Subaerial exposure surface within carbonate deposits at Zlatni rt cape, Rovinj, Istria – a record of a Late Jurassic emergence of the Adriatic Carbonate Platform

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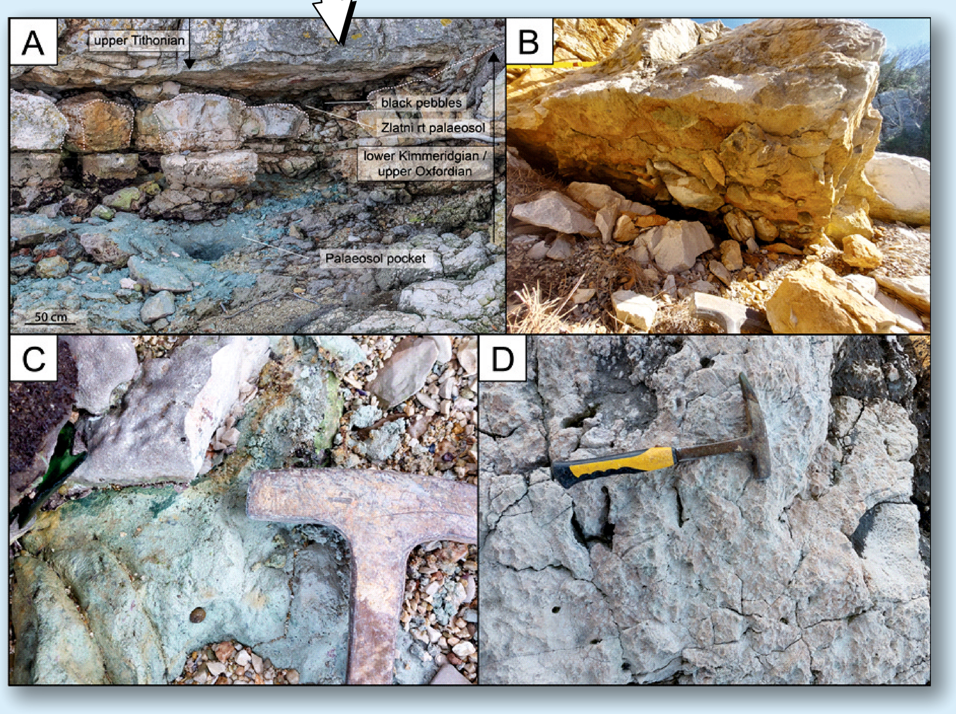
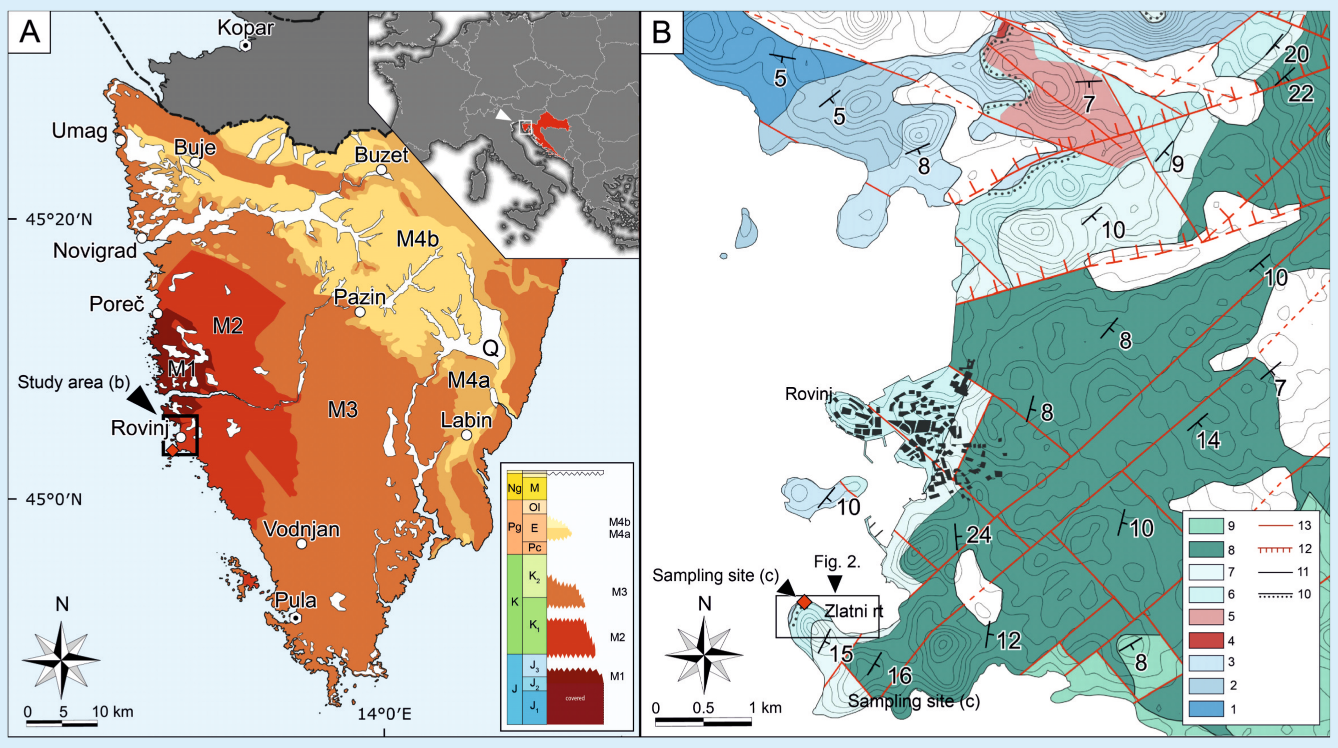


