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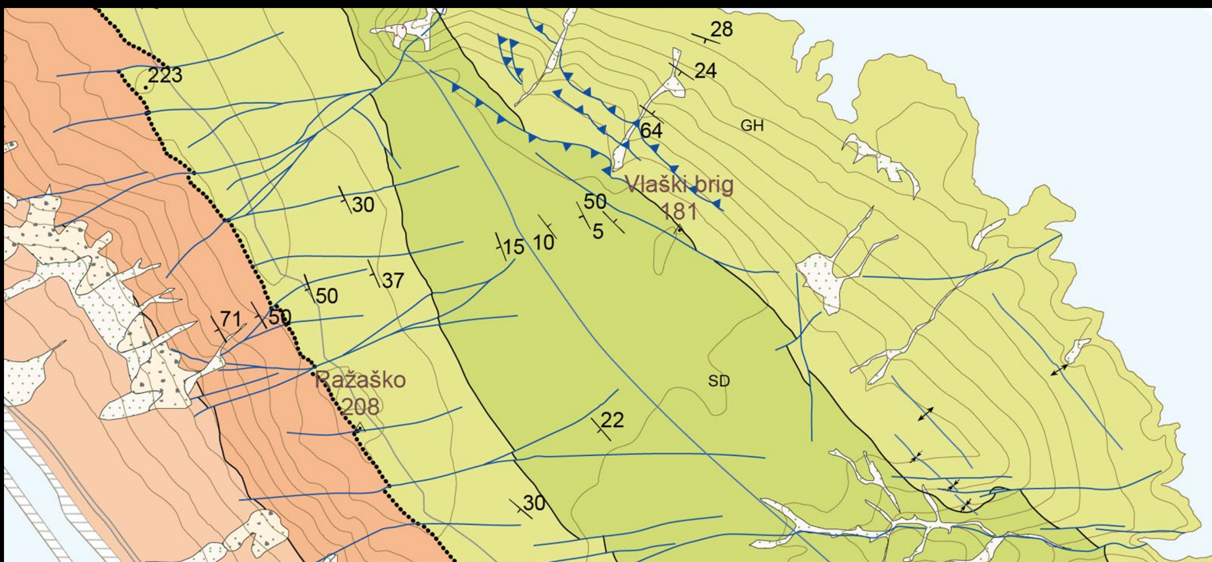

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Geological and structural map of the southeastern Pag Island, Croatia: field constraints on the Cretaceous – Eocene evolution of the Dinarides foreland

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Cover page Figure
The side facing the Velebit channel in the north-western part of the mapped area, showing multiple thrust faults verging in opposite directions.

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Abstract

The sedimentary succession exposed in the Northern Dalmatia Islands mainly consists of Cretaceous to Neogene shallow water carbonates, folded and imbricated within the External Dinarides thrust belt. During Cretaceous times, carbonate sediments were deposed on a heterogeneous, tectonically-influenced carbonate platform, which was then uplifted and eroded, as evidenced by a regional unconformity embracing the Late Cretaceous and Paleocene. Sedimentation resumed during the Eocene, when the area was part of the foreland basin of the Dinaric belt. With our geological and structural map of the southeastern Pag Island at the 1:25,000 scale, we refined the stratigraphic and structural setting and the tectono-sedimentary evolution of the area.

Keywords: External Dinarides, Pag Island, Adriatic Carbonate Platform, thrust and fold belt, foreland basin.

Introduction

The hanging wall of the outermost Dinaric thrust is an imbricated belt of deformed Cretaceous to Neogene sediments (Figure 1; External Dinarides after Pamić et al., 1998), which recorded the transition from a long-lasting carbonate platform (the Adriatic Carbonate Platform, Vlahović et al., 2005) to a laterally heterogeneous Eocene – Oligocene foreland basin (e.g., Tari, 2001; Korbar, 2009; Vlahović et al., 2012). The large-scale tectono-sedimentary architecture of the region was well outlined since the earliest surveys conducted during the 19th century (Hauer, 1868), and the first geological map of the Pag Island at the 1:75,000 scale was published as early as the 1912 (Schubert and Waagen, 1913). The Basic Geological Map (*Osnovna Geološka Karta*) of Jugoslavia at the scale 1:100,000 (sheets Gospić, Zadar and Silba, Majcen et al., 1976; Mamužić and Sokač, 1973; Sokač et al., 1976) constitutes the most recent synthesis of the regional geology. However, the sedimentary succession was surveyed with chronostratigraphic criteria and the structural setting, due to the small scale of representation and out-of-date interpretative concepts, is not fully reliable. In our new geological and structural map (see Figure 1 for map location), we mapped the area by identifying lithostratigraphic units correlated with the sedimentary formations at the regional scale, and surveyed in detail the tectonic structures. This allowed us to refine the stratigraphy and structural architecture of the folds outcropping in the area, and to document a pre-unconformity (thus pre-Eocene) tectonic stage.

Methods and techniques

The geological and structural map of the southeastern Pag Island is based on field surveys conducted between February 2017 and May 2018, integrated with the interpretation of high-resolution satellite images available from the Bing portal (https://www.bing.com/maps) and the geoportal of the Croatian Geodetic Service (https://geoportal.dgu.hr/). Field surveys were based on printed aerial photographs, or on GPS equipped tablets, mainly at the 1:5,000 scale, and locally at the 1: 2,000 scale. During the field surveys, we measured several stratigraphic columns across the area, and compared facies associations with published data, referring in particular to the megafacies described by Tišljar et al. (2002). Where no official formational names were available, we used the most commonly used names in the literature about the region (Gušić and Jelaska, 1990) and on the recently published geological maps at the 1:50,000 scale (e.g., Fuček et al., 2012). Structural data of fault kinematics were collected in selected locations along major fault zones. Since mapping was focused on the Meso-Cenozoic geological formations, the very limited Quaternary deposits were not surveyed in detail, and were only mapped as either Holocene loose deposits or Pleistocene cemented ones.
The map was digitized in UTM fuse 33N coordinates with WGS84 Datum with the GIS software ArcMap 10.6 and QGis 2.18.21. The background topographic map has been obtained by combining (i) 20 m-contours extracted, using the 3DAnalyst ArcGIS extension, from the photogrammetric Digital Elevation Model provided by the Croatian Geodetic survey, with (ii) topography elements (roads, perimeters of inhabited areas, salt ponds) downloaded from the OpenStreetMap® project and licensed under the Creative Commons Attribution-ShareAlike 2.0 license. The final printable map was obtained by editing the layouts from the GIS software with the vector graphics software Adobe Illustrator CS5®.

