

Microfacies characteristics of carbonate cobble from Campanian of Slovenj Gradec (Slovenia): implications for determining the *Fleuryana adriatica* De Castro, Drobne and Gušić paleoniche and extending the biostratigraphic range in the Tethyan realm

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Abstract

A carbonate cobble was collected in a creek near Slovenj Gradec (Slovenia). It comprises *Trochactaeon* gastropods as well as foraminifera *Fleuryana adriatica* and *Cuneolina ketini* from a subtidal environment with agglutinated and porcelaneous benthic foraminifera. Packstone-grainstone of the structural type contains the abovementioned foraminiferal taxa, which are previously undetermined in this part of the Upper Cretaceous Tethyan realm. Stratigraphic data from this area, together with the determined microfossil assemblage of the carbonate cobble, indicate the upper part of Lower Campanian age, implying an extension of the *F. adriatica* and *C. ketini* stratigraphic range. The paleoniche within the Tethyan realm in which *F. adriatica* thrive is the shallowest part of the subtidal, close to peritidal conditions. It was developed on a relatively harder substrate that resulted from a laterally more pronounced paleorelief which enabled the shifting of hyaline benthic foraminifers towards the shallowest part of the subtidal. Their paleoniche is laterally absent from protected paleoenvironments with soft muddy substrate and a relatively high carbonate sedimentation rate, colonized with elevator rudists, as well as from relatively higher water energy paleoenvironments with completely hard grainstone-rudstone substrate.

Keywords:

Lower Campanian, *Fleuryana adriatica*, *Cuneolina ketini*, benthic foraminifera, paleoniche, carbonate deposits

1. Introduction

Near the Upper Cretaceous Slovenj Gradec locality, carbonate cobble rich in Gosau-type gastropod fauna (see **Figure 1**) was collected from a creek during previous field investigations (**Moro et al., 2016**). In a paper by **Mikuž et al. (2012)**, typical Gosau gastropods *Trochactaeon* cf. *goldfussi* (d'Orbigny) and *Trochactaeon giganteus* (Sowerby) were determined. To determine microfacies characteristics, a single thin section was also made from the carbonate cobble with trochactaeons. Within the agglutinated-porcelaneous foraminiferal assemblage, *Fleuryana adriatica* De Castro, Drobne, and Gušić was determined, biostratigraphically important for the Upper Campanian to Late Maastrichtian (**De Castro et al. 1994; Velić 2007; Fleury, 2014; Solak et al., 2017**). Determination of *F. adriatica* suggests a younger age of the eroded carbonate cobble compared with the nearby Slovenj Gradec succession, which has a chronostratigraphic age of the upper part of the Lower Campanian (**Moro et al., 2016**). Considering the other

Gosau-type sedimentary successions where Campanian acteonelloids always lie below rudists bearing limestones (**Sanders and Baron Szabo, 1997; Kollmann, 2014**), the biostratigraphical range of *F. adriatica* (Upper Campanian to Late Maastrichtian) (**Fleury, 2014; Solak et al. 2017**) needs to be reconsidered.

Latest Jurassic to Early Cretaceous orogen convergence (**Marton et al., 2017**) was thrust in the investigated area, which was overridden by a nappes system. Subsequently, large parts of the orogen were uplifted and subareally eroded (**Ratschbacher et al., 1989; Sanders et al., 2004**). A characteristic of the Late Cretaceous tectonics of the Alpine-Carpathian-Pannonian part of the Tethyan realm is the synchronous formation of Gosau-type sedimentary basins. Initial subsidence from Cenomanian to Campanian times within Gosau-type basins is associated with the development of a fluvial-lacustrine to shallow marine environment and the deposition of conglomerates, coal-bearing marls, siliciclastics rich in corals and acteonelloid gastropods and rudist limestones on the top of the succession (**Willingshofer et al., 1999**). As a result of the oblique orogenic convergence, the abovementioned deposits were mainly



Figure 1. Photographs (above, below and from the side) of the carbonate cobble

controlled by strike-slip extensional tectonics (Willingshofer et al., 1999; Faupl and Wagreich, 2000; Sanders et al., 2004). Emersion, regression, and Miocene transgression (Mioč, 1978; Brlek et al. 2016; Sremac et al., 2016; 2018; Bošnjak et al., 2017) hide Upper Cretaceous outcrops and make them hard to find for possible paleoreconstruction.

This paper aims to resolve the question of the stratigraphical disparity between the carbonate cobble and the Slovenj Gradec succession, as well as to determine the extension of the biostratigraphical range and paleoecological niche of the *Fleuryana adriatica* microfossil association for the Tethyan realm.

2. Geological background of *Fleuryana adriatica* and the associated microfossil assemblage

Upper Cretaceous Tethyan localities with findings of *F. adriatica* and associated microfossils are rare, and research studies range from the description of a new species and determination of associated microfossils to paleoenvironmental reconstructions and chronostratigraphical determinations.

