RGNZ/MGPB

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
DOI: 10.17794/rgn.2025.3.14

Original scientific paper

Lithofacies types of Eocene-Oligocene deposits from the top of Promina Mountain, (Karst Dinarides, Croatia)

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Abstract
Clastic deposits from the upper part of the Promina Beds, situated at the top of Promina Mt. (External-Karst Dinarides) in Croatia, were investigated. The aim of this study is to present and promote geological peculiarities of the Promina Mt. and its surroundings. Sedimentary succession in the study area comprises 3 lithofacies types, as the main findings of this study: carbonate conglomerates, calcarenites and calcareous mudstones. The results obtained by the combined field recording of the sedimentary succession and micropetrography are presented in the lithological column PRO-21, showing the determined lithofacies types and their characteristics. Attributed shelf to delta sedimentary environments were further discussed.

Keywords:
clastic deposits, lithofacies, Eocene-Oligocene, Karst Dinarides, Promina

1. Introduction

External (Karst) Dinarides are the typical area in the world where the karst relief was first investigated and karst terminology defined (**Cvijić, 1893**). Although they are predominantly built of Mesozoic platform limestones and dolomites, prone to karst relief development under suitable tectonic and climate conditions, younger mixed clastic and carbonate deposits also developed while the Dinarides were arising. These were deposited in a broad range of sedimentary environments, ranging from the marine, transitional to continental. These younger sedimentary rocks of different lithofacies are well described within the National Parks, Nature Parks and Geoparks, but in the other areas with the Mesozoic karst carbonates in the Republic of Croatia they are somehow underestimated and poorly validated. One small part of these areas with Eocene-Oligocene clastic deposits will be described in this study, aiming to promote its geological peculiarities and sustainable landscape validation.

Promina Mountain, located in the Dalmatian hinterland (in Croatian: Dalmatinska Zagora) in southern Croatia, is surrounded by the mountains Svilaja, Dinara and Velebit. Several large karst poljes (fields: Petrovo, Kosovo and Kninsko poljes) are located between the mountains and two karst rivers, Krka and Čikola, flowing through the fields. The Eocene-Oligocene molasse Promina Beds in the External (Karst) Dinarides consist of conglomerates, calcarenites, thin-bedded turbidites, marls and limestones, with the occasional appearances of the coal beds. Promina Mountain is the type locality in which the Promina Beds appear, and this study focused on their upper part, outcropping near the top of the mountain. Research is conducted in the broad area surrounding the Mountain House "Promina", located at 850 m asl.

Eocene - Oligocene deposits were investigated in the ravine of the Driskoč occasional stream (see **Figures 1a and 1b**), as well as on the road from the Mali Točak Spring towards the Mountain House "Promina" (see **Figure 1c**), with a altitude difference of ca. 90 m. A lithological column of an about 70 m thick sedimentary sequence is recorded, and sampled rocks were subject to micropetrography and laboratory analyses to define lithofacies.

2. Geological setting

The Promina Beds were investigated in the broad area of Drniš several times in the past. The first investigations were associated with the search of bauxite and coal, and paleontological investigations were conducted at the same time. The first description of the Promina Beds was made by **Kerner (1894)**, who divided them into the following units, starting from the oldest towards the younger: 1. breccias and conglomerates; 2. first marl ho-

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Received: 26 February 2025. Accepted: 24 April 2025.
Available online: 3 July 2025

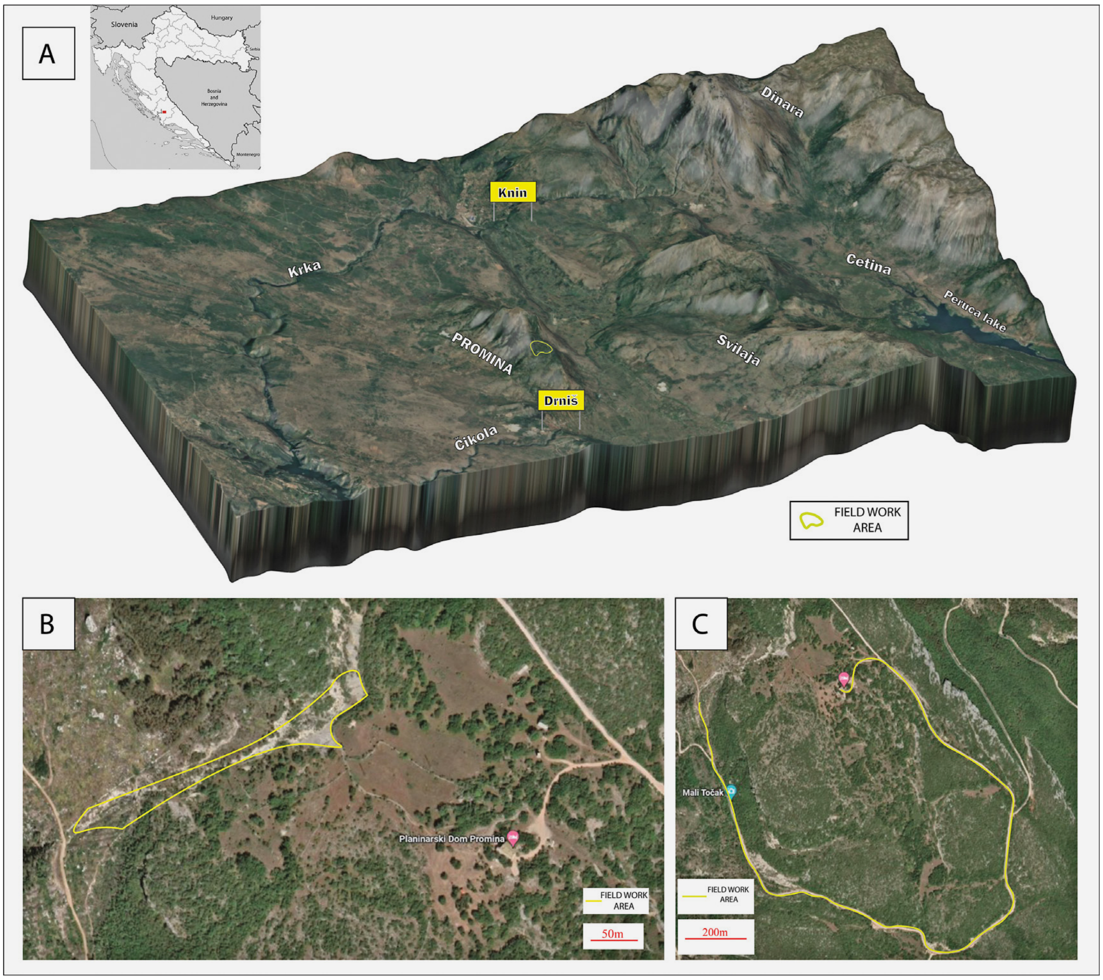


Figure 1 a-c. Geographic position of the research area in Promina Mountain. **a)** Promina Mountain in the External Dinarides, southern Croatia. **b)** Research area – ravine of the Driskoč occasional stream. **c)** Research area – the road from the Mali Točak Spring toward the Mountain House "Promina". **a-c** Adapted from Google Maps.

rizon; 3. conglomerate zone; 4. middle marl zone; 5. upper conglomerates zone; 6. third marl zone; 7. upper Promina conglomerates.