Regional setting

The Northern Dalmatian islands are part of the External Dinarides, a belt of folded and thrusted sediments of Carboniferous to Neogene age (Pamić et al., 1998; Placer et al., 2010), forming the shallower part of the detached and highly deformed upper crust of the Adriatic plate (Korbar, 2009). This sector of the Adriatic plate was characterized by nearly continuous deposition of shallow water carbonates since Carboniferous times and, from the Lias to the

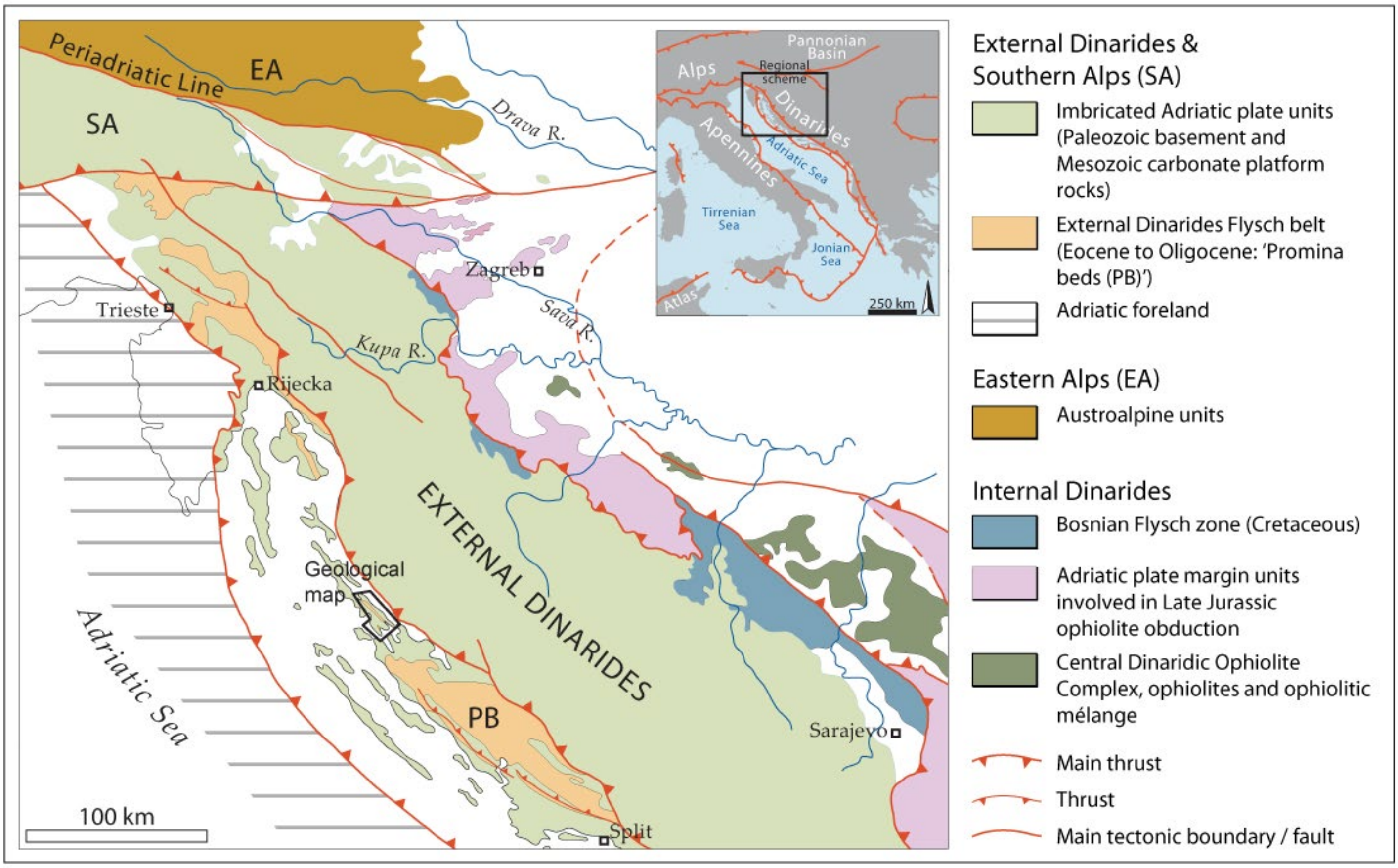

Figure 1 – Location of the map within a simplified regional scheme of the northern Dinarides (redrawn and simplified after Tomljenović et al., 2008; Ustaszewski et al., 2008; Korbar, 2009).

Late Cretaceous, it was a well-defined paleogeographic domain known as the Adriatic Carbonate Platform, hereafter AdCP (Velić et al., 2002; Vlahović et al., 2002; 2005). During Cretaceous times, the AdCP had a laterally heterogeneous facies distribution and underwent repeated subaerial exposures and episodic platform drownings (Tišljar et al., 2002; Vlahović et al., 2005). Relative sea level changes occurred due to the interplay between global eustatic variations and synsedimentary tectonics during the polyphasic convergence between Eurasia and Adria plates, which began in Late Jurassic times (Aubouin et al., 1970; Schmid et al., 2008) and is still active (Kastelic and Carafa, 2012; Kastelic et al., 2013). With the propagation of the orogenic front to the SW, the AdCP underwent dissection and emersion during a major event recorded by a regional unconformity surface, locally bearing bauxite (Vlahović et al., 2005; Kovačević Galović et al., 2012; Peh and Kovačević Galović, 2016). Sedimentation resumed in Early Eocene times, when the Northern Dalmatia constituted the foreland basin of the Dinarides. The foraminiferal limestone (Tišljar et al., 2002; Ćosović et al., 2004) was deposited on a carbonate ramp, interpreted as a retreating forebulge flank (Korbar, 2009; Babić and Zupanič, 2016; Ćosović et al., 2018). Shallow water carbonates were replaced during middle Eocene times by clastic hemipelagic sediments known as Dalmatian flysch (e.g., Babić and Zupanič, 2008), and by the upper Eocene-lower Oligocene regressive molasse sequence of the Promina Beds (Mrinjek, 1993; Tari Kovačić and Mrinjek, 1994; Vlahović et al., 2012; Zupanič and Babić, 2011), exposed some tens of kilometres to the southeast of the Pag Island. Sedimentological studies demonstrated that the Promina Beds were deposed during fold growth, thus constraining imbrication and folding in the southeastern part of the External Dinarides to Late Eocene-Oligocene times (Ćosović et al., 2018; Vlahović et al., 2012). Another clastic body which characterizes the External Dinarides is the so-called Jelar breccia, a chaotic polymictic breccia of prevailing Jurassic to Cretaceous carbonate clasts and including also clasts of middle Eocene age (Pamić et al., 1998; Korbar, 2009; Vlahović et al., 2012). The origin of the breccia is still poorly understood because of its unclear structural position and intense younger tectonic deformation, and is interpreted as associated with gravitational collapse of early stage anticlinal structures (Korbar, 2009;

Vlahović et al., 2012). In Late Oligocene – Miocene times, an extensional tectonic event is recorded throughout the Dinaric chain (Ilić and Neubauer, 2005; van Unen et al., 2018), and in the same period a system of intramontane lakes developed, one of which is recorded by lacustrine sediments preserved in the Pag Island (Bulić and Jurišić-Polšak, 2009; Jiménez-Moreno et al., 2009). After the late Miocene, a contractional to strike-slip tectonic setting resumed in consequence of the indentation and anticlockwise rotation of the Adria microplate (Ilić and Neubauer, 2005), which is still ongoing, as documented by GPS velocity studies and crustal stress patterns (e.g., Faccenna et al., 2014; Heidbach et al., 2016).