(A) Zlatni Rt-1 outcrop – palaeosol can be seen as a horizon embedding the black pebbles and as infills of the karstified channels and cavities in the bedrock, where it forms a palaeosol pocket which hosts most of the palaeosol material.

(B) Zlatni Rt-2 outcrop – 20 cm thick layer of transgressive breccia, composed from boulders of the Muča unit and black pebbles.

(C) Contact zone between the palaeosol and the bedrock on the Zlatni Rt-1 outcrop, in which centimeter thick crusts of glauconite can be seen.

(D) Bioclastic limestones of the Muča unit, which comprise the bedrock of the unconformity in the Zlatni Rt area.



GEOLOGICAL MAPS OF STUDY AREA

(A) Geological map of Istria, modified after Velić et al. (1995) together with the inset of its location within Europe and Croatia; Legend: M1 – 1st Megasequence (lower Bathonian–lower Kimmeridgian); M2 – 2nd Megasequence (upper Tithonian–lower/upper Aptian); M3 – 3rd Megasequence (lower/upper Albian–Upper Santonian); M4a – Carbonate deposits of the 4th Megasequence (lower–middle Eocene); M4b – Clastic deposits of the 4th Megasequence (middle– upper Eocene); Q – Quaternary deposits.

(B) Geology of the studied area modified after Matičec et al. (2015) and the data provided by the GEO-5 company:, 1 – Monsena unit, 2 – Lim unit, 3 – Muča unit, 4 – Bauxite (uncovered), 5 – Bauxite (covered), 6 – Kirmenjak unit, 7 – Zlatni Rt unit, 8 – Rovinj unit, 9 – Materada unit, 10 – Unconformity, 11 – Normal geological boundary, 12 – Reverse faults, 13 – Normal faults.