Investigations made by **Kerner (1894)** are significant because the first geological map with the accompanied description of geology for the Drniš - Kistanje area was made. Additionally, paleontological and sedimentological characteristics of the area were described, as well as tectonics and ore deposits. According to the paleontological analyses of the fossil molluscs, the Promina Beds were firstly determined as Miocene (**Danielli, 1901**), and later (**Oppenheim et al. 1902**; **Schubert, 1905**) as Eocene - Oligocene deposits.

The Promina Beds of Promina Mt., as well as the origin of the deformation structures in several parts of the Promina Beds, were described later (**Zupanič, 1969a; Zupanič, 1969b**). The two main groups of these deformation structures were distinguished: biogenic and gravitational (**Zupanič, 1969a**).

Due to the significance of bauxite exploration in the Drniš area, paleo relief and tectonics were further investigated. Interpretation of the bauxite formation in Drniš and Promina Mt. area was given by (**Sakač, 1970**). According to **Ivanović et al. 1977 & Ivanović et al. 1978**, the thickness of the Promina Beds varies, from 1,900 m in the centre of the sedimentary basin to 3,100 m in the Promina Mt. area near Drniš.

The origin and development of the Promina basin is described by **Mrinjek et al. 2012**, and detailed sedimentological investigations were made by **Babić & Zupanič, 2007; Babić et. al., 2010; Zupanič & Babić, 2011**.

The Promina foreland basin is a so-called piggyback basin, sensu **Ori & Friend (1984)**, developed in the coastal area of the then ascending External (Karst) Dinarides, parallel to the collapse and gradual drowning of the Adriatic Carbonate Platform - AdCP (**Vlahović, 2012**). The basin constantly deepened and foraminiferal limestones enriched with miliolids were deposited in the centre of the basin (**Babić et. al., 2010**). The Promina Beds were deposited during the Middle Eocene in the proximal part of the Promina basin, as molasse deposits from the ascending mountains. In the Middle Eocene, "blind" re-

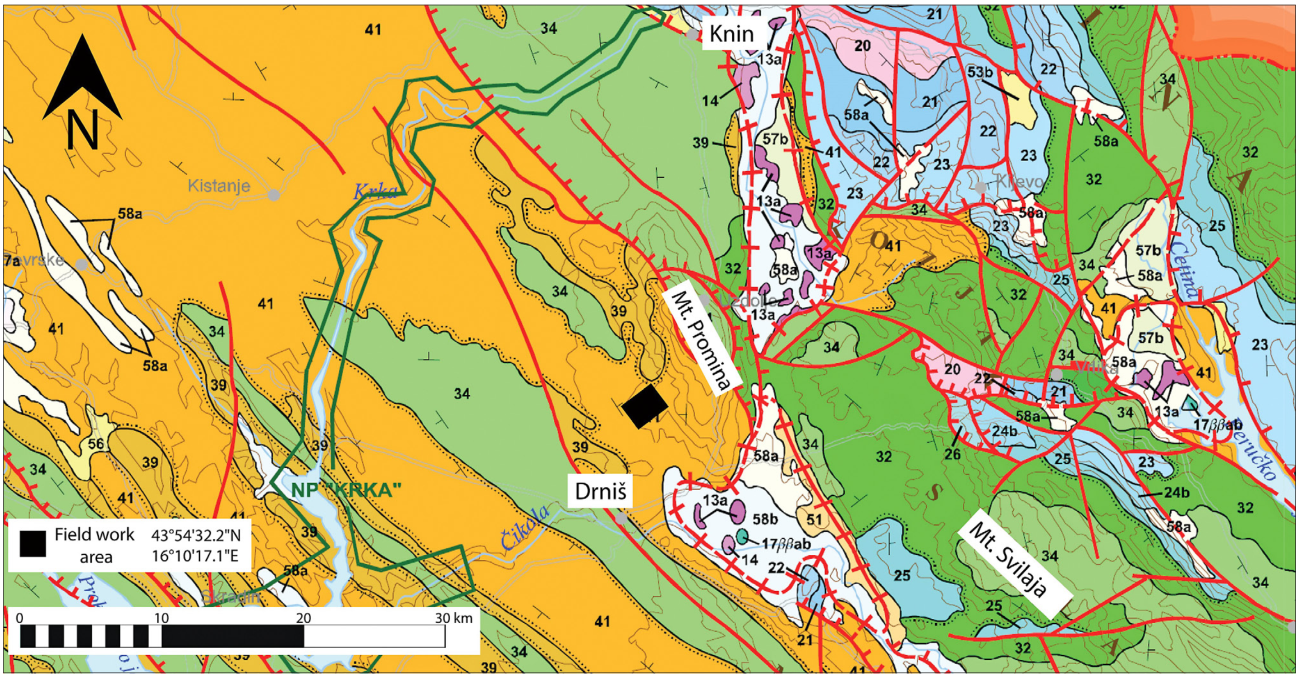


Figure 2. Geological map of the research area (adapted from **URL 1**). Legend (from **Velić & Vlahović, 2009**): 13a – P_3 evaporitic and clastic deposits (Upper Permian); 14 – T_1 mixed clastic and carbonate deposits (Lower Triassic); 17 ββab – T_{2-3} magmatic rocks (Middle to Upper Triassic), ββab- spilite diabase and andesitic basalt; 20 – $T_3^{2,3}$ dolomites (Upper Triassic); 21 – J_1 limestones and dolomites (Lower Jurassic); 22 – J_2 thick-bedded limestones and dolomites (Middle Jurassic); 23 – J_3 limestones and dolomites (Upper Jurassic); 25 – $J_3^{2,3}$ forereef and reef limestones and dolomites (Kimmeridge, Tithonian); 32 –K_1 limestones and dolomites (Lower Cretaceous); 34 – K_2^{1-6} rudist limestones (Cenomanian-Maastrichtian); 39 –?Pc-$E_{1,2}$ Liburnian deposits, foraminiferal limestones and transitional beds (?Upper Palaeocene, Lower and Middle Eocene); 41 –E, Ol Promina Beds (Eocene, Oligocene); 56 – pQ_2 aeolian sand (pQ_2) (Holocene); 57b – bQ_2 marsh deposits (bQ_2) (Holocene); 58a – $dprQ_2$ diluvium and proluvium deposits ($dprQ_2$) (Holocene).

verse faults caused topographic heights to uplift, avoiding the gradual drowning caused by sea-level rise. Similar processes occurred in the deep-water areas, causing turbidite currents to flow toward the southeastern part of the basin (**Mrinjek et al. 2012**). While reverse faulting progressed toward the southeast, small subbasins with neritic sedimentation developed (**Mrinjek et al. 2012**). The Promina Beds near Drniš and in the Promina Mt. area were deposited in the youngest part of the basin.