Map description

Stratigraphy

The sedimentary succession of the Adriatic Carbonate Platform (AdCP)

The Milna Formation (MI) of Cenomanian age consists of a sequence of shallowing upward cycles of intertidal limestones, including storm layers with large bioclasts, massive pelletal wackestones, intraformational breccias, paleosols and very abundant microbial laminae (Figure 2a). The laminites are locally deformed in meters to decametre-sized slumps (Figure 2b). Channelized and cross-laminated packstone-grainstone layers are subordinate to the peritidal facies (Figure 2c). During the deposition of the Milna Formation, the AdCP was covered by a shallow sea subjected to temporary sea level excursions, likely controlled by syn-sedimentary tectonics, as suggested by the occurrence of slumping structures, present also in other sectors of the AdCP (Korbar et al., 2012; Prtoljan et al., 2007).

The Milna Formation is sharply overlain by the Sveti Duh Formation (SD), consisting of nodular beds of whitish-yellowish wackestones and packstones rich in crinoids, foraminifera, sponge spicules and thin-shelled bivalves. The top of the Milna Formation is marked by a stained and burrowed surface, with the overlaying wakestone-packstone infilling the burrows, interpreted as a hard ground surface (Figure 2d). Between Cenomanian and Turonian times, several sectors of the AdCP were drowned with deposition of pelagic and ramp carbonate sediments (Gušić and Jelaska, 1993). The rise in relative sea level is correlated with the global Bonarelli anoxic event or OAE 2 (e.g., Korbar et al., 2012), although areas which maintained a shallow marine sedimentation suggest that tectonic uplift locally overtake the sea level rise (e.g., Vlahović et al., 2002).

The Sveti Duh Formation passes transitionally to the shallow water carbonates of the Gornji Humac Formation (GH). The Gornji Humac Formation is characterized by high lateral and vertical facies variability, including banks of well-bedded pelletoidal wackestones-packstones and microbial laminated limestones in shallowing-upward cycles, well sorted cross-laminated packstone-grainstones with channelized geometry and massive floatstone-mudstone layers (Figures 3a, b). Coarse clasts of rudists are very diffuse within the wakestone-packstone and mudstone banks (Figure 3c), and, especially in the upper part of the formation, rudstone beds of rudist shell fragments (coquinites) are widespread. The mudstone banks reach up to 3 m in thickness, in the lower part are composed of floatstone with large rudist fragments, and often terminate at the top with a thick (up to 40 cm) layer of centimetre-scale cavities filled by darker sediments and cemented by calcite, interpreted as bird's eyes structures. Mudstone-floatstone banks are the main lithology of the formation in the northwestern part of the area, while elsewhere cross-laminated packstone-grainstones are more abundant. Hectometric discordant bodies of coarse-grained, channelized carbonate breccias crosscut the strata of the Gornji Humac, Sveti Duh and Milna Formations (Figure 4b and d). Bed parallel, lens shaped dolomitized masses are common, and are mostly de-dolomitized with precipitation of late-stage calcite crystals, forming recrystallized limestone bodies with whitish-pinkish colour in outcrop (Figure s 4a and c). Dedolomitization is almost complete in the outcrops of the major anticline SE of the Pag village, while in the anticline close to the village of Vlašići, dolostone is mostly preserved. A layer of whitish to pinkish recrystallized limestones also marks the upper 20 – 50 m of the Gornji Humac Formation, below the erosional surface truncating it (Figure 3c). The erosive surface is lined by intraformational breccias, oxidized and vadose cement, and irregular cavities filled by brownish silty or sandy grainstone (Figure 3d). The Gornji Humac Formation is characterized by facies associated with shallow marine conditions, including both low energy environments as lagoons and peritidal/tidal flats, and high energy environments of shoreface and tidal bars. The overall abundance of rudist debris suggests a close proximity to reefal or perireefal areas. Synsedimentary tectonics is likely to have controlled the paleobatimetry of the platform, and the formation of fault escarpments associated with carbonate breccias deposits.

The sedimentary succession of the Dinaric foreland basin

In the area of the Pag Island, the stratigraphic gap marked by the erosive surface atop of the Gornji

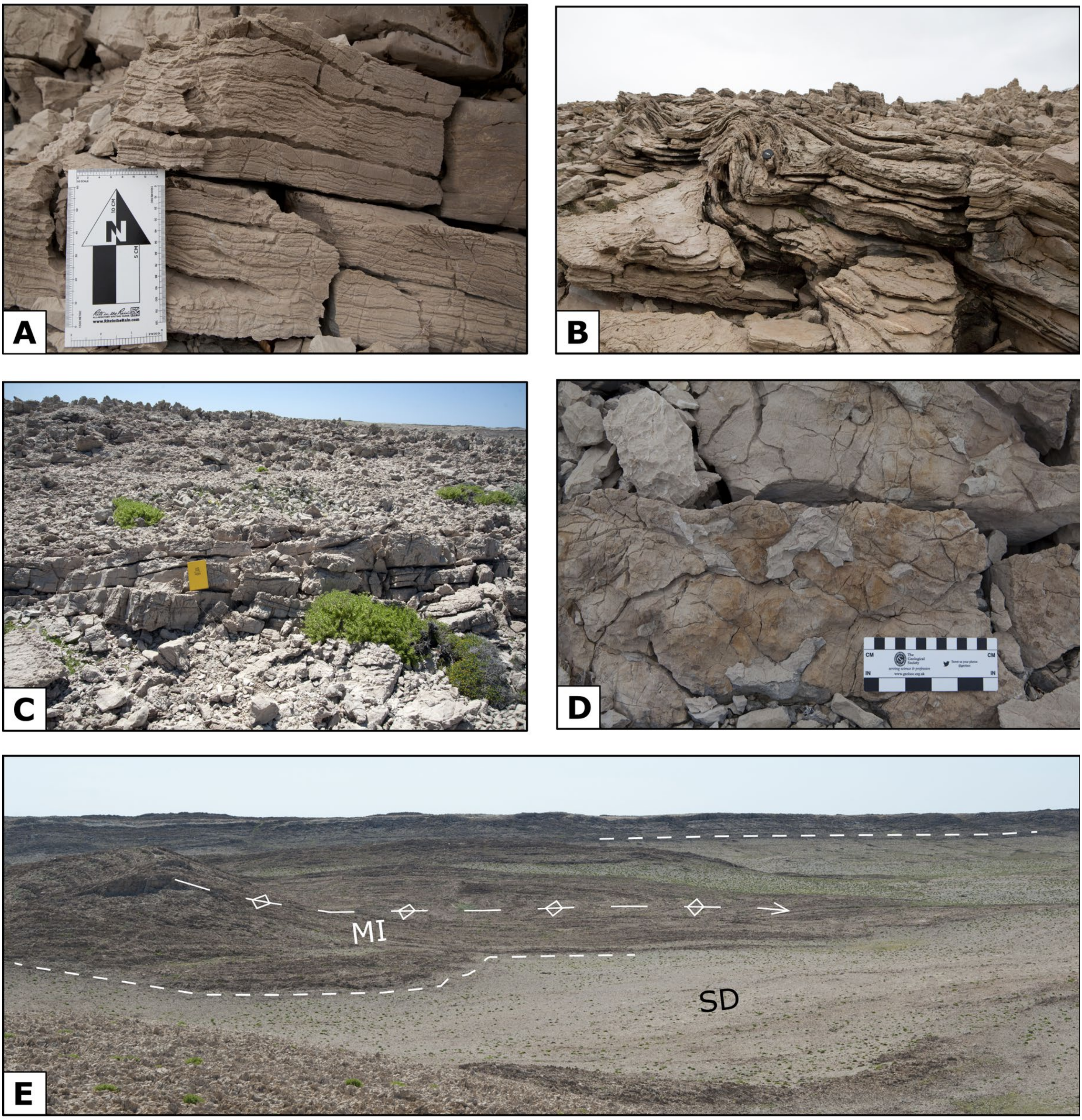

Figure 2 – Field pictures of the AdCP Milna and Sveti Duh Formations. (A) Detail of a stromatolite-rich interval. (B) Slumped laminated limestones. (C) Pinch-outs of channelized packstone-grainstone cross laminated interval within the Milna Formation. (D) The stained and burrowed surface at the interface between the Milna and Sveti Duh Formations. Plagues of light grey wackestone infill strata-parallel burrows. (E) Panoramic view of the sharp contact of the Sveti Duh Formation with the Milna Formation.