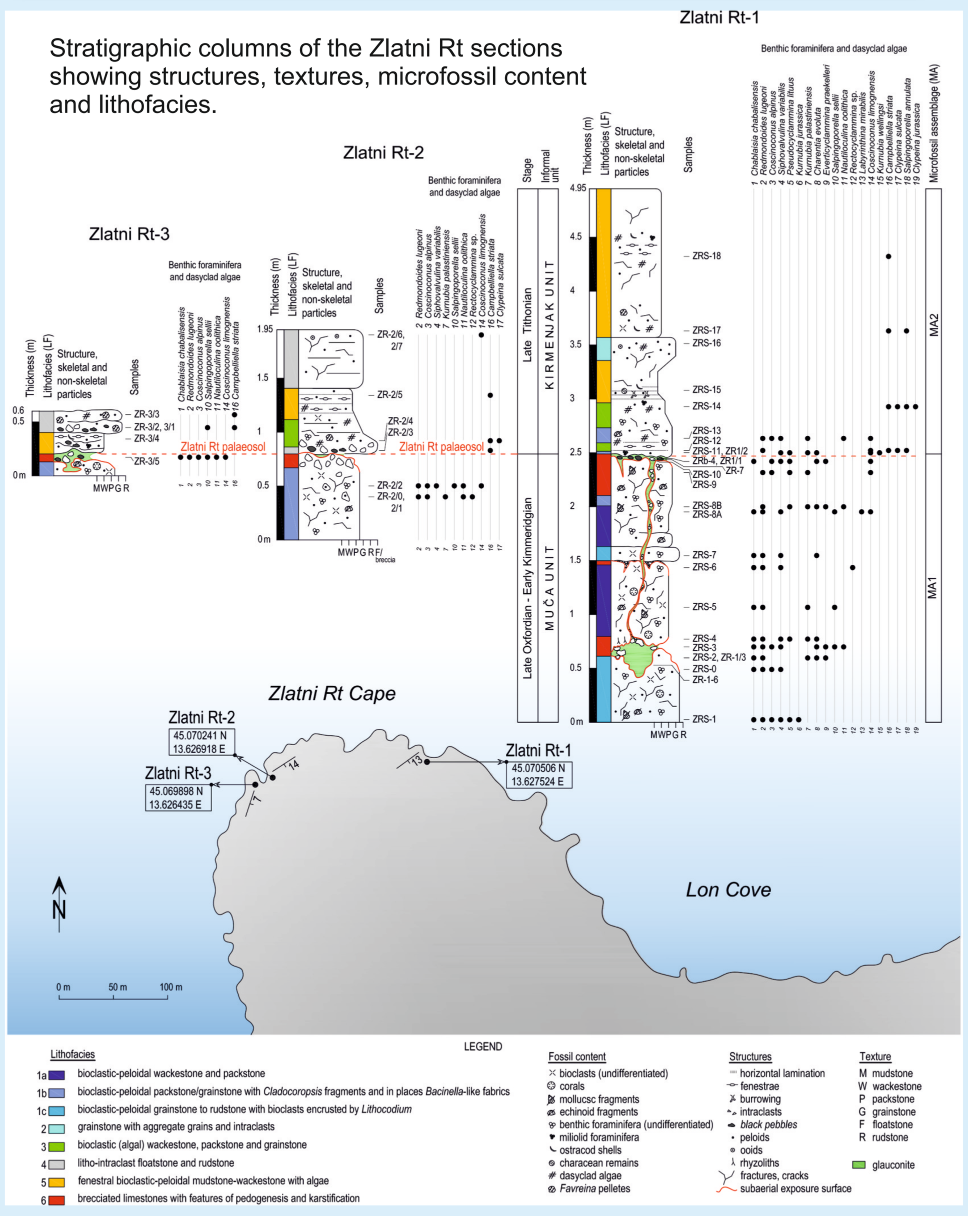
INTRODUCTION

Middle and Upper Jurassic carbonates comprise the first large-scale sequence deposits in Istria, ending with the deposition of the Oxfordian to lowermost Kimmeridgian Muča unit. This succession is overlain by the second large-scale sequence (Upper Tithonian−Lower/Upper Aptian) – deposition of the upper Tithonian Kirmenjak unit.

These two large-scale sequences are separated by important discontinuity – stratigraphic hiatus of different duration – reflecting a compressional tectonic event caused by ophiolite obduction along the NE Adria Microplate margin.

Subaerial exposure phase – marked by the Rovinj breccias formed during the regression preceded the subareal exposure – display a gradual transition from Muča and Lim units – composed of fragments belonging to both units.