The Promina Beds at the type locality Promina Mt. are about 1,100 m thick, and eight stratigraphic units with facies variations were distinguished within (**Zupanič & Babić, 2011**). The described succession of the Promina Beds consists of various deposits, from deep-water and coastal, to alluvial, lake and marsh. Succession begins with alluvial deposits, transported and deposited in braided rivers at low sea-level. Transgressive-regressive cycles of sedimentation continue while sea-level rises and fall alternate (**Babić et al., 2010**). Large amounts of sediment were transported to the marginal parts of the basin, mainly due to tectonics and deformation, which are considered as the main factors influencing the development of sedimentary sequences in the succession (**Zupanič & Babić, 2011**).

A major part of the coastal zone in the External Dinarides is built of the Upper Mesozoic and Paleogene platform carbonates followed by Paleogene clastics, including flysch deposits and the Promina Beds. Flysch deposits in the Dinarides indicate intensive orogen denudation and deposition in deep foreland basins. They are thinning towards the inner parts of the basin and gradually vanish from the sedimentary succession (**Babić & Zupanič, 2007**). The Promina Beds directly overlay deformed Paleogene and Cretaceous limestones in the area without flysch deposits, like in Promina Mt. According to (**Babić & Zupanič, 2007**), they can be grouped as: 1) sediments below sequence boundaries; 2) alluvial sediments; 3) fossiliferous limestones; and 4) delta-shelf succession. Sediments below sequence boundaries are Cretaceous and Eocene shallow water carbonates - fossiliferous and bioturbated limestones of wackestone, packstone and mudstone type (classified according to **Dunham, 1962**). They contain *Discocyclina*, *Nummulites*, *Actynoclina* and *Milliolida* benthic foraminifera, as well as some gastropods and corals (**Babić & Zupanič, 2007**). On the top of the sedimentary succession, conglomerates with abundant matrix appear. They are interpreted as shelf deposits, with material brought by the rivers from the orogen. In the thick sequence of alluvial deposits (ca. 500 m) on the eroded Cretaceous carbonate basement, conglomerates and sandstones prevail, with some intercalations of mudstones. Conglomerates are horizontal and cross-stratified, deposited in braided river environments (**Babić &**

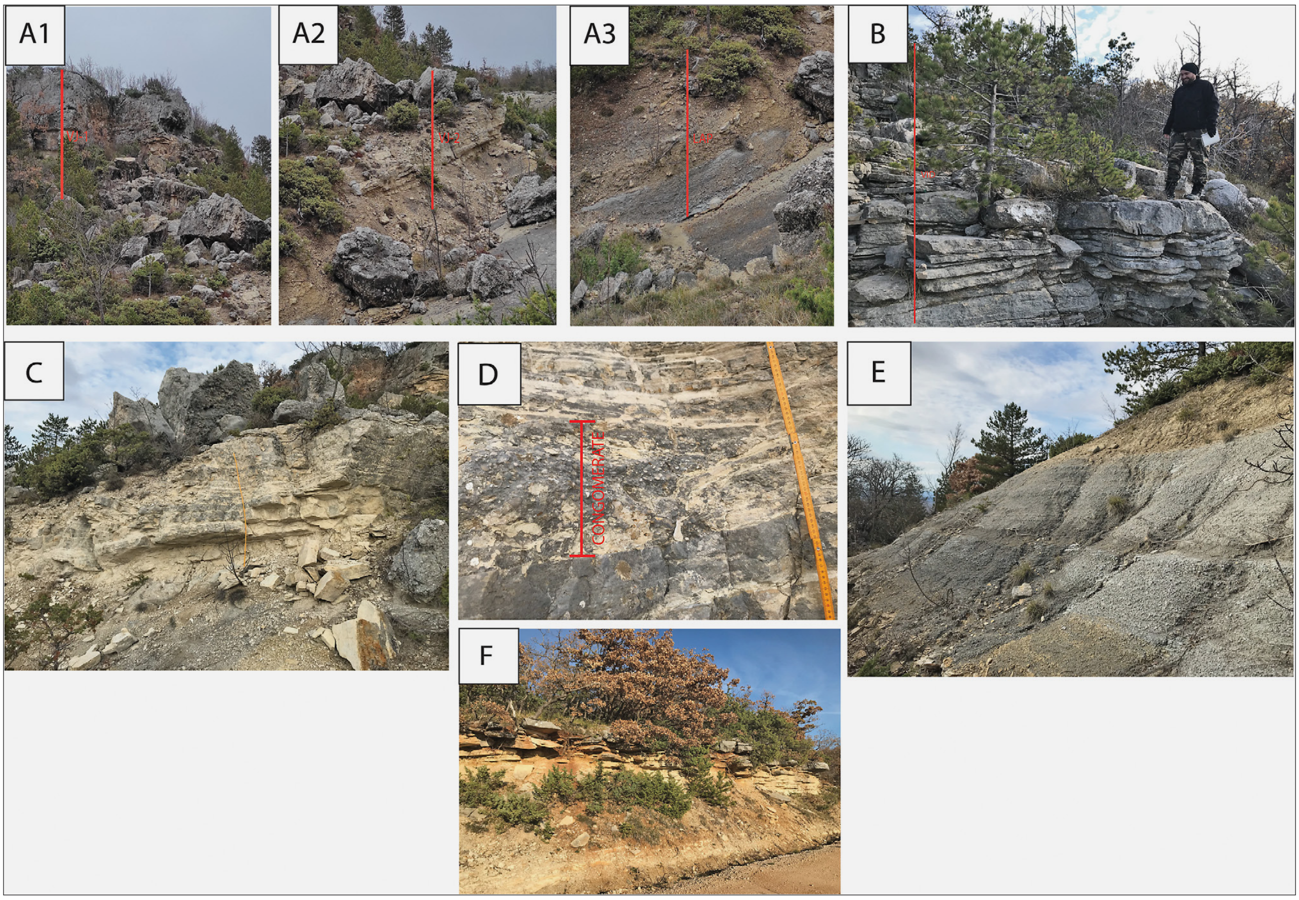


Figure 3. A-F Field work in the ravine of the Driskoč occasional stream and along the mountain road. **A1** The VJ-1 segment with predominant calcarenites. **A2** VJ-2 segment with predominant calcarenites; **A3** A part of LAP segment with predominant calcareous mudstones. **B** A detail from the VID segment with predominant calcarenites. **C** and **D** Details of the VJ segment. Well-sorted fine conglomerate interbed in the calcarenites. **E** A detail from the LAP segment. **F** A detail from the PUT segment with calcarenites and mudstones.