Figure 3 – Panoramic field pictures of the AdCP Gornji Humac Formation. (A) Panoramic view of the Gornji Humac Formation in the northern part of the Pag anticline. Meter-thick beds of white mudstone alternated with minor light brown packstone beds are the dominant facies association in this area. (B) View of the alternation of packstone, rudstone and mudstone banks having prevailing brownish color, the dominant facies association in the central and southern sectors of the Pag anticline.

Humac Formation lasted from Coniacian-Santonian to Ypresian times (Jelaska et al., 1994; Korbar, 2009). Sedimentation resumed with the deposition of benthic-foraminifera-rich carbonates with subordinate remnants of molluscs, echinoderms and bryozoans. These rocks, informally known in literature as 'foraminiferal limestone' (FL) (Tišljar et al., 2002; Ćosović et al., 2004), have an angular discordance on the order of 10° with bedding in the Gornji Humac Formation below the erosional surface, as visible in several outcrops (Figure 5a). The foraminiferal limestone includes Miliolids – rich wackestones-packstones, in undulating 20 – 30 cm thick beds (Figure 5b), and meter-thick cross-laminated banks

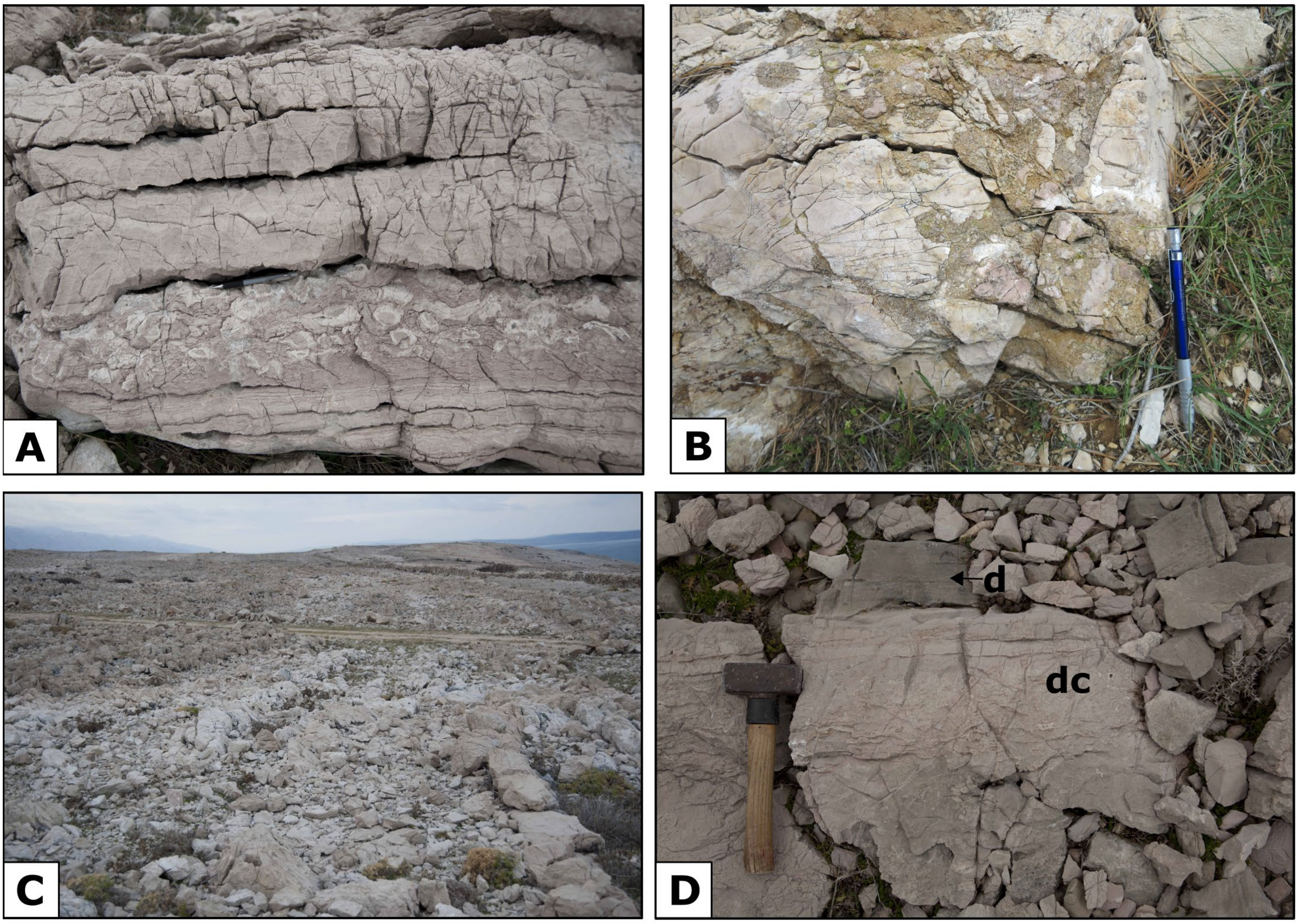

Figure 4 – Field pictures of the AdCP Gornji Humac Formation. (A) Detail of a storm layer rich in rudist shells, sharply overlying a stromatolite-rich bed. The pinkish color is typical of the recrystallized upper part of the formation, below the erosion surface. (B) Detail of the infilling of karst cavities along the erosional surface at the top of the Gornji Humac Formation. (C) Field picture of a couple of bed-parallel, white crystalline bodies of dedolomitized dolostone within the Gornji Humac Formation. (D) Detail of the transition of the late diagenetic greyish dolostone (d) to pinkish crystalline limestone (dc).

of Alveolinid- and Nummulite-rich floatstones with packstone to grainstone matrix. The foraminiferal limestone, as described also in other sectors of the External Dinarides, is composed of facies typical of foraminiferal banks in an inner to middle carbonate ramp, alternating with mud-rich facies suggesting a more restricted lagoonal setting (Ćosović et al., 2004; 2018; Marjanac and Ćosović, 2000; Španiček et al., 2017). In the southern part of the mapped area, the top of the foraminiferal limestone consists of meter-thick banks of rudstones with abundant bioclasts of echinoderms and multicentimetric benthic foraminifera (Figure 5c), in sharp contact with the overlying hemipelagic pelites and marls of the Dalmatian flysch. The top surface of the foraminiferal limestone is stained by iron oxydes and is intensely burrowed and bioturbated. Moreover, the uppermost layers of foraminiferal limestone below the stained surface bear glauconite. Accordingly, the top of foraminiferal limestone can be interpreted as a drowning surface. In the northern sector of the map, the foraminiferal limestone passes upward, with a fast transition, to a fining-upward sequence of marly limestones and greyish, glauconite-bearing marls (Figure 5d). The occurrence of planktonic foraminifera (*Globigerinae*) documents a significant deepening of the depositional environment to shelf or shallow bathyal conditions. Though only few tens of meters thick, this interval is recognized elsewhere in the region and referred to as 'transitional beds'(Ćosović et al., 2004; Marjanac and Ćosović, 2000), which is locally found at the base of the Dalmatian flysch (DF), characterized by a sudden increase in the clastic over the carbonatic component.