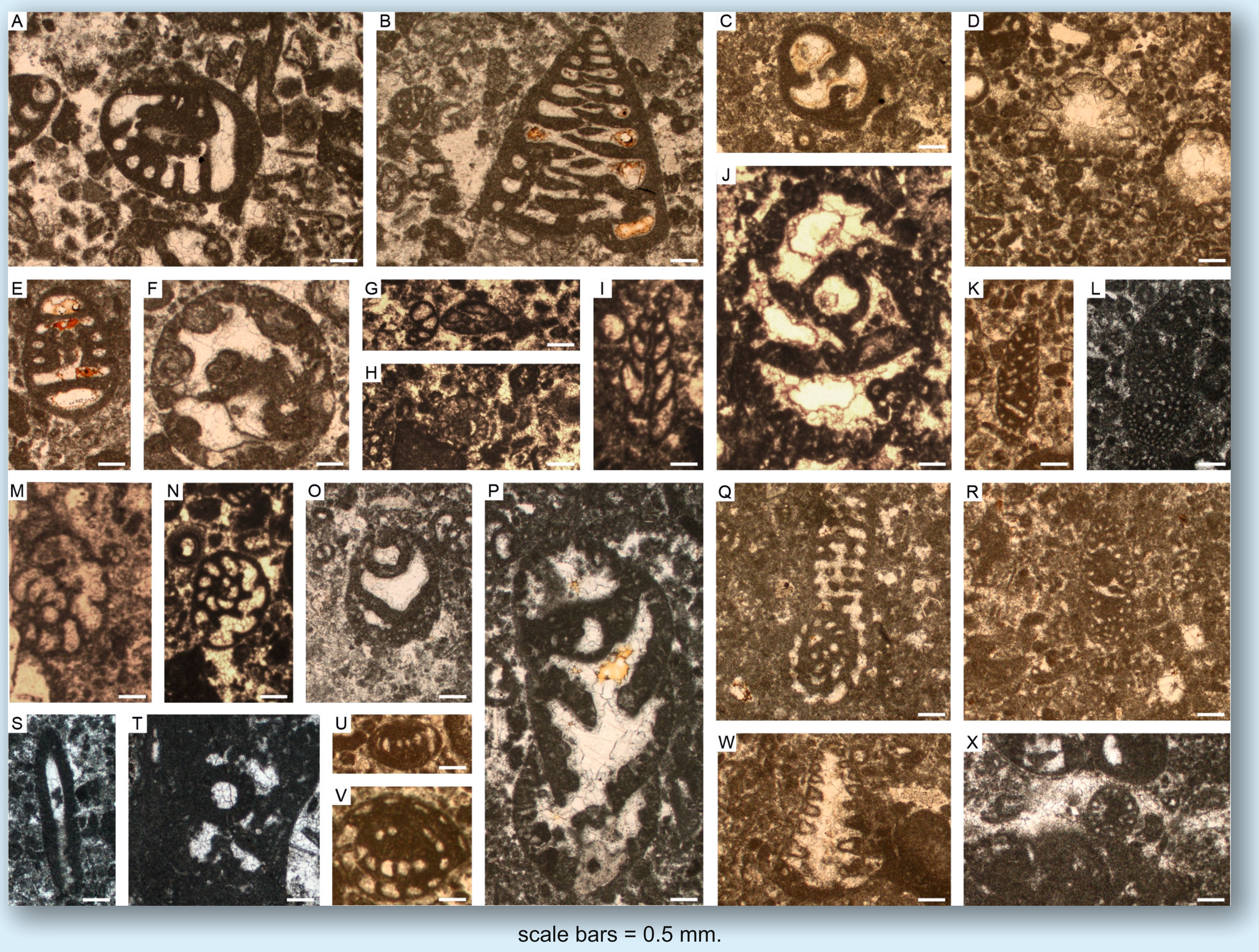
REGIONALLY RECOGNISED SUBAERIAL EXPOSURE PHASE – locally marked by BAUXITES that filled palaeodepressions within the Lim and Muča unit limestones and the Rovinj breccias. In other places subaerial exposure is mostly recorded by PALAEOSOLS – best examples can be found at ZLATNI RT locality in Rovinj.