Zupanič, 2007), and sandstones are horizontal to cross-laminated, filling depressions during low water levels. A lower lacustrine unit is deposited in lakes and marshes at high groundwater level, triggered by sea level rise (**Zupanič & Babić, 2011**). Middle lacustrine units occur in places. A sharp erosional boundary then formed on top of the alluvial deposits. The coastline moved inland and a shallow carbonate shelf was formed (**Babić & Zupanič, 2007**). Fossiliferous limestones and equivalent stromatolitic limestones and marls with molluscs were deposited, occasionally followed by coal deposits, significant for the Promina Mt. area due to its extensive mining production in the past. Distal shelf mudstones follow, marking the so-called maximum flooding surface. The coastline once again moved towards the sea, indicated by the transition from mudstones with planktonic foraminifera, followed by sandstones and massive conglomerates. These sandstones are horizontal and cross-laminated, abundant with plant debris, and some foraminifera can be found as well, clearly indicating the transition shelf to delta transition (**Babić & Zupanič, 2007**). The upper lacustrine unit is extremely thin and hard to find in the field, probably deposited in the lakes on the delta plain (**Zupanič & Babić, 2011**). Massive alluvial deposits, so-called terminal alluvium with grain-supported and matrix-supported conglomerates and minor sandstone beds, appear on top of the succession. These are attributed to the so-called Gilbert-type delta environment (**Gilbert, 1885; Barrel, 1912**), a type of delta formed by the entering of the river into a large water body - a lake or a sea. Sedimentary succession in this type of delta consists of three parts: 1) bottomset, mainly with mudstone; 2) foreset made of steeply inclined sand and small gravel beds; and 3) topset, made of massive gravels. At the beginning of the terminal alluvium deposition, marginal parts of the basin were uplifted, partly eroded and finally covered with alluvial deposits. Denudation followed since Neogene, thus forming recent relationships in Promina Mt. (**Zupanič & Babić, 2011**).

3. Methods

A detailed lithological column has been recorded in the ravine of the Driskoč occasional stream, which is cut perpendicular on the strike of sedimentary beds, from the Mali Točak Spring up the hill toward the Mountain House

"Promina", (see **Figure 1b**), as well as along the road towards the Mountain House "Promina" starting from the Mali Točak Spring (see **Figure 1c**). Samples of rocks for micropetrography and laboratory analysis were also taken when another change in lithology was detected.

A lithological column was recorded in the segments (see details in **Figures 3A-F**), due to the availability of the different parts of the sedimentary succession in the field (according to **Collinson & Thompson, 1988; Tucker, 1991; Stow, 2005**), and finally compiled together (see **Appendix A**) in a total thickness of 68 metres. The determined lithofacies are distinguished in the column.

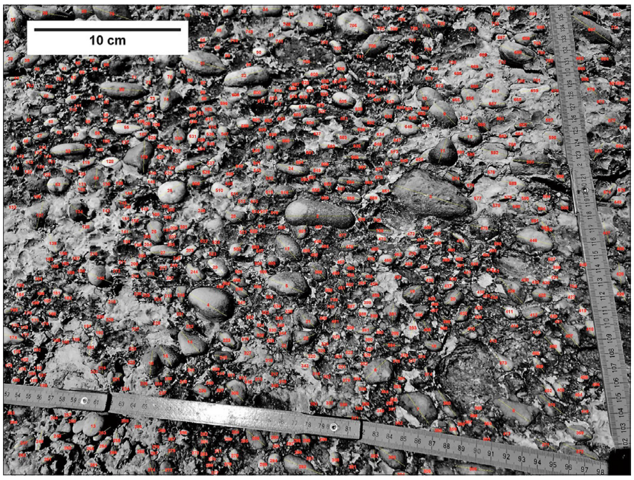


Figure 4. Photograph of the conglomerate after image analysis was made with the *ImageJ* software. The red numbers mark the measured pebbles. The results of the measurements are presented in the **Appendix B**.

Thin sections were made from the collected samples (according to (**Müller, 1967; Tucker, 1991**) and micro petrographically analysed (after **Tucker, 2001**). Lithofacies were defined (after **Reading, 1986**) according to their lithological characteristics. Marl samples taken from the LAP segment were subjected to volumetric analysis of $CaCO_3$ shares (**Tucker, 1991; Müller, 1967**), and an average value from three consecutive measurements has been assigned. All analytical procedures were made in the Laboratory for Geological Materials (LaGeMa) at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb. On the photograph taken in the field showing the part of the conglomerate bed, an image analysis has been performed to measure the diameters of 757 pebbles in total (**Müller, 1967; Tucker, 1991**). Measurements were performed by using *ImageJ* open-source software (**URL 2**).

4. Results

The compiled lithological column PRO-2 is 68 m thick (see **Appendix A**), and consists of the recorded segments, explained separately below in the following subchapters. Total of 61 samples were taken in the field, ranging from 5 to 15 in the particular segments. The determined lithofacies are distinguished in the column.

4.1. Segment VID-dolje

The lithological column begins with the VID-dolje segment, recorded in the Driskoč ravine. The boundaries between the lithofacies are clearly visible. A thick bed of

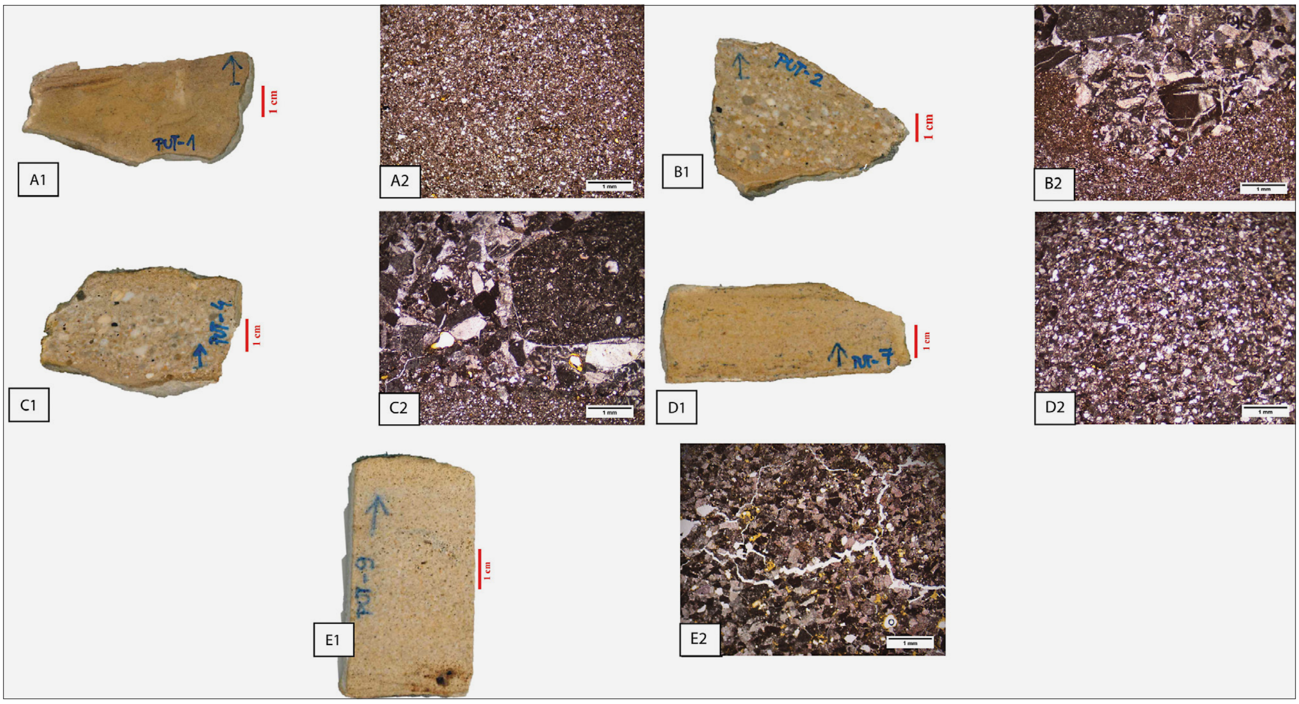


Figure 5. Polished plates and accompanied microphotographs of the thin sections from the samples taken in the segment PUT. **A1-A2** Sample PUT-1. Fine calcarenite; **B1-B2** Sample PUT-2 Coarse calcarenite; **C1-C2** Sample PUT-4. Coarse calcarenite; **D1-D2** Sample PUT-7. Fine calcarenite; E1-E2 Sample PUT-9. Middle coarse calcarenite.

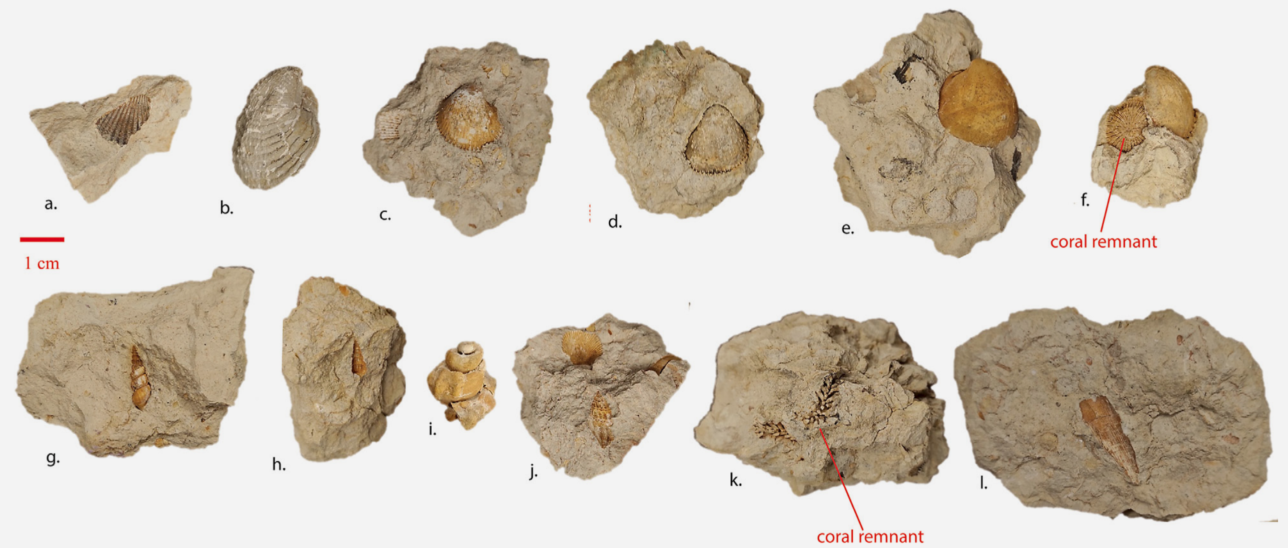


Figure 6. Some of the fossil assemblage of Eocene-Oligocene fossils from calcareous mudstones between the VID-dolje and PUT segments. - a.-e. bivalves; g.-j. gastropods; f. and k. corral remnants; l. plant debris.

middle-coarse (after Wentworth, 1922) conglomerates, with the average pebble diameters of 1.458 cm determined by image analysis (see **Figure 4** and **Appendix B**), is detected at the bottom. All pebbles were derived from the Lower Eocene foraminiferal limestones.

Dark grey to light yellow calcareous mudstone lithofacies, interbedded with 20-40 cm thick beds of calcarenites, follow in the succession. Lenticular and through-cross stratified calcarenite layers (3 m thick) and conglomerates with limestone pebbles of the same thickness, end up the recorded segment.

4.2. Segment PUT

At the outcrops along the road toward the M.H. "Promina" the segment PUT has been recorded in the continuity of the previously described segment VID-dolje. The segment begins with a 35 cm thick calcarenite bed interbedded with thin silt beds (see **Figures 5 A1-A2**). Calcarenites are separated by the erosional boundary from the overlying conglomerates showing normal gradation (see **Figures 5 B1-B2**). A thin bed (2-5 cm thick) of the fine conglomerate follows (see **Figures 5 C1-C2**), overlain by an 80 cm thick bed of well sorted calcarenites (see **Figures 5 D1-D2**) with wavy lamination and mudstone interbed. Calcarenites gradually pass into mudstones (see **Figures 5 E1-E2**) near the top of the segment. It ends up with 0.5 m thick beds of middle-coarse conglomerate with carbonate pebbles lithofacies. Within the described alteration of calcarenites, silts and mudstones lithofacies, sedimentary structures of horizontal, wavy and lenticular stratification were recognized. These structures suggest mud and sand deposition due to alternating high and low energy conditions in coastal environments. Massive conglomerate lithofacies follow further in the succession.

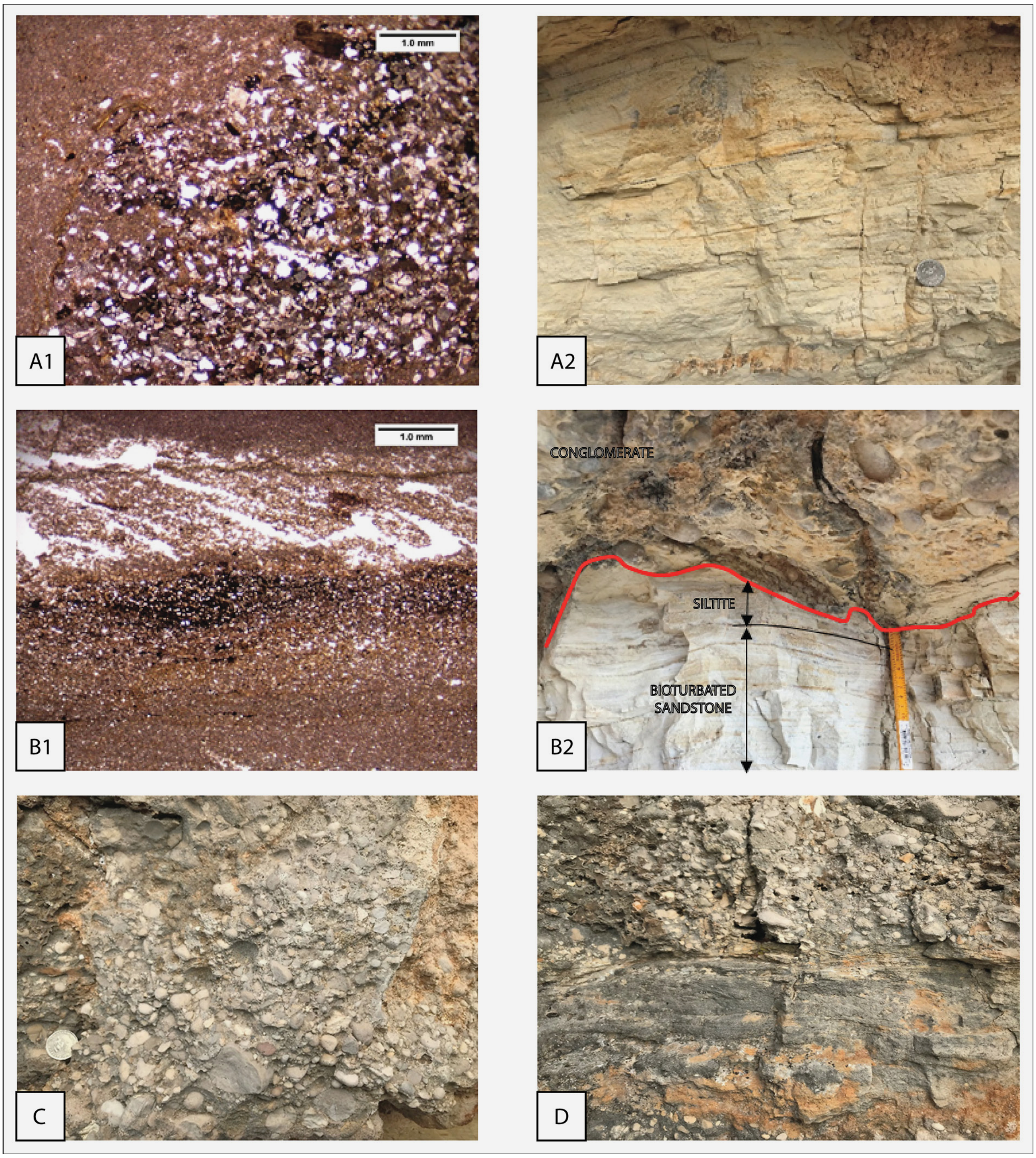
Between the segments VID-dolje and PUT, a sequence of calcareous mudstones with abundant fossil assemblage of gastropods and bivalves, with the occasional solitary corral and plant phragments is recorded (see **Figure 6**).

4.3. Segment VID-gore

The segment VID-gore begins with a 1.5 m thick light brown bed of calcarenites with horizontal lamination (see **Appendix A**). Individual beds in the set are 5-20 cm thick. Laminated calcarenite with alternating bioclastic and micritic laminae is the lithofacies confirmed by micropetrography (see **Figure 7B1**). A thin bed of fine conglomerate lithofacies appears between the two calcarenite sets. The conglomerate contains well rounded pebbles, derived from the various types of limestones. The segment ends up with the horizontally laminated calcarenites almost 5.5 m thick, in places interbedded with the conglomerates, and finally with carbonate conglomerates on top of the segment. Thin-laminated calcarenites show more pronounced lamination upward, with coarser bioclasts and lithoclasts. Massive, extremely coarse-grained conglomerate, 1.10 m thick, were followed by a 2 m thick bed of poorly sorted, grain supported conglomerate with various limestone pebbles and cemented with calcite cement. Some pebbles contain fossils, mainly foraminifera, indicating that the pebbles were derived from Cretaceous and Eocene limestones.

4.4. Segment LAP

In the LAP segment, dark to light grey colour fine-grained sediments, about 4 m thick, were described and assigned in the field as marl deposits. Volumetric analysis showed about 83% as the average value for $CaCO_3$ share in their composition. They are determined re-aasigned as



Figures 7A-D. Details from the segment VJ-1. **A1** Microphotography of bioturbated silts filled with calcarenites. **A2** Laminated and bioturbated silts with calcarenites interbeds. **B1** Microphotography of laminated calcareous mudstones and silts. B2 Erosional contact of the carbonate conglomerates with the underlying silts and calcarenites. **C** Normally graded carbonate conglomerates. **D** Cross-stratified calcarenite interbeds within carbonate conglomerates.

the grey calcareous mudstone lithofacies. The change of their colour is assigned as a result of weathering.

4.5. Segment VJ-2

The VJ-2segment is built of a 2 m thick set of calcarenite beds, with one interlayer of fine conglomerate. Three units within the set were distinguished by the lamination present: (i) a 50 cm thick horizontally laminated calcarenite; followed by (ii) a 20 cm thick calcarenite with trough-cross lamination; and (iii) a similar 20 cm thick calcarenite with trough-cross lamination, but darker than the previous one. A lense-like interbed of fine-grained and well-sorted conglomerate is present within. The segment ends up with a 90 cm thick set of 2 horizontally laminated calcarenite beds. Light calcareous mudstone, similar to the one previously described in the LAP segment, and a 4.5 m thick set of horizontally laminated yellow to light brown calcarenite beds with abundant bioclasts and wave ripples, ends up the segment.

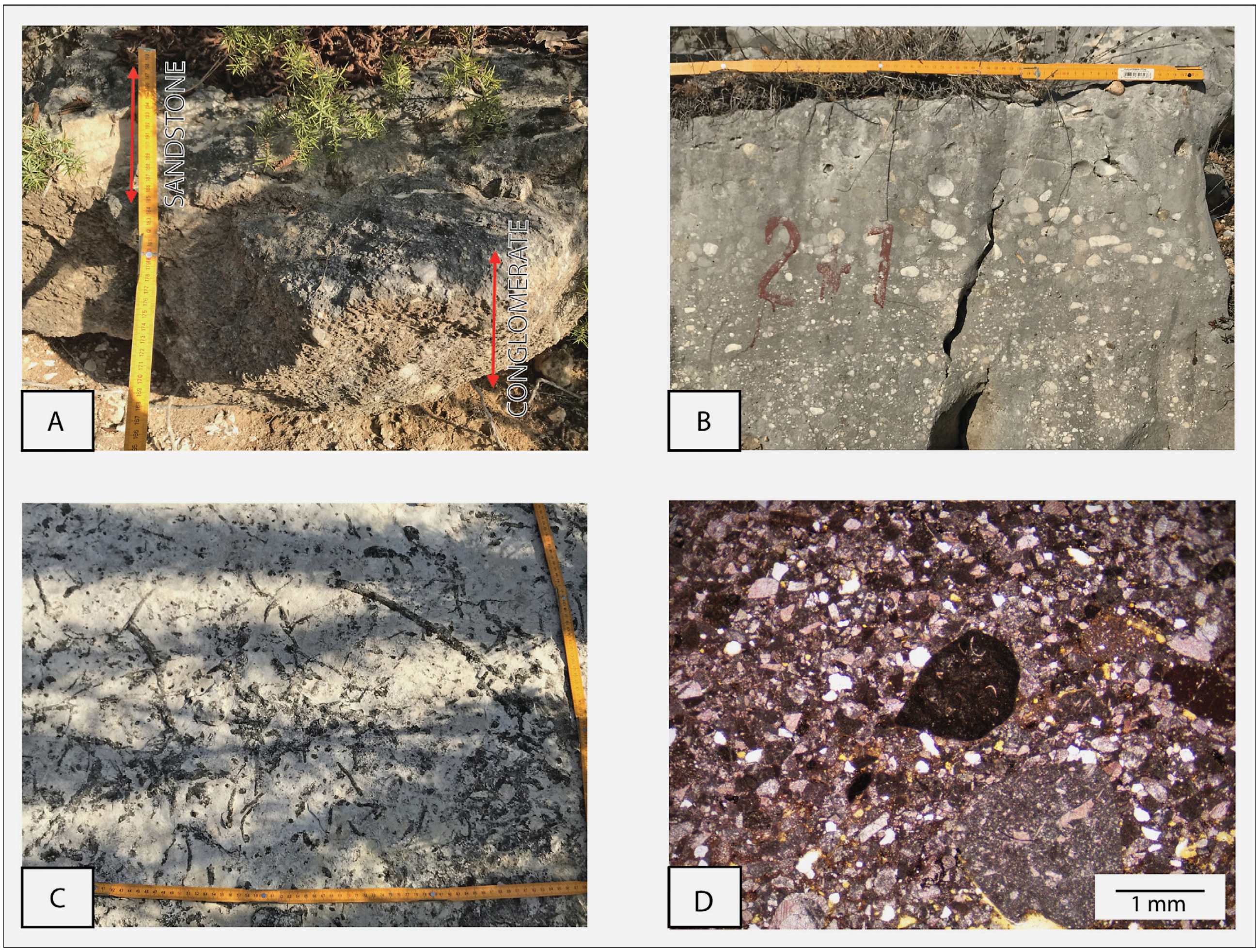


Figure 8. A-D Details from the determined lithofacies, detected along the road from the Mali Točak Spring towards the Mountain House "Promina". **A** Alternating conglomerate and calcarenite beds. **B** Alternating conglomerate beds. **C** Biogenic structures in calcarenite. **D** Microphotography of the bioturbated calcarenites.

4.6. Segment VJ-1

Segment VJ-1 begins with 1.3 m thick calcarenite and silt bed alternations. They are horizontally laminated, having dark thick silt beds and thin light calcarenite laminae. Small fossil shells were detected in the silt laminae, as well as burrows filled with calcarenite.

The horizontally bedded, yellow to light brown silt bed 5-10 cm thick follow on the bioturbated calcarenites (see **Figures 7A1-A2**).

Alternating light brown silt and dark brown mudstone laminae can be clearly seen in **Figure 7B1**. The described silts are in erosional contact with the conglomerates that follow on top of them (see **Figure 7B2**).

These are about 6.5 m thick massive carbonate conglomerates, without the bedding visible. They are normally graded and poorly sorted in the lower part, having well-rounded pebbles derived from various types of limestones (see **Figure 7C**).

A horizontal and cross-stratified well-lithified bright yellow to brown calcarenite interbed, 50 cm thick, appears within carbonate conglomerates (see **Figure 7D**).

4.7. Deposits exposed along the road from the Mali Točak Spring towards the ''Promina'' Mountain House

Several interesting details within the observed succession were documented on the outcrops along the road and associated with the compiled lithological column PRO-21 (see **Appendix A**). Alternating conglomerate and calcarenites beds (see **Figure 8A**), as well as alternating conglomerate beds (see **Figure 8B**), were detected along the road. Near the Mali Točak Spring, in the lower part of the recorded succession, biogenic structures in calcarenite were detected (see **Figures 8C-D**).

5. Discussion

The Promina Beds at Promina Mountain near Drniš represent the Eocene-Oligocene deposits which transgressively overlie Cretaceous and Paleogene carbonates. These sediments were deposited in various sedimentary environments, resulting in broad lithofacies distribution. The main lithofacies are carbonate conglomerates, calcarenites and mudstones, with occasional coal beds appearing in the youngest part of the succession. Mentioned lithofacies were determined in the observed succession, except the coal beds, which appear mainly toward Siverić, on the other side of Promina Mt. One of the main characteristics of these deposits is the frequent alternation of different lithofacies.

Previous research (**Zupanič & Babić, 2011**) described appearance of Promina Beds within eight units: the basal alluvium; the first lacustrine unit; the lagoonal and lacustrine deposits; the second lacustrine unit; the shelf-delta alternation; shallow water limestones with fossils; the third lacustrine unit; and terminal alluvium deposits. Deposition in the Promina basin occurred in several stages (**Babić & Zupanič, 2007**). Elevated relief in the orogenic belt of then ascending Dinarides provided the constant supply of the materials that filled the depressions, causing the development of the alluvial plains. After that, the transgression took place, indicating sea level rise and moving the coastline towards the land. The whole area was covered with shallow sea and lagoon, and the lastly a erosional boundary in the alluvial deposits formed. Later, sea level rise caused maximal movement of the coastline towards the land. Transport of the material from the orogenic belt led to suitable conditions for the Gilbert-type delta development (**Zupanič & Babić, 2011**). An increased supply of the coarse-grained clastics occurred due to intensive uplift, and the source area from where the material was brought by the rivers, was exclusively made of carbonates (**Babić et al., 2010**).

Lithofacies described in this study can be compared with the descriptions of the deposits from the previous research in the same area. These deposits are assigned as transitional, from the shelf and coastal to delta environments (unit U5 in (**Zupanič & Babić, 2011**)). This unit comprised about 300 m of the deposits, and different lithofacies of conglomerates, calcarenites and mudstones, as well as their alternations, are present in the area.

5.1. Calcareous mudstone lithofacies

This lithofacies is mainly present in two intervals within the observed succession: (i) interval from 3rd to 17th metre in the recorded column; and (ii) interval from 39th to 58th metre in the recorded column (see **Appendix A**). Calcareous mudstone lithofacies appears as dark grey to yellow, depending on the surficial weathering and discolouration, as well as on the occasional erosion in the ravine. In the first interval, it is occasionally interbedded with calcarenites and silts. It often contains large amounts of the fossil material, especially bivalves and molluscs as well as corals and some plant debris. These mixed fossil assemblage imply a transition from marine (indicated by corrals) to continental (indicated by plant debris) environment. Linear biogenic structures (burrows) found in the lower parts of this interval indicate stable sedimentation from the suspension in the marine environment. The 39th to 58th Metre of the calcareous-mudstone lithofacies is massive (see segment LAP in **Appendix A** and **Figure 3F**), and further is often interbedded with calcarenites and silts. Fossil assemblage is relatively poor comparing with the previous interval, containing some bivalves. These are calcite-rich (calcareous) mudstones containing about 83% of $CaCO_3$, deposited in steady marine water environments, presumably in the deeper part of the shelf. Interbeddingwith the calcarenites is more often in the upper parts of both observed mudstone predominant intervals, indicating higher water energy environments in the shallower parts of the shelf.

5.2. Calcarenite lithofacies

Calcarenite lithofacies occur between the two predominantly mudstone intervals, (i.e. between 17th and 39th metre in the recorded succession) (see **Appendix A**). These are clearly visible in the recorded segment PUT (see **Appendix A** and **Figures 3f, 5** and **6**) as horizontally to wavy-laminated calcarenites, occasionally also with the wave ripples. These deposits accumulated in the shelf environments, under the changing energy hydrodynamic conditions, reflected in horizontal lamination in silts and calcarenites (see **Figures 7 A1, A2** and **B1**). This lithofacies also occurs as horizontally laminated calcarenites, as well as calcarenites with silt interbeds between 46th and 58th metre in the recorded column PRO-21 (see VJ-1; VJ-2 and VID-gore segments in **Appendix A**, as well as in **Figures 3a-d** and **7**). These calcarenites contain various small bioclasts and carbonate lithoclasts and the minor share of the siliciclastic grains. In the lower part of the VJ-1 segment, vertical burrows between the interbedded calcarenites and silts were observed, reflecting interchange of the hydrodynamic conditions in the shallow part of the shelf. Predominantly carbonate sand material was brought to shelf probably by surge currents and deposited.

5.3. Carbonate conglomerate lithofacies

Conglomerate lithofacies is determined at several intervals in the recorded succession (see **Appendix A**). First, it appears at the beginning of the column PRO-21, as massive (at least 3 m thick) middle coarse-grained (with average pebble size around 1.5 cm – see **Figure 4** and **Appendix B**) carbonate conglomerate, incorporating pebbles derived from the Eocene foraminiferal limestones. Several carbonate fine and medium coarse grained conglomerate sequences are interbedded within predominantly calcarenite lithofacies in the VID-dolje, PUT and VID-gore segments in the recorded column (see **Appendix A**, as well as the **Figures 5 B1-B2, C1-C2** and **8 A-B**). Finally, recorded succession ends up with the thick conglomerate sequence (at least 9 m thick) in the VJ-1 segment of the column (see **Appendix A**, as well as the **Figures 3A** and **7 B2, C, D**). They have erosional surfaces cut into the underlying calcarenites and silts (see **Figure B2**).

In these upper conglomerate bodies, Cretaceous pebbles were also detected, along with the prevailing Eocene foraminiferal limestone pebbles. These deposits are originated by intensive erosion of the previously deposited and then emerged carbonate deposits in the hinterland, material of which is brought into the basin by the rivers. The deposition of such large amounts of the coarse material is caused by a decrease of the flow velocity while flow enters the large water body, the sea or the lake.

Conglomerate lithofacies is therefore likely deposited within the delta, as suggested (**Babić & Zupanič, 2007; Babić et. al., 2010; Zupanič & Babić, 2011)**, and probably in the Gilbert type delta environments (**Postma, 1995, Postma & Roep, 1995**).

6. Conclusions

Considering all the above presented and discussed, several conclusions can be drawn from this study:

Promina Mountain in the External (Karst) Dinarides, in the southern Croatia, represents an ideal locality to investigate the succession of the Promina Beds. Investigation of these deposits gave insight into the origin and characteristics of sedimentary environments present in the research area.

Lithofacies study in one part of it, in the area near the top of the mountain, detected three major lithofacies: calcareous mudstone, calcarenite and carbonate conglomerate lithofacies.

Lithofacies relationships, accompanied with the recorded lithological column show several transitions from mudstone-calcarenite-conglomerate lithofacies, revealing transition from shelf to delta sedimentary environments.

Mixed fossils indicate transition from marine (shelf) to the continental (delta) environments.

The Eocene-Oligocene deposits exposed at the top of the Promina Mountain near Drniš provide an excellent and rare opportunity to promote geological peculiarities of the Karst Dinarides for sustainable landscape management purposes.

Acknowledgement

The authors also wish to thank Nediljka Prlj Šimić from the Croatian Natural History Museum in Zagreb for valuable determinations of the fossil assemblage.

Funding

This research is partially supported by the "Mathematical research in geology IX" project (led by T. Malvić) at the University of Zagreb.

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Appendix A Lithological column PRO-1.

Appendix B Table 1 Results of the measurement of pebble diameters in conglomerate macrophotography with *ImageJ* software.

SAŽETAK

Eocensko-oligocenski litofacijesi vrha planine Promine (Krški Dinaridi, Hrvatska)

Istraživani su litofacijesi gornjega dijela prominskih naslaga vršnoga dijela planine Promine (Vanjski (Krški) Dinaridi, Hrvatska). Litofacijesi karbonatnih konglomerata, kalkarenita i kalcitičnih muljnjaka opisani su u sedimentacijskome slijedu na istraživanome području. Determinirani litofacijesi i njihove karakteristike prikazani su litološkim stupom PRO-21, kao rezultati terenskoga rada i mikropetrografske analize. Sedimentacijski su okoliši interpretirani i razmatrani.

Ključne riječi:
klastične naslage, litofacijes, eocen-oligocen, Krški Dinaridi, Promina

Author's contribution

Uroš Barudžija (PhD, Assoc. Prof.): conceptualization, investigation, methodology, resources, supervision, writing – original draft, writing – review & editing. **Tomislav Puncet** (M.S. geol.): conceptualization, investigation, software, visualization, methodology, writing – original draft. **Ana Maričić** (PhD, Assoc. Prof.): supervision, validation, writing – review & editing.
All authors have read and agreed to the published version of the manuscript.