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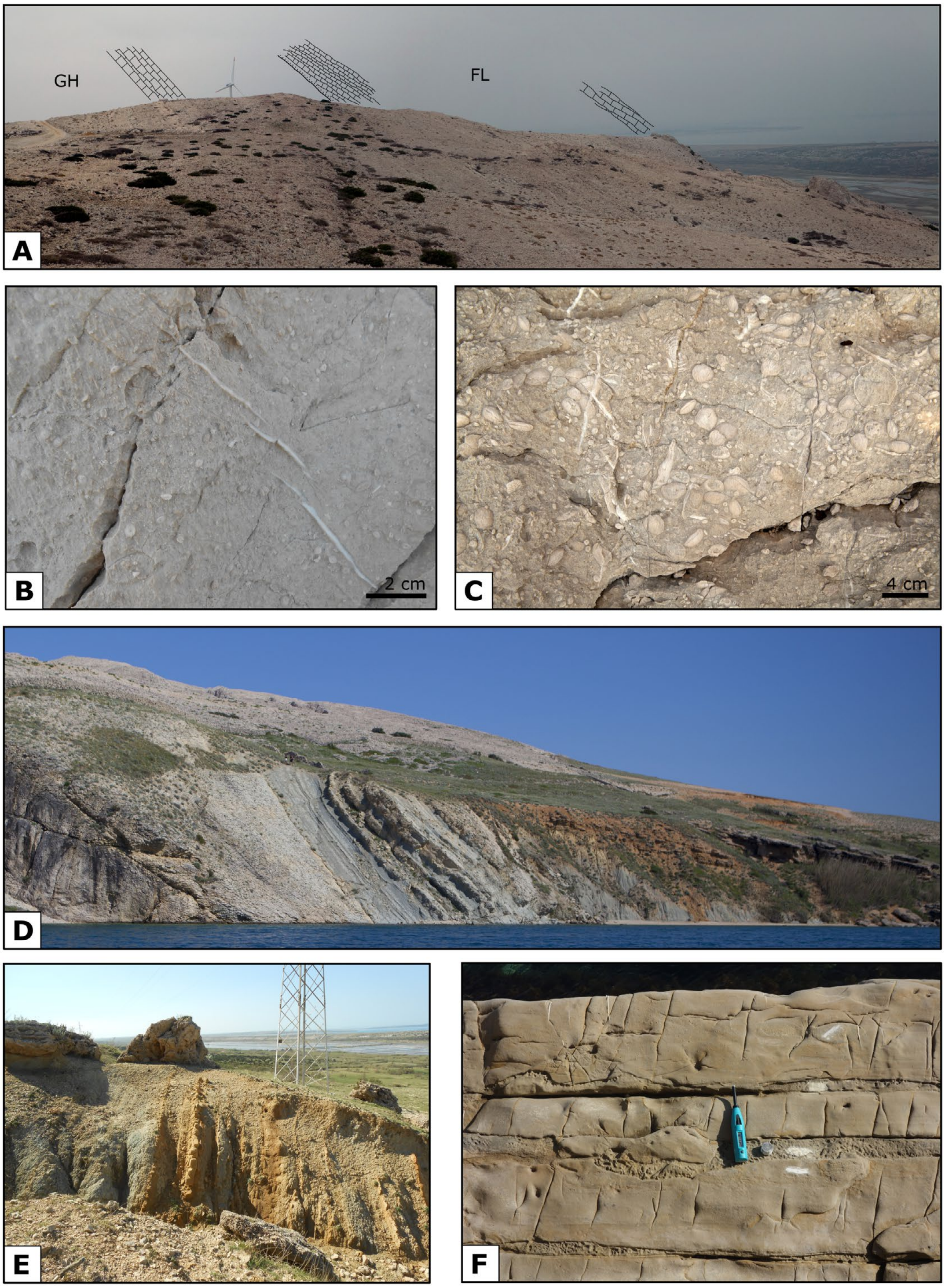

Figure 5 – Field pictures of the External Dinarides foreland units. (A) Panoramic picture taken along the southwestern limb of the Pag anticline north of the Pag town, looking to the SE. To highlight the angular unconformity of about 10° between the Gornji Humac Formation on the left and the foraminiferal limestone on the right, the strata are schematically drawn in section above the horizon line. The base of the foraminiferal limestone consists of mud-rich, well stratified inner ramp deposits, passing upward to a bar of coarse grained rudstone – packstone. (B) Mud-rich inner ramp limestone within the foraminiferal limestone. (C) Top layers of the foraminiferal limestone, composed of thick beds of rudstone with packstone matrix, with abundant Nummulites, bivalve shells and echinoderms, associated with a deep, open carbonate ramp. (D) Panoramic view, along the coast north of the Pag town, of the sharp transition from foraminiferal limestone (on the left) to gray-blue, glauconitic marls and marly limestones of the transitional beds. (E) Outcrop of the Dalmatian flysch near the Stara Vasa village, consisting of dominant pelites and marls, with thin layers of fine grained sandstone. The blocks on the top are disarticulated remnants of Pleistocene cemented deposits. (F) Detail of a bank of amalgamated sandstone within the Dalmatian flysch.

In the Island of Pag, the Dalmatian flysch consists of a sequence of prevailing pelites and marls, with interbedded fine-grained sandstones and multimetric intervals of amalgamated sandstone beds. Pelites and marls have grey-blueish color and are interbedded with thin layers of fine-grained arenites, sometimes cross-laminated (Figure 5e). The amalgamated sandstone are banks of yellowish to grey, fine to very fine arenites, with at least 50% of non-carbonate component (Figure 5f), with erosive base, sometimes with mud chips and plane-parallel lamination in their lower part. The association of facies of the Dalmatian flysch in the Island of Pag, as well as recent calcareous nannofossils data suggest a relatively shallow hemipelagic depositional environment under fluvial influence, in a shallow foredeep or thrust-top basin (Babić and Zupanič, 2008). The Dalmatian flysch exposed in the Island of Pag registered first a progradation of clastic units, culminating with the deposition of one (in the southern part of the mapped area) or more (in the northern sector) plurimetric banks of amalgamated sandstone, followed by a retrogradation with the reduction or cessation of coarse clastic input and the deposition of hemipelagic marls and pelites.

Pleistocene to recent deposits

Quaternary deposits are rare in the southeastern part of the Pag Island, where we mapped Pleistocene and Holocene strata. Pleistocene alluvial deposits contain angular, well sorted and cross-bedded subangular clasts, having reddish to yellowish color and cemented by vadose calcite. Cemented polymictic breccias with subrounded clasts also occur. Such cemented sediments were deposed in presence of a higher base level than the present-day one and are nowadays subject to erosion. They have been interpreted as deposed in glacial and periglacial conditions during the Middle Pleistocene (Marjanac and Marjanac, 2004; Marjanac, 2012; Marjanac and Marjanac, 2016). Holocene deposits consist mostly of (i) colluvial sediments produced by intense soil erosion, (ii) slope deposits in proximity of limestone cliffs, and (iii) lacustrine to marsh deposits in the larger valley floors.

Tectonic features

The tectonic structure of the Northern Dalmatia is dominated by NW-SE trending thrusts and folds (Mamužić and Sokač, 1973; Sokač et al., 1976). The mapped area includes a large anticline east of the Pag village, and a train of folds with lower amplitude in the surrounding of the Povljana village (Figure 6 and Table 1 – Geological map). The anticlines have box geometry with high-angle to overturned limbs and gently undulating crestal zones. The folds in the surroundings of Povljana are nearly symmetric, while the Pag anticline is asymmetric, and verges to the regional foreland in the southern sector (section B-B', Table 1 – Geological map), and to the hinterland in the northern sector (section A-A', Table 1 – Geological map). The change in polarity of the limbs asymmetry occurs through a major EW trending strike-slip fault, offsetting the fold in sinistral sense (Figure 6). Due to the erosion and the high amplitude of the Pag anticline, the fold core is exposed and consists of a stack of thrust sheets that produces intense shortening of the detached laminated limestones of the Milna Formation (Figure 7a). The Pag anticline backlimb is structurally complex, with several undulations produced by backthrusts (Figure 7b) and out-of-the-syncline, foreland verging thrusts (Mitra, 2002). A triangle zone with oppositely verging thrusts is exposed along the northeastern Pag coast, juxtaposing the foraminiferal limestone on the overlying transitional beds (Figure 7c, Cover Image). The box geometry and the occurrence of oppositely verging thrusts crosscutting the fold limbs suggest that folds are the shallow expression of pop-up structures, and likely originated as detachment folds (e.g., Mitra, 2002).
Several subvertical strike-slip faults crosscut the folded sedimentary sequence (Figure s 6c, 8; Table 1 – Geological map). The main sets strike NS, EW and NE. At the map scale, NS faults offset the sedimentary markers in dextral sense, EW faults in sinistral sense. However, field structural measurements demonstrate that most faults, including thrust faults, experienced a long-lasting activity with opposite strike-slip kinematics, and underwent buttressing. Most of the subvertical strike-slip faults are localized along the fold limbs dipping at high angle, produce offsets of less than 100 m, and their offsets decrease to vanish towards the fold axes (Figure 6). According to along strike variability of limb dip in adjacent compartments, these faults acted as tear faults accommodating differential limb rotation during fold tightening. Few major fault zones separate fold domains having different structural architecture, thus suggesting that they compartmentalized the folds since the early stages of fold growth (Figure 6). Major transversal faults crosscut all the structural elements of the folds thus indicating that strike-slip activity continued after folding.

Relations between tectonics and sedimentation

To explore the relations between tectonics and sedimentation, we restored the thicknesses of the

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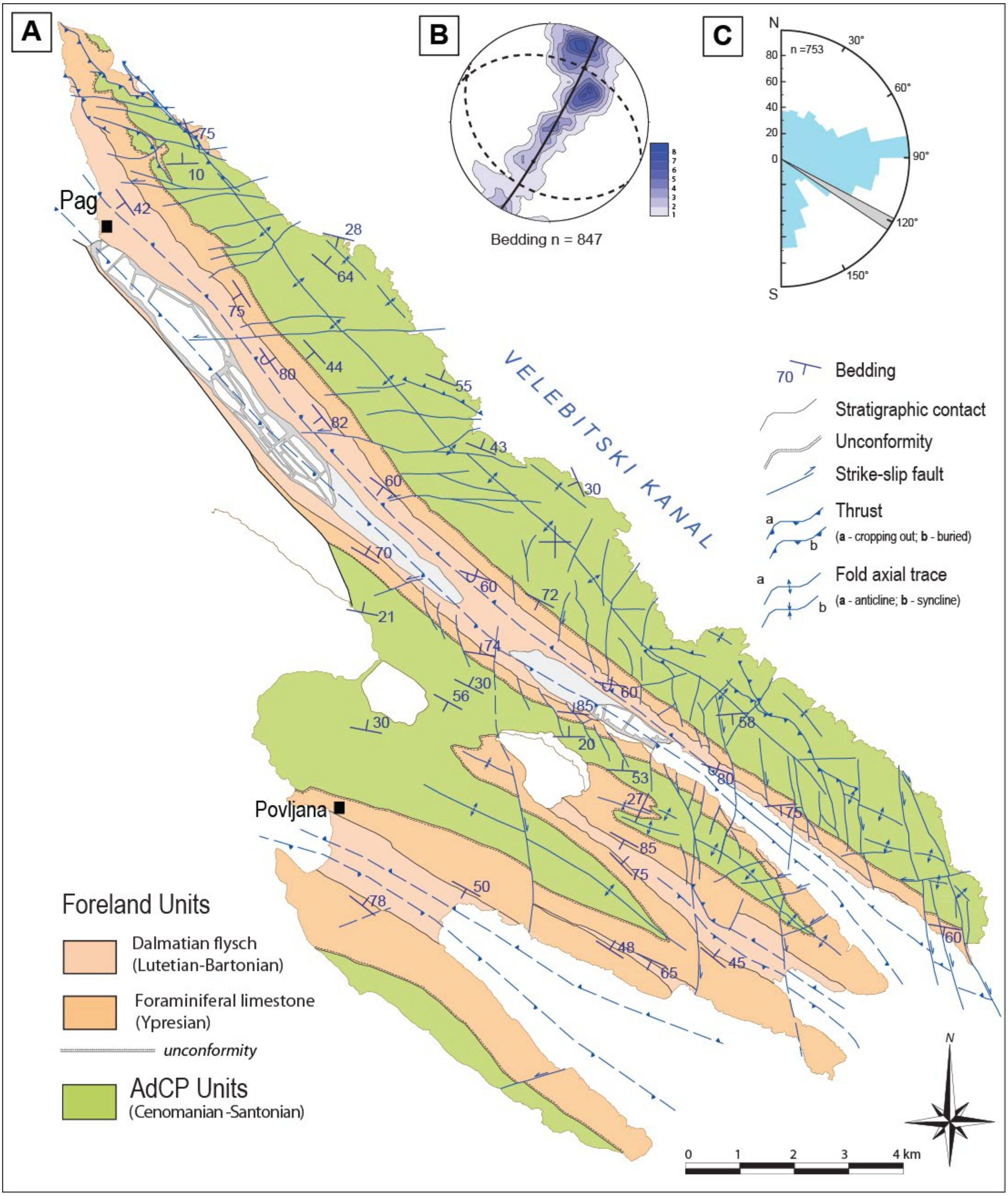

Figure 6 – Structural scheme and cumulative structural data. (A) Simplified structural scheme of the area. The geological sections A-A' and B-B' are in Table 1 – Geological Map. (B) Contoured stereoplot of the poles to bedding measured in the study area. Lower hemisphere, equal area projection. (C) Rose diagram of the strikes of the main faults traced within the study area. The strike of the average fold axis is reported in grey.