RESULTS

LITHOFACIES (LF) OF THE ZLATNI RT SECTIONS

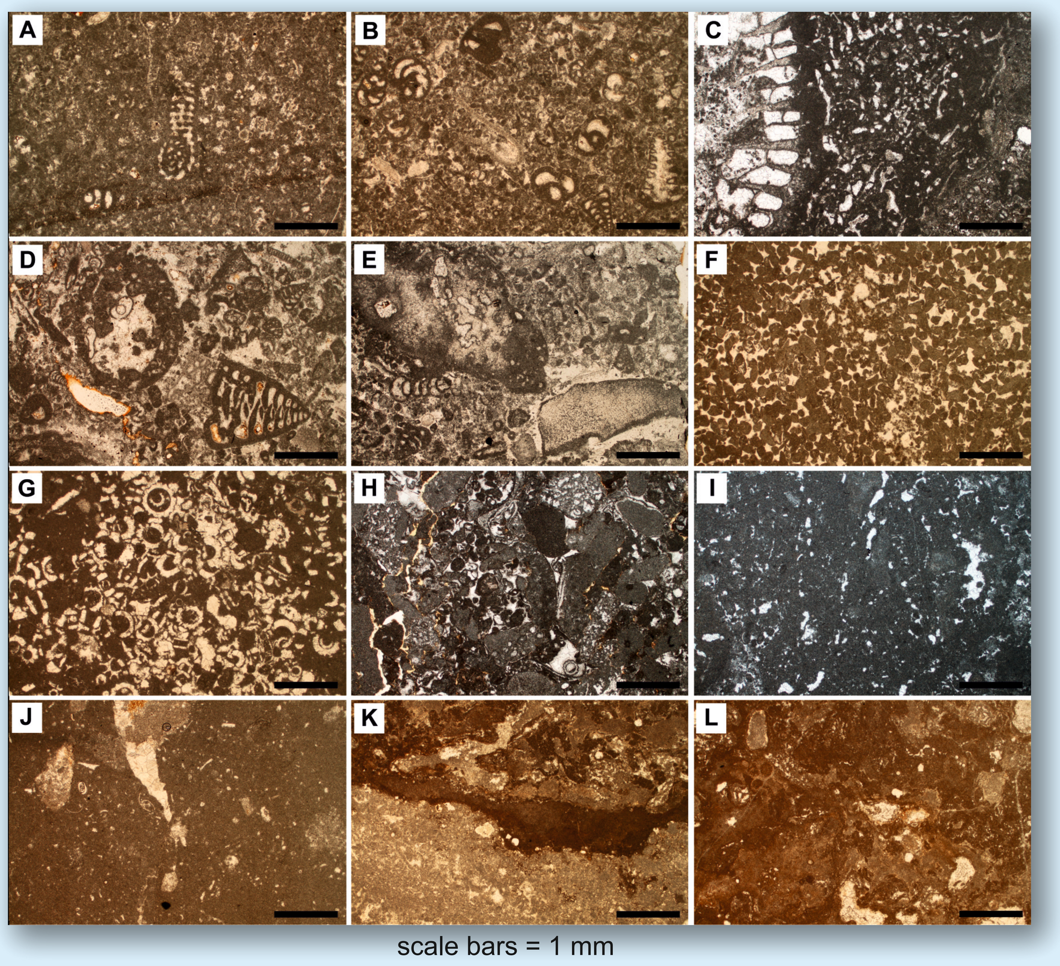
Zlatni Rt lithofacies (LF) (types and subtypes)			Texture, sedimentary structures, skeletal and non-skeletal particles	Important microfossils	Depositional environment
LF1	Bioclastic-peloidal limestones with diverse bioclasts and various micro-encrusters	**LF1a** Bioclastic-peloidal wackestone and packstone	Wackestone-packstone and packstone with common to abundant peloids and benthic foraminifera. Common are fragments of echinoderms, hydrozoans and bivalves. Rivulariacean-like (*Cayeuxia*) cyanobacteria, Solenoporacea and calcareous sponges are present. In places coral and gastropod fragments are encrusted by *Lithocodium*.	*Chablaisia chablaisensis*, *Redmondoides lugeoni*, *Coscinoconus alpinus*, *Protopeneroplis striata*, *Mohlerina basiliensis*, *Siphovalvulina variabilis*, *Pseudocyclammina lituus*, *Kurnubia jurassica*, *K. palastiniensis*, *Charentia evoluta*, *Everticyclammina praekelleri*, *Salpingoporella sellii*, *Thaumatoporella parvovesiculifera*, *Nautiloculina oolithica*, *Rectocyclammina* sp., *Labyrinthina mirabilis*, *Coscinoconus limognensis*, *K. wellingsi*	Low to moderate water energy shallow carbonate platform (CP) interior
		LF1b Bioclastic-peloidal packstone/grainstone with *Cladocoropsis* fragments and *Bacinella*-like fabrics	Packstone/grainstone with common to abundant well sorted small peloids and larger bioclasts. Abundant are benthic foraminifera and common are fragments of echinoderms, *Cladocoropsis*, corals and bivalves, and Rivulariacean-like cyanobacteria and *Bacinella*-like fabrics. Large bioclasts (e.g. corals, bivalves, *Cladocoropsis*) often micritized. Rare algae fragments.		Moderate water energy shallow CP interior
		LF1c Bioclastic-peloidal grainstone to rudstone with bioclasts encrusted by *Lithocodium*	Grainstone to rudstone with common to abundant peloids, bioclasts and small intraclasts. Benthic foraminifera are abundant to common, as well as fragments of echinoderms, *Cladocoropsis*, corals and bivalves which are often encrusted by *Lithocodium*. Echinoderm fragments show syntaxial overgrowth cement. Large bioclasts are commonly micritized and in places show shelter porosity.		Moderate to high water energy shallow CP interior
LF2	Grainstone with aggregate grains and intraclasts		Well sorted grainstone with aggregate grains, small peloids and intraclasts. Small bioclasts are rare.		Moderate water energy open shallow CP
LF3	Bioclastic (algal) wackestone, packstone and grainstone		Wackestone, packstone and grainstone with abundant dasyclad algae, pelids and small intraclasts. Rare small benthic foraminifera, *Favreina* pellets, peloids and small intraclasts are also present.	*Campbelliella striata*, *Clypeina jurassica*, *C. sulcata*, *Salpingoporella annulata*, *Favreina* cf. *salevensis*	Low to moderate water energy restricted CP interior
LF4	Litho-intraclast floatstone and rudstone		Floatstone and rudstone with different sized, unsorted litho- and intraclasts (mudstone, peloidal-ooid grainstone, bioclastic packstone and fenestral wackestone) with pressure-solution contacts, shelter porosity in places and isopachous cement. *Favreina* pellets and fragments of dasyclad algae.	*Campbelliella striata*; *Salpingoporella annulata* *Favreina* cf. *salevensis*	Moderate to high water energy very shallow subtidal
LF5	Fenestral bioclastic-peloidal mudstone–wackestone with algae		Fenestral mudstone-wackestone and wackestone-packstone with peloids and small intraclasts. Lamination is also present. Rare bioclasts include dasyclad algae, ostracods, small benthic foraminifera (mostly miliolids) and charophyta.	*Campbelliella striata*, *Istriloculina* sp.	Low water energy restricted very shallow subtidal and intertidal with influence of brackish/fresh water
LF6	Brecciated limestones with features of pedogenesis and karstification		Brecciated surfaces with irregular relief, dissolution potholes, grey clay filling the depressions and dissolution potholes, glauconite present in one dissolution pothole, black pebbles, rhizoconcretions, clotted fabrics with peloid accumulations, alveolar-septal fabrics.		Terrestrial conditions



scale bars = 0.5 mm.

MICROFOSSIL ASSEMBLAGE FROM THE ZLATNI RT SECTION, MUČA UNIT (MA1):

A, **E** *Chablaisia chablaisensis* (samples ZRS-1; ZRS-2), **B**, **C** *Redmondoides lugeoni* (ZRS-2, ZRS-1), **D** *Coscinoconus alpinus* (ZRS-13), **F** Indeterminable agglutinated foraminifera ZRS-3), **G** *Mohlerina basiliensis* (ZRS-1), **H** *Protopeneroplis striata* (ZRS-1), **I** *Siphovalvulina variabilis* (ZRS-2), **J** *Pseudocyclammina lituus* (ZRS-2), **K** *Kurnubia jurassica* (ZRS-0), **L** *K. palastiniensis* (ZR-2/1), **M**, **N** *Charentia evoluta* (ZRS-0, ZRS-3), **O** *Everticyclammina praekelleri* (ZRS-6), **P** *Rectocyclammina* sp. (ZRS-6), **Q** *Labyrinthina mirabilis* (ZRS-8a), **R**, **X** *Kurnubia wellingsi* (ZRS-12, ZR-1/2), **S**, **T** *Salpingoporella sellii* (ZR-3/5, ZR-3/1), **U**, **V** *Nautiloculina oolithica* (ZRS-13), **W** *Coscinoconus limognensis* (ZRS-9).



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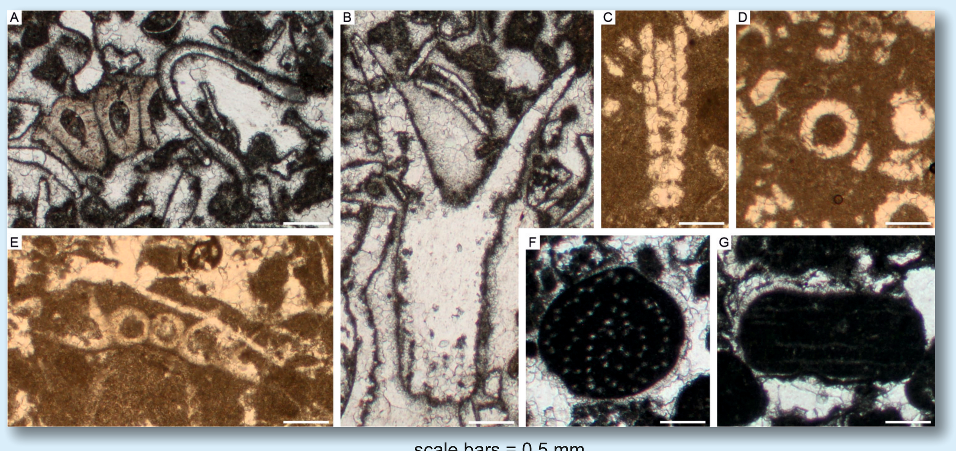
LITHOFACIES (LF) OF THE ZLATNI RT SECTIONS

(A) LF1a: Bioclastic-peloidal wackestone and packstone with *Labyrinthina mirabilis* (sample ZRS-8a).
(B) LF1b: Bioclastic-peloidal packstone–grainstone with *Charentia evoluta*, *Coscinoconus limognensis*, *Siphovalvulina variabilis* and *Redmondoides lugeoni* and *Coscinoconus limognensis* (sample ZRS-8b).
(C) LF1b: Bioclastic-peloidal packstone/grainstone with coral fragment encrusted by *Lithocodium–Bacinella*-like fabrics (sample ZR-3/5).
(D) LF1c: Bioclastic-peloidal grainstone to rudstone with unidentified agglutinated foram and *Redmondoides lugeoni* (sample ZRS-2).
(E) LF1c: Bioclastic-peloidal grainstone–rudstone with micritized fragments of *Cladocoropsis* encrusted by *Troglotella incrustans* (sample ZRS-0).
(F) LF2: Grainstone with aggregate grains, peloids small intraclasts (sample ZRS-16).
(G) LF3: Bioclastic (algal) wackestone–packstone with *Campbelliella striata* and *Salpingoporella annulata* (sample ZRS-14).
(H) LF4: Litho-intraclast floatstone–rudstone with *Campbelliella striata* (sample ZR2/3).
(I) LF5: Fenestral bioclastic-peloidal wackestone (sample ZR3/4).
(J) LF5: Fenestral bioclastic-peloidal mudstone–wackestone with ostracods and miliolids (sample ZRS-18).
(K) LF6: Subaerially exposed packstone–grainstone with brownish soil crust (calcrete) (sample ZRS-4).
(L) LF6: Calcrete with rhizoconcretions, clotted fabrics with peloid accumulations and alveolar-septal fabrics (sample ZRS-4).



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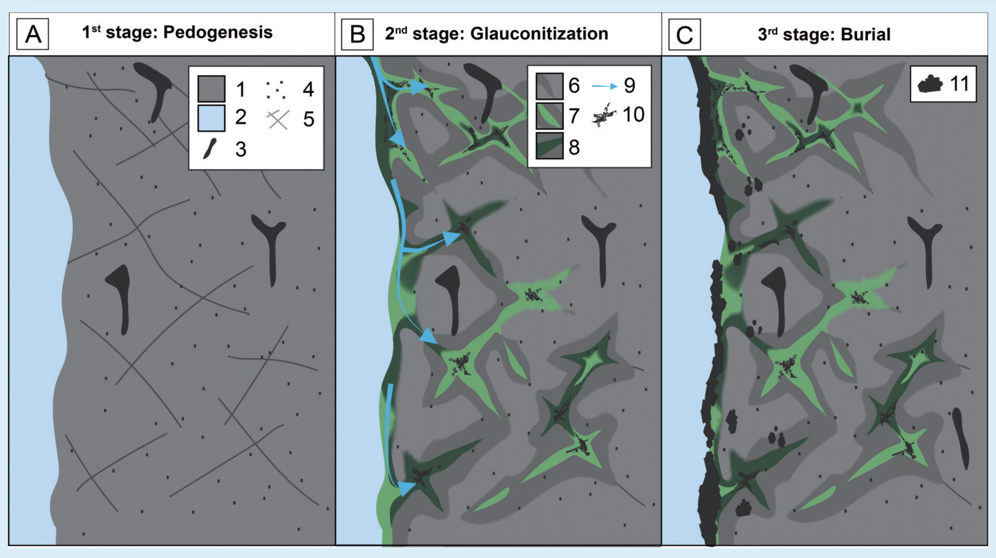
MICROFOSSIL ASSEMBLAGE FROM THE ZLATNI RT SECTION, KIRMENJAK Unit (MA2):

A fragments of *Clypeina sulcate*, *Campbelliella striata* (ZR-2/4),
B *Campbelliella striata* (ZR-2/4),
C, **D** *Salpingoporella annulata* (ZRS-14),
E Fragmenats of *Clypeina jurassica* (ZRS-14),
F, **G** *Favreina salevensis* (ZR-3/2, ZR-3/3).

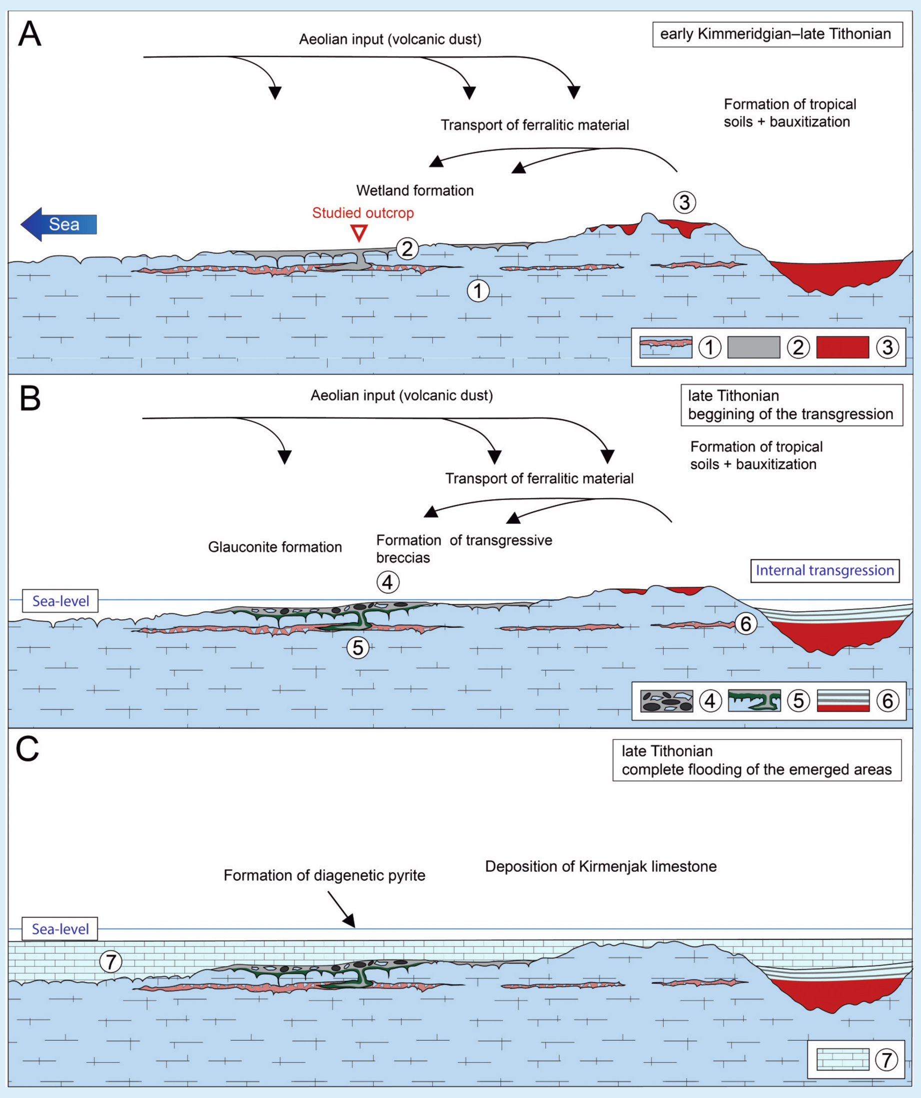


The different stages in the evolution of the Zlatni Rt palaeosol with the description of most important processes during each stage.

(A) Pedogenic stage: formation of pyritised roots (3), formation of pedogenic pyrite (4), pedogenic illite (1Md) and mixed layered illite-smectite.

(B) Glauconitization stage: microbially facilitated dissolution of clayey groundmass (6), formation of oxidized (7) and reduced (8) glauconite and ingression of marine porewater (9), precipitation of pyrite veins (10).

(C) Burial stage: precipitation of coarse euhedral pyrite (11); Legend: 1 – clayey groundmass, 2 – carbonate bedrock, 3 – pyritized roots, 4 – pedogenic pyrite, 5 – fractures, 6 – dissolution halo, 7 – oxidized glauconite, 8 – reduced glauconite, 9 – circulation of marine porewater, 10 – pyrite veinlets, 11 – diagenetic pyrite.



PALAEOENVIRONMENTAL EVOLUTION OF THE ZLATNI RT PALAEOSOL AND ITS SURROUNDING AREA

schematic representation

(A) Early Kimmeridgian to late Tithonian subaeral exposure phase marked with the **formation of bauxites together with tropical and wetland soils.**

(B) Late Tithonian – beginning of the transgression marked with the **formation and deposition of black pebbles, transgressive breccias coupled with glauconite formation.**

(C) Flooding of the emerged carbonate terrain marked with the deposition of Kirmenjak limestone and the cyclical cover sequence of the Rovinj bauxites (Šinkovec, 1974); 1 – karstified upper Oxfordian to lower Kimmeridgian units with subaerial exposure horizons, 2 – wetland soils, 3 – tropical soils and bauxites, 4 – transgressive breccias, 5 – glauconite formation, 6 – alternation of clays and brackish/freshwater limestones in the Rovinj deposit, 7 – upper Tithonian Kirmenjak unit.

CONCLUSION

A very well preserved palaeosol level at the Zlatni Rt locality documents one of unique terrestrial palaeoenvironments that existed during the late Kimmeridgian to early Tithonian in the northern part of the Adriatic Carbonate platform.

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