In the Maastrichtian of the Latium area (Italy) (Chiocchini and Mancinelli, 2001), *F. adriatica* occurs within a vertical exchange of laminated dolomites and partly dolomitized mudstones/wackestones of “Discorbidae e Miliolidae biozone” (Chiocchini and Mancinelli, 2001; Chiocchini et al., 2012). Associated microfossils are mostly composed of Ostracoda, Miliolidae, and Charophyta, while *Laffiteina marsicana*

Farinacci, *Fleuryana adriatica* De Castro Drobne and Gušić and *Rhapydionina liburnica* Stache are present only in the upper part of the unit. The biostratigraphic age is determined as the uppermost Maastrichtian.

In Central Anatolia of Turkey, the paleoenvironment of *C. ketini* is described as reefal limestones with basal transgressive conglomerates, laterally passing into ophiolitic conglomerate, pelagic limestones, and limestones with chert nodules (Inan, 1988). The associated microfossil assemblage consists of *Loftusia minor* Cox, *L. harrisoni* Cox, *Siderolites calcitrapoides* Lamarck, *Omphalocyclus macroporus* (Lamarck), *Orbitoides media* (D’Archiac), *O. apiculatus* Schlumberger, *Torreina torrei* Palmer, *Pseudomphalocyclus blumenthali* Meriç, *Cuneolina* sp. and *Operculina* sp. According to the associated hyaline larger benthic foraminifers, the chronostratigraphic range of *C. ketini* is determined as the Upper Maastrichtian (Inan, 1988).

In Haftoman Formation of Central Iran (Wilmsen et al., 2018), representing an eperic carbonate platform, *C. ketini* thrives in a low- to moderate-energy paleoenvironment of an outer platform characterized by bioclastic rudstone/floatstone/boundstone. Associated fossils are *Nezazatinella* sp., textularids, miliolids, coiled recumbent rudists, echinoderms, and ostracods green algae (*dasyclad/Cymopolia?* sp.). This paleoenvironment is in a lateral exchange with (1) bafflestones with small elevator rudists and red algae, (2) bioclastic rudstones with orbitoids, miliolids, inoceramids, rudists fragments, udotecan green algae, red algae, and gastropods, and (3) bindstone with red algae, fragments of corals, bryozoans, rudists, thick-shelled bivalves, *Orbitoides media* (D’Archiac), *Praesiderolites douvillei* Wannier, and miliolid foraminifera. The presence of hyaline larger benthic foraminifers suggests a biostratigraphic range of *C. ketini* as Middle to Late Campanian (Wilmsen et al., 2018).

In western Central Taurides, the paleoenvironment of *F. adriatica* is peritidal of a restricted platform without any siliciclastic input and the occasional influence of more open water circulation (Solak et al., 2017). The associated microfossil assemblage consists of *Moncharmontia apenninica* (De Castro), *Murgeina* sp., *Arenobulimina* sp., *Bolivinopsis* sp., *Rotalispira scarsellai* (Torre), *Nezazatinella* sp., *Nezazata* spp., *Minouxia* sp., *Stensioeina surrentina* Torre, *Accordiella conica* Farinacci, *Scandonea samnitica* De Castro, *Murciella* gr. *cuvillieri* Fourcade, *Biconcava* sp., *Pseudocyclamina sphaeroidea* Gendrot, Rhapydionininae, *Cuneolina* gr. *pavonia* D’Orbigny, discorbids, miliolids, Nubeculariidae, algae (*Thaumatoporella parvovesiculifera* Raineri, Dasycladacea and charophyta oogonia), cyanobacteria *Gahkumella huberi* Zaninetti, *Decastronema kotori* Radoičić, and ostracods. Associated macrofossils are rudists, mainly radiolitids and gastropods. The biostratigraphic range is from the Upper Campanian (smaller-size specimens) to the Maastrichtian (identical to typical specimens) (Solak et al., 2017).



Figure 2. Microphotographs of microfacies. a.- Laminated and partly bioturbated packstone-grainstone; b. - Packstone-grainstone with rare fragments of macrofossils; c, d. - Floatstone rudstone with fragments of macrofossils, abundant miliolids and *Dicyclina* (d); e, f. - Small gastropod within floatstone – rudstone with miliolids and *Nezazatinella* (e)

In the Zagros zone in SW Iran (Schlagintweit and Rashidi, 2016), *F. adriatica* thrives in foraminiferan-dasycladacean soft substrate wackestones-packstones and the very low water energy of the shallow protected inner platform area (lagoon). The associated microfossil assemblage consists of *Omphalocyclus macroporus* (Lamarck), *Spirolina farsiana* Schlagintweit and Rashidi, *Loftusia* spp., *Accordiella tarburensis* Schlagintweit and Rashidi, *Dicyclina schlumbergeri* Munier-Chalmas, *Broeckinella arabica* Schlagintweit and Rashidi, *Gyro-*

conulina columellifera Schroeder & Darmoian, *Neobalkhania bignoti* Cherchi, Radoičić, & Schroeder, and *Laffiteina monodi* Marie. Dasycladales are represented by *Pseudocymopolia anadyomenea* (Elliott), *Pseudocymopolia?* sp., and *Salpingoporella pasmanica* Radoičić. Rudists are present through broken shells within packstone/grainstone-floatstone/rudstones. Besides the abovementioned taxa, in the shallowest, upper part of the succession, the foraminiferal association comprises: *Antalya korayi* Farinacci & Köylüoğlