predominantly composed of peritidal limestones: mostly fenestral mudstones, microbial laminites, skeletal wackestone-packstone with ostracods and benthic foraminifera (miliolids, rotaliids etc.), and floatstones containing late Maastrichtian requieniid and radiolitid rudists (Fig. 11). Mean $^{87}Sr/^{86}Sr$ values of 0.7078450 and 0.7078446 from the requieniid rudists indicate a terminal Maastrichtian age for this part of the section (Korbar *et al.*, 2015).

The middle part of the succession comprises a ~5 m thick intraformational massive deposit, which is deposited over the strongly eroded top of reddish microbial laminites. This is interpreted as the K–Pg boundary event deposit that in its lower part includes a polygenic, matrix-supported, unsorted (chaotic) carbonate breccia, characterized by ripped-up Maastrichtian platform-limestone lithoclasts, up to boulder sized, and a polygenic microbreccia in a muddy matrix. The microbreccia contains small, rare intraclasts of pelagic mudstone containing terminal Maastrichtian planktonic foraminifera. The deposit is overlain by mudstone containing a planktonic foraminiferal association belonging to the basal Palaeogene.While facies suggest that the deposit was emplaced over the inner platform by a large tsunami, the biostratigraphic assessment of this section and the presence of enhanced concentrations of platinum group elements, such as iridium in the topmost part of the massive deposit, lend support to the hypothesis that this tsunamite is related to the K–Pg event, triggered by the Chicxulub impact in Yucatán (Korbar *et al.*, 2015, 2017a; Korbar, 2019).

The K–Pg event deposit is overlain by a ~30 m thick unit, predominantly mudstone, which in the lower part contains rare dwarf globigerinids typical of the basal Palaeocene (Danian). Mudstones-wackestones with rare ostracods, small miliolids and discorbid benthic foraminifera, and very rare characean calcareous algae, are recognized up-section (Fig. 11). The section terminates in a series of thick-bedded, recrystallized fenestral limestones characterized by distinct and deeply penetrating palaeokarstic features, pedogenic carbonates (calcretes), and some bauxites. The features mark a prominetnt subaerial exposure of the Palaeocene platform top, during which distinct discontinuity surfaces were formed (Brlek et al., 2014), representing a well-known regional unconformity (Vlahović *et al.*, 2005; Korbar, 2009). The unconformity is overlain by a few beds of brackish-water limestones of the Kozina member containing gastropods, which pass upward to the open-ramp limestones with predominantly *Nummulites* and *Discocyclina*, forming the Eocene succession of the Foraminiferal Limestones, which is eventually overlain by a thick succession of the Dalmatian Flysch (Marjanac *et al.*, 1998). The unstable outcrops of the marls in the lower part of the flysch succession are artificially stabilized by concrete and are no longer available for observation at this locality (Podstine Cove).

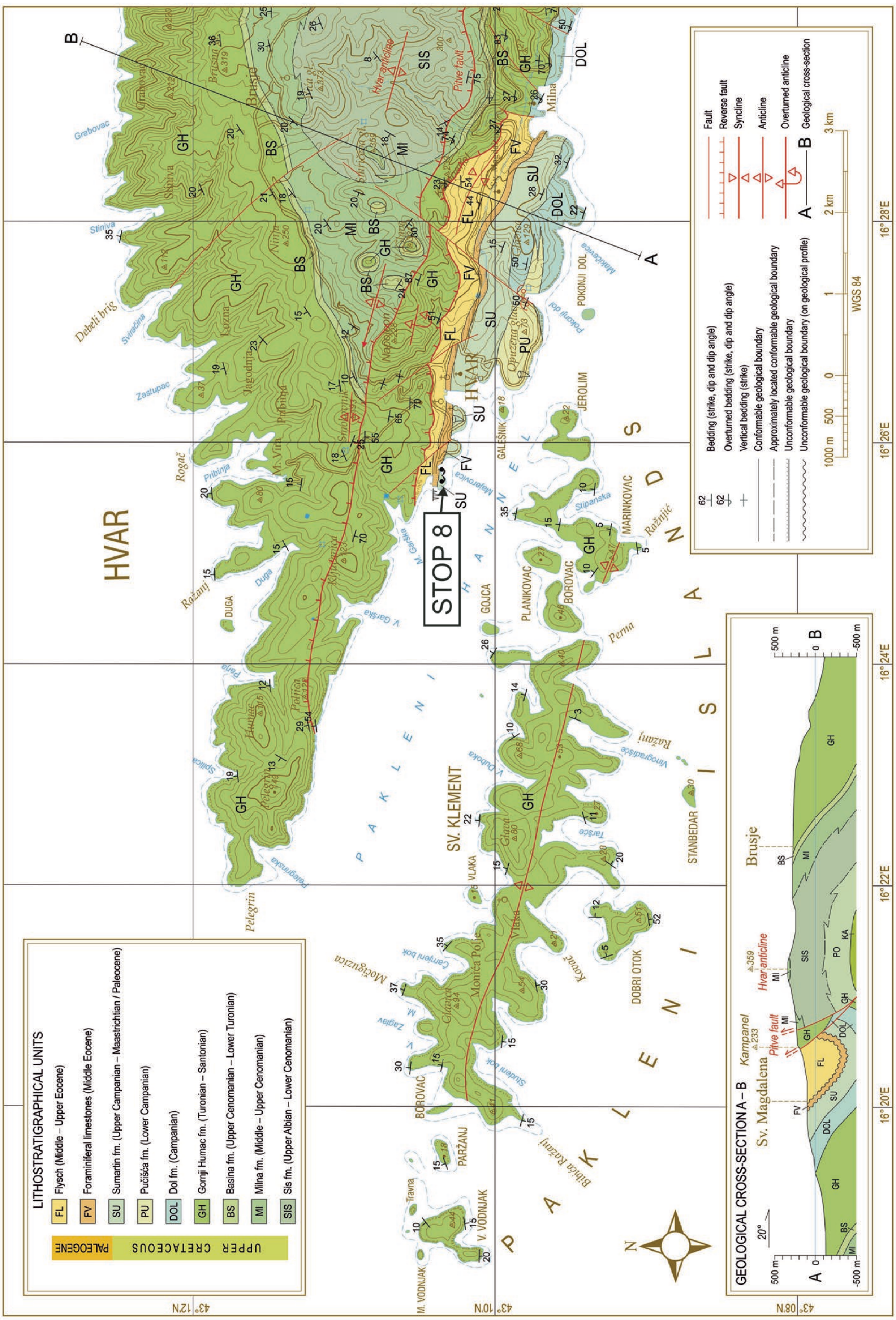

Fig. 10. A geological map and cross-section of the western part of the island of Hvar (from Oštrić *et al.*, 2015).

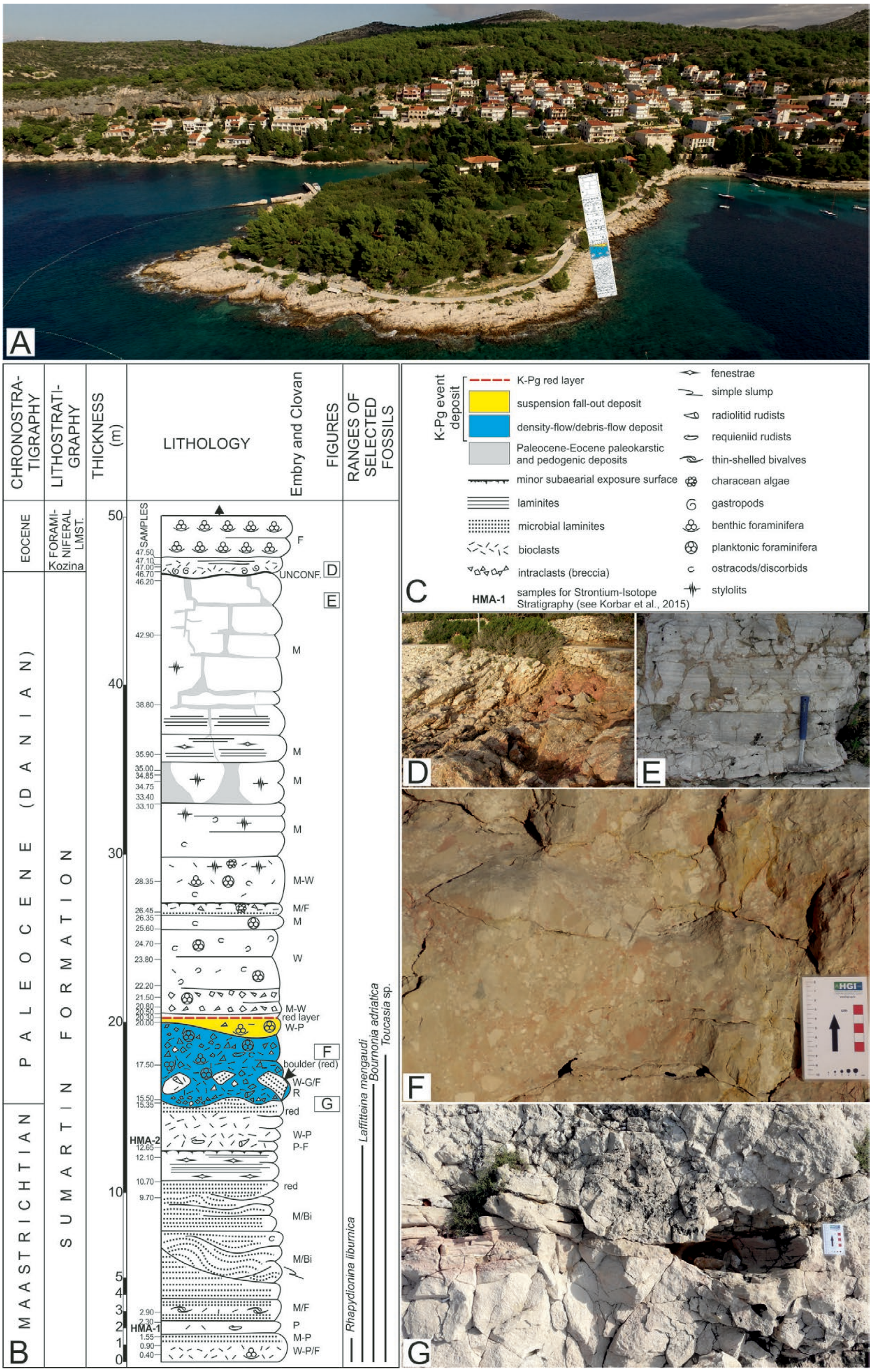

Fig. 11. Hvar K–Pg section at Majerovica – Kovač (see Korbar *et al.*, 2015). A) Panoramic photograph from the south to Kovač Promontory, Majerovica Cove (right), and Podstine Cove (background left), indicating the position of the measured section. B) Stratigraphic column Hvar – Majerovica. C) Legend for B. D) Palaeocene platform top covered by reddish-brown calcrete and bauxite (right) and the overlying Eocene Foraminiferal Limestones (left). E) Discontinuity surfaces and palaeokarst infillings by calcrete within the Palaeocene succession of peritidal carbonates (see Brlek *et al.*, 2014). F) K–Pg boundary event-bed (tsunamite?): polymictic, chaotic carbonate breccia characterized by abundant muddy matrix. G) K–Pg boundary: uneven erosional contact of the underlying reddish microbial peritidal laminites and the overlying chaotic carbonate breccia.

Acknowledgments

Most of the fieldwork was undertaken within the former National projects "The basic geological map of the Republic of Croatia, scale 1:50.000" (181-1811096-1093) and "Stratigraphy and Geodynamic Context of Cretaceous Deposits in the NE Adriatic Region" (181-1191152-2697). We would like to thank colleagues Antun Husinec, Damir Palenik and Igor Vlahović for their collaboration during the measuring and logging of the Cretaceous sections on the islands of Vis and Biševo. We thank Marko Budić (HGI) for adaptation of the official geological maps. Many thanks to Blanka Cvetko Tešović for the critical review. ■

References

Babić, Lj, Crnjaković, M. and **Asmerom, Y.** (2012) Uplifted Pleistocene marine sediments of the Central Adriatic Island of Brusnik. *Geologia Croatica*, **65** (2), 223–232.

Ballard, R.D., Holcomb, R.T. and **van Andel, T.H.** (1979) The Galapagos Rift at 86°W: 3. Sheet flows, collapse pits and lava lakes of the rift valley. *J. Geophys Res.*, **84**: 5407–5422.

Belak, M. and **Koch, G.** (2009). Evaporitno-karbonatno-klastično-vulkanogeni kompleks (gornji ladinik, karnik – T22, T31). In: Tumač Geološke karte Republike Hrvatske 1:300.000 (Eds I. Velić and I. Vlahović,), p. 38, Hrvatski geološki institut, Zagreb (In Croatian).

Belak, M., Koch, G., Grgasović, T., Vlahović, I., Velić, I., Sokač, B. and **Benček, Đ.** (2005) Novi prinos stratigrafiji evaporitno-karbonatno-klastično-vulkanogenog kompleksa Komiškog zaljeva (otok Vis, Hrvatska) (New Contribution to the Stratigraphy of Evaporitic-Carbonate-Clastic-Volcanogenic Complex of Komiža Bay (Island of Vis, Croatia). In: *Abstract Book*, I.Vlahović and R. Biondić), *3. Hrvatski geološki kongres (Third Croatian Geological Congress)*, Opatija, , 13–14.

Brlek, M., Korbar, T., Košir A., Glumac B., Grizelj, A. and **Otoničar, B.** (2014) Discontinuity surfaces in Upper Cretaceous to Paleogene carbonates of central Dalmatia (Croatia): Glossifungites ichnofacies, biogenic calcretes and stratigraphic implications. *Facies*, **60** (2), 467–487.

Cvetko Tešović, B., Martinuš, M., Golec, I. and **Vlahović, I.** (2020) Lithostratigraphy and biostratigraphy of the uppermost Cretaceous to lowermost Palaeogene shallow-marine succession: top of the Adriatic Carbonate Platform at the Likva Cove section (island of Brač, Croatia), *Cretaceous Res.*, **114**, 104507.

De Min, A., Jourdan, F., Marzoli, A., Renne, P.R. and **Juračić, M.** (2009) The tholeiitic Magmatism of Jabuka, Vis and Brusnik Islands: a Carnian magmatism in the Adria Plate. *Rendiconti online della Società Geologica Italiana*, **9** (3), 85–87.

Davey, S.D. and **Jenkyns, H.C.** (1999) Carbon-isotope stratigraphy of shallow-water limestones and implications for the timing of Late Cretaceous sea-level rise and anoxic events (Cenomanian–Turonian of the peri-Adriatic carbonate platform, Croatia). *Eclogae Geologicae Helvetiae*, **92**, 163–170.

Font, E., Keller, G., Sanders, D. and **Adatte, T.** (2017) Comment on "Post-impact event bed (tsunamite) at the Cretaceous-Palaeogene boundary deposited on a distal carbonate platform interior": *Terra Nova*, **29**, 329–331.

Geletti, R., Del Ben, A., Busetti, M., Ramella, R. and **Volpi, V.** (2008) Gas seeps linked to salt structures in the Central Adriatic Sea. *Basin Research*, 20, 473–487.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Bleeker, W. and **Lourens, L.J.** (2004) A new Geologic Time Scale, with special reference to Precambrian and Neogene. Episodes, **27**, 83–100.

Grandić, S., Biancone, M. and **Samaržija, J.** (2001) Geophysical and stratigraphic evidence of the Triassic rift structuration in the Adriatic offshore area. *Nafta*, **52** (12), 383–396.

Grandić, S., Veseli, V. and **Kolbah, S.** (2002). Hydrocarbon potential of Dugi otok basin in offshore Croatia. *Nafta*, **53**, (6–7), 215–224.

Grandić, S., Kratković, I. and **Rusan, I.** (2010) Hydrocarbon potential assessment of the slope deposits along the SW Dinarides carbonate platform edge. *Nafta*, **56**, (7–8), 325–338.

Gušić, I. and **Jelaska, V.** (1990) Stratigrafija gornjokrednih naslaga otoka Brača u okviru geodinamske evolucije Jadranske karbonatne platforme (Upper Cretaceous stratigraphy of the Island of Brač within the geodynamic evolution of the Adriatic carbonate platform). *Djela Jugoslavenske akademije znanosti i umjetnosti*, **69**, Institut za geološka istraživanja, OOUR za geologiju, 160 pp., Zagreb.

Gušić, I. and **Jelaska, V.** (1993) Upper Cenomanian-Lower Turonian sea-level rise and its consequences on the Adriatic-Dinaric carbonate platform. *Geol. Rundsch.*, **82** (4), 676–686, Stuttgart.

Herak, Ma., Herak, D. and **Markušić, S.** (1996). Revision of the earthquake catalogue and seismicity in Croatia (1908–1992). *Terra Nova*, **8**, 86–96.

van Hinsbergen, D.J.J., Torsvik, T.H., Schmid, S.M., Maţenco, L.C., Maffione, M., Vissers, R.L.M., Gürer, D. and **Spakman, W.** (2020) Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic, *Gondwana Research*, **81**, 79–229.

Huck, S., Rameil, N., Korbar, T., Heimhofer, U., Wieczorek, T.D. and **Immenhauser, A.** (2010) Latitudinally different responses of Tethyan shoal-water carbonate systems to the Early Aptian oceanic anoxic event (OAE 1a). *Sedimentology*, **57** (7), 1585-1614, doi: 10.1111/j.1365-3091.2010.01157.x

Jenkyns, H. C. (1991) Impact of Cretaceous sea level rise and anoxic events on the Mesozoic carbonate platform of Yugoslavia. Amer. Ass. Petrol. Geol. Bull., **75** (6), 1007–1017.

Koch, G. and **Belak, M.** (2003) Evaporitic-carbonate deposits of Komiža diapiric structure (Island of Vis, Croatia): their palynostratigraphy and sedimentological features. In: *Abstract Book* (Ed I. Vlahović), *22nd IAS Meeting of Sedimentology*, Opatija, Croatia, 17–19.09.2003, Zagreb, Croatian Geological Survey.

Korbar, T. (2009) Orogenic evolution of the External Dinarides in the NE Adriatic region: a model constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates. *Earth Science Reviews*, **96**, (4), 296–312.

Korbar, T., Cvetko Tešović, B., Radovanović, I., Krizmanić, K., Steuber, T. and **Skelton, P.W.** (2010) Campanian *Pseudosabinia* limestones from the Pučišća Formation on the island of Hvar (Adriatic Sea, Croatia), *Turkish J. Earth Sci.*, **19** (6), 721–731.

Korbar, T. (2019) The Cretaceous-Paleogene boundary tsunamite on the Adriatic carbonate platform and possible source of a hypothetical Atlantic-to-western-Tethys megatsunami. In: *250 Million Years of Earth History in Central Italy: Celebrating 25 years of the Geological Observatory of Coldigioco*, (Eds C. Koeberl, and D. Bice), *GSA Spec. Paper*, **542**, 319–332.

Korbar, T., Belak, M., Fuček, L., Husinec, A., Oštrić, N., Palenik, D. and **Vlahović, I.** (2012a) Basic Geological Map of the Republic of Croatia, scale 1:50.000 – sheet Vis 3 and Biševo 1, 571/3 i 621/1. Croatian Geological Survey, Zagreb, Croatia, ISBN: 978-953-6907-27-4

Korbar, T., Glumac, B., Cvetko Tešović, B. and **Cadieux, S.B.** (2012b) Response of a carbonate platform to the Cenomanian–Turonian drowning and OAE 2: A case study from the Adriatic Platform (Dalmatia, Croatia). *Journal of Sedimentary Research*, **82**, 163–176.

Korbar, T., Montanari, A., Premec Fućek, V., Fuček, L., Coccioni, R, Mcdonald, I., Claeys, P., Schulz, T. and **Koeberl, C.** (2015) Potential Cretaceous-Paleogene boundray tsunami deposit in the intra-Tethyan Adriatic Carbonate Platform section of Hvar (Dalmatia, Croatia). *Geological Society of America Bulletin*, **127**, (11–12), 1666–1680.

Korbar, T., Mcdonald, I., Premec Fućek, V., Fuček, L. and **Posilović, H.** (2017a) Post-impact event bed (tsunamite) at the Cretaceous–Palaeogene boundary deposited on a distal carbonate platform interior. *Terra Nova*, **29**, 135–143.

Korbar, T., McDonald, I., Premec Fućek, V., Fuček, L., and **Posilović, H.** (2017b) Reply to Comment by Eric Font, Gerta Keller, Diethard Sanders and Thierry Adatte on „Post-impact event bed (tsunamite) at the Cretaceous-Palaeogene boundary deposited on a distal carbonate platform interior“: *Terra Nova*, **29**, 332-334.

Korbar, T., Fuček, L., Premec Fućek, V. and **Oštrić, N.** (2020) Maastrichtian to Palaeocene and Eocene pelagic carbonates on the island of Svetac (central Adriatic, Croatia). *Geologia Croatica*, **73**, (2), 95–106.

Marjanac, T., Babac, D., Benić, J., Ćosović, V., Drobne, K., Marjanac, Lj., Pavlovec, R. and **Velimirović, Z.** (1998). Eocene carbonate sediments and sea-level changes on the SE part of Adriatic Carbonate Platform (Island of Hvar and Pelješac Peninsula, Croatia). In: Hottinger, L., Drobne, K. (eds.), Paleogene shallow benthos of the Tethys, *Dela*, Slovenska akademija znanosti in umetnosti (SAZU), Znanstvenoraziskovalni center SAZU, Ljubljana, **34** (2), 243–254.

Masse, J-P., Fenerci-Masse, M., Korbar, T. and **Velić, I.** (2004) Lower Aptian Rudist Faunas (Bivalvia, Hippuritoidea) From Croatia. *Geologia Croatica*, **57 (**2), 117–137.

McPhie, J., Doyle, M. and **Allen, R.** (1993) Volcanic textures – a guide to the Interpretation of Textures in Volcanic Rocks. *Centre for Ore Deposit and Exploration Studies*, University of Tasmania.

Mišur, I., Budić, M., Kurečić, T. and **Korbar, T.** (2021) Tectonic Influence on Speleogenesis of Sea Caves on Biševo Island (UNESCO Global Geopark Vis Archipelago, Adriatic Sea, Croatia). *Geosciences*, **11** (8), 341.

Oštrić, N., Jelaska, V., Fuček, L., Prtoljan, B., Korolija, B., Gušić, I., Marinčić, S., Šparica, M., Korbar, T. and **Husinec, A** (2015) Osnovna geološka karta Republike Hrvatske (Basic Geological Map of the Republic of Croatia) M 1:50 000: list (sheet) Otok Hvar. Hrvatski geološki institut (Zavod za geologiju), 1 list (sheet), Zagreb, ISBN: 978-953-6907-49-6, In Croatian.

Pikelj, K., Hernitz-Kučenjak, M., Aščić, Š. and **Juračić, M.** (2015) Surface sediment around the Jabuka Islet and the Jabuka Shoal: Evidence of Miocene tectonics in the Central Adriatic Sea. *Marine geology*, **359**, 120–133.

Saftić, B., Kolenković Močilac, I., Cvetković, M., Vulin, D., Velić, J., and **Tomljenović, B.** (2019) Potential for the Geological Storage of CO2 in the Croatian Part of the Adriatic Offshore. *Minerals*, **9**(10):577. https://doi.org/10.3390/min9100577

Scisciani, V. and **Calamita, F.** (2009) Active intraplate deformation within Adria: examples from the Adriatic region. *Tectonophysics*, **476**, (1–2), 57–72.

Steuber, T., Alsuwaidi, M., Hennhoefer, D., Sulieman, H., Al-Blooshi, A., McAlpin, T.D. and **Shebl, H.** (2022) Environmental change and carbon-cycle dynamics during the onset of Cretaceous oceanic anoxic event 1a from a carbonate-ramp depositional system, Abu Dhabi, U.A.E. *Palaeogeography, Palaeoclimatology, Palaeoecology* **601**, 111086.

Velić, J., Malvić, T. Cvetković, M., and **Velić, I.** (2015) Stratigraphy and petroleum geology of the Croatian part of the Adriatic basin. *J. Pet. Geol.*, **38**, 281–300.

Vlahović, I., Tišljar, J., Velić, I., Matičec, D., Skelton, P.W., Korbar, T. and **Fuček, L.** (2003) Main events recorded in the sedimentary succession of the Adriatic Carbonate platform from the Oxfordian to the Upper Santonian in Istria (Croatia). In: *Evolution of Depositional Environments from the Palaeozoic to the Quarternary in the Karst Dinarides and the Pannonian basin* (Eds I. Vlahović and J. Tišljar), *Field Trip Guidebook of 22nd IAS Meeting of Sedimentology*, 19–56. Institute of Geology Zagreb, Opatija, Croatia.

Vlahović, I., Tišljar, J., Velić, I. and **Matičec, D.** (2005) Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **220** (3-4), 333–360.