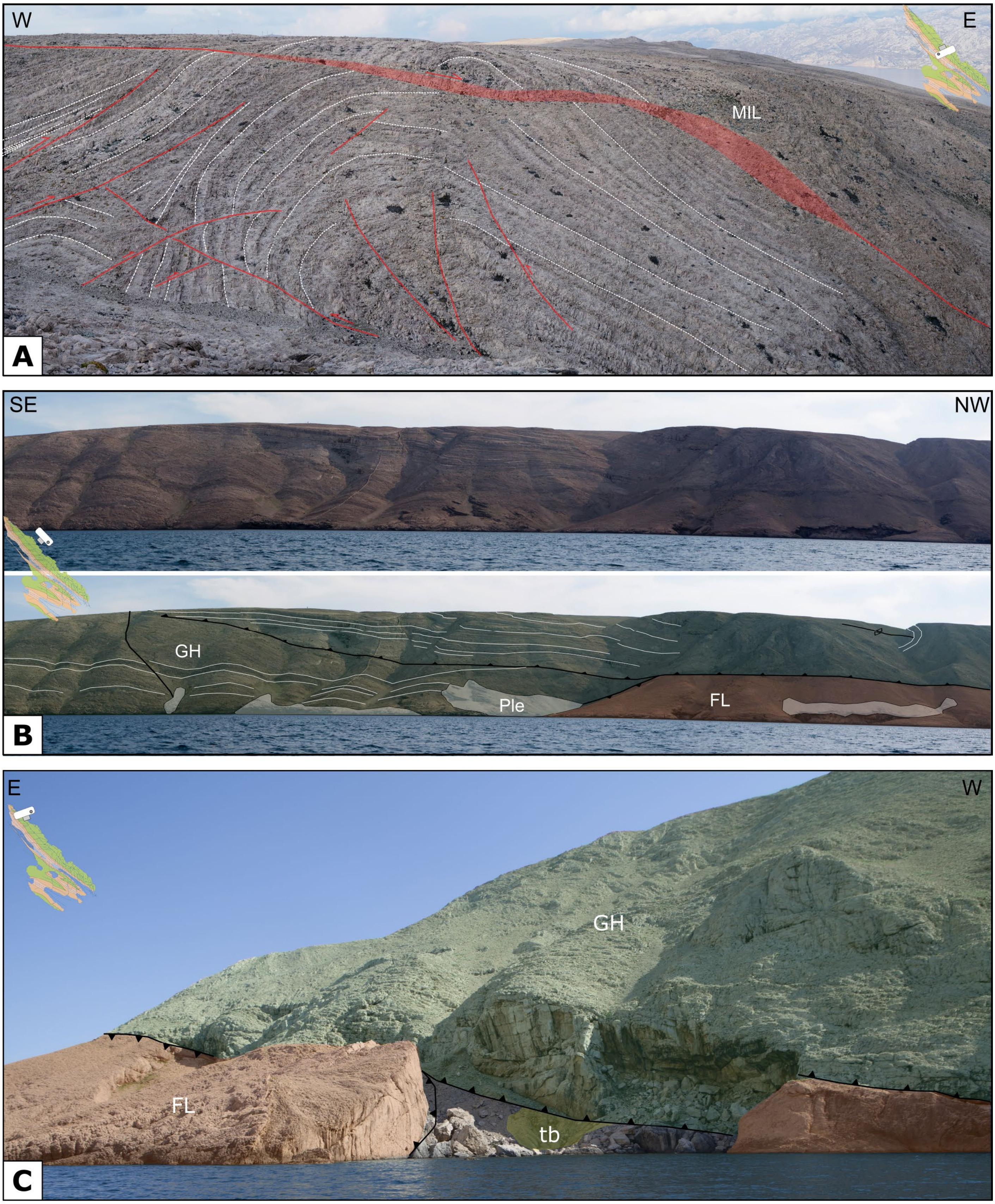

Figure 7 – Field pictures of tectonic structures. (A) A thrust stack in the nucleus of the Pag anticline. Faults are depicted in red, some of the strata are highlighted in dashed white. View to the NW. (B) Panoramic view of the backlimb of the Pag anticline, in its northern sector, and line drawing of the large scale tectonic structures. Picture taken looking to the SW from the Velebit Channel. (C) Detail of the triangle zone cropping out along the backlimb of the Pag anticline, at the contact between two oppositely verging thrusts. Picture taken looking to the SW from the Velebit Channel.

individual formations continuously cropping out in the central sector of the forelimb of the Pag anticline (Figure 6), by assuming the drowning surface atop the foraminiferal limestone as horizontal (Figure 8). The thickness of the Gornji Humac Formation abruptly increases of about 100 m when crosscut by N-S striking faults in the surroundings of the village of Miškovići (Figure 8). The offset of the lower limit of the Gornji Humac Formation is not mimicked by the Cretaceous – Paleogene unconformity, which is roughly parallel to the top of the foraminiferal limestone (Figure 8). The same distribution of map-scale displacements, with higher values affecting strata below the unconformity, is found also along other N-S trending faults (Table 1 – Geological map). This suggests that part of the displacement along the N-S-striking faults was accumulated before the unconformity, hence affecting the stratigraphic succession when still horizontal. Based on the cutoff angle between faults and bedding, when the sedimentary succession was horizontal, the displacement caused by N-S trending faults was normal. We thus suggest that the sedimentary sequence was deformed by a system of normal faults before the Ypresian. It cannot be excluded that these faults were active also during the deposition of the AdCP formations, as it might be suggested by the lateral variations in the sedimentary facies associations (Figure 8a), reflecting a NW to SE variability in the paleobathimetry of the platform (Figure 4b, d).

Discussion: Implications for the tectono-sedimentary evolution of the region

The structural and stratigraphic data synthetized in our geological and structural map allowed us to refine the knowledge about the tectonic and sedimentary evolution of the area. Here, we summarize and discuss our findings in the framework of the regional geology, by recognizing the following evolutionary stages.

i) AdCP stage (Cenomanian – Santonian): during the Late Cretaceous, the area shared the large scale evolution of the AdCP, influenced by global sea level variations and synsedimentary tectonics: deposition of intertidal limestones during the Cenomanian (Milna Formation), platform drowning during the Turonian (Sveti Duh Formation) and the restoration of a shallow marine environment during the Coniacian – Santonian (Gornji Humac Formation) (Tišljar et al., 1998; Vlahović et al., 2005). As described in other locations across the Dalmatian Islands, in the Pag Island synsedimentary tectonics produced emersion surfaces and slumping structures in the Milna Formation (Tišljar et al., 1998; Prtoljan et al., 2007; Korbar et al., 2012). In response to the global sea level rise "Bonarelli event" (or OEA 2) (Korbar and Husinec, 2003; Husinec and Jelaska, 2006; Korbar et al., 2012), about 100 m of distal ramp limestones were deposed on a hard ground surface marking the drowning of the Milna Formation platform. Shallow water platform carbonate deposition was restored during the Coniacian-Santonian, on a laterally heterogeneous platform with rudist communities, closed lagoons, tidal flats and shoreface bars, locally crosscut by channelized bodies of carbonate breccias. The lateral variability of depositional environment suggests that also during the Coniacian – Santonian the carbonate platform was subject to sysnsedimentary tectonics. Indeed, the Pag Island is very far from the AdCP platform margins located, to the SW, in the Adriatic Sea offshore the Dalmatian Islands and on the NE on the mainland around Karlovac (Dragičević and Velić, 1994; Vlahović et al., 2002; Vlahović et al., 2012).

ii) Extensional faulting and regional unconformity (Santonian – Ypresian): by analysing the displacement distribution on the well-exposed forelimb of the Pag anticline, we recognized normal faults offsetting the AdCP formations and truncated by the regional Late Cretaceous-Paleocene unconformity surface (Figure 8). The Santonian - Ypresian sedimentary hiatus registered at the Pag Island is among the longest in the Dalmatian Islands (Jelaska et al., 1994; Korbar, 2009), thus it is difficult to constrain the age and geodynamic context of the pre-unconformity faults.

iii) Dinaric foreland basin (Ypresian - Lutetian): the erosive surface truncating the Gornji Humac Formation constitutes the bedrock of the Eocene to Oligocene foreland basin of the Dinaric belt. Since the Ypresian, the study area underwent a marine transgression leading to the deposition of the ramp carbonates of the foraminiferal limestone in a shallow foredeep setting, with a paleobathimetry controlled by the retreating forebulge (Babić and Zupanič, 2016). The foraminiferal limestone is covered by the thick succession of the hemipelagic clastic deposits of the Dalmatian flysch. The transition from the foraminiferal limestone is sharp, marked

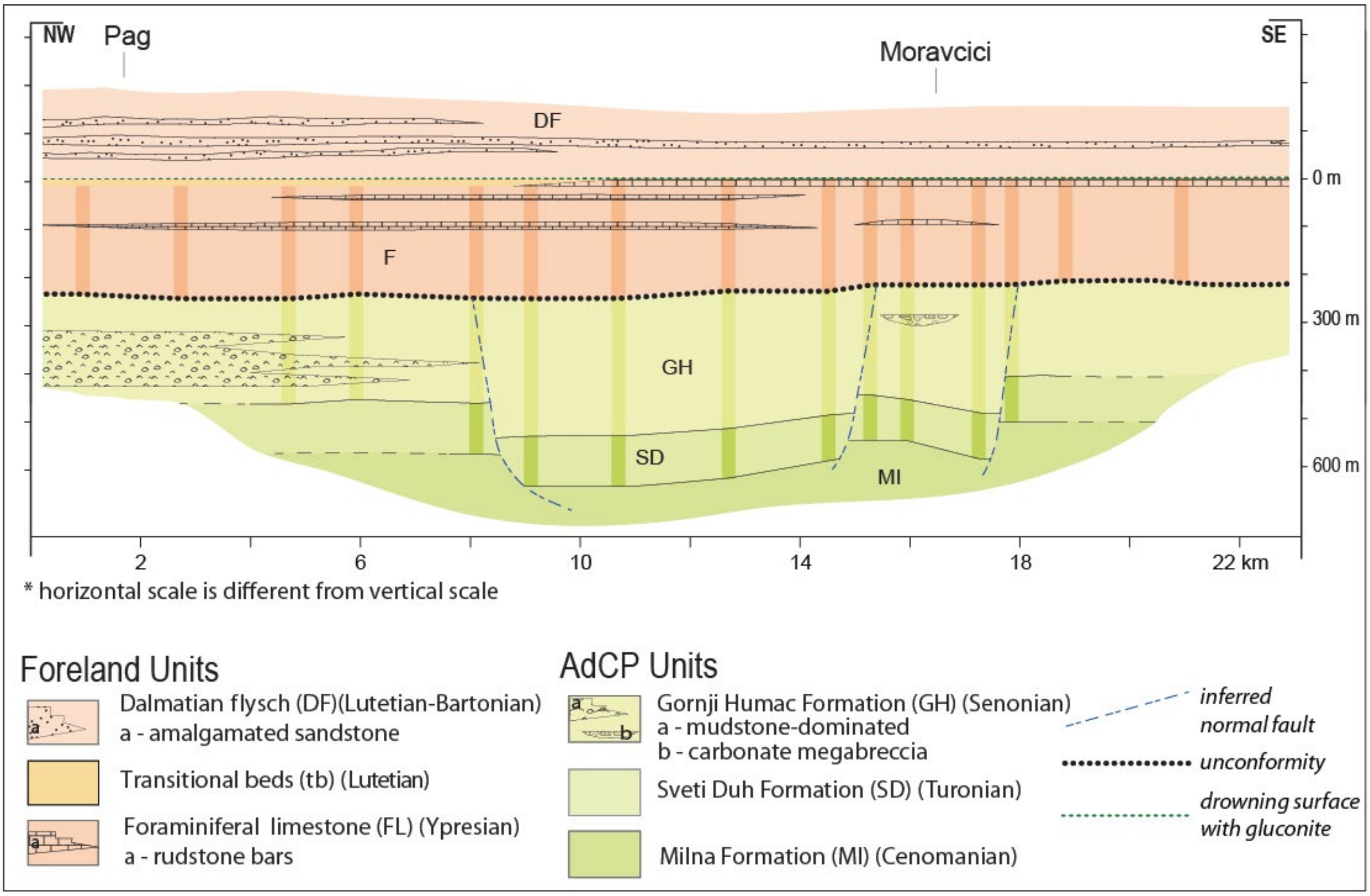

Figure 8 – Relations between faults and sedimentation. The thicknesses of the sedimentary formations as measured along the SW limb of the Pag anticline, restored to a horizontal top-foraminiferal limestone. Columns in darker colour are the projection of thicknesses measured on the map on a vertical section striking NW-SE. The variations in the facies associations is represented as well.

by a glauconite-bearing drowning surface in the southern part of the mapped area, and by the glauconite-bearing marls of the transitional beds in the northern sector. Sedimentological and paleocurrent analyses suggests that the Dalmatian flysch of the Pag Island was deposed in river-fed distal prodelta settings, in NW-SE trending basins compartmentalized by early structural deformation (Babić et al., 1993; Babić and Zupanič, 2008). Another evidence claiming for an early stage bathymetrically diversified proximal foreland basin is the persistency of contemporary (Lutetian) carbonate deposition on structural highs interpreted as the crest of growing anticlines (Ćosović et al., 2018).

iv) Tectonic shortening and thrust imbrication (Lutetian – Burdigalian): although the early stage propagation of blind thrusts controlled the physiography of the basin of the Dalmatian flysch, the main stage of folding and thrusting in the Pag Island postdates it, thus it is of post-Lutetian age. In the Ravni-Kotari peninsula, some tens of kilometres south-east of the study region, a Middle Eocene to Oligocene succession of neritic to terrestrial deposits ('Promina beds') was accumulated in a piggyback basin (Korbar, 2009) with a ridge-and-swale bathymetry controlled by blind-thrusts anticlines. Growth strata and migrating unconformable onlaps with the bedrock indicate that the Eocene Promina Beds were deposed during fold growth, and include clastic carbonates derived from the erosion of the anticline crests (Vlahović et al., 2012; Ćosović et al., 2018). The Oligocene upper part of the Promina beds is a 'molasse' sequence of orogeny-derived clastic deposits within fluvio-deltaic complexes progradating on the Dalmatian flysch (Korbar, 2009; Zupanič and Babić, 2011; Vlahović et al., 2012). The non-folded Early Miocene lacustrine deposits of the Island of Pag, north of the mapped area, constrain the upper age of folding to pre-Burdigalian times (Jiménez-Moreno et al., 2009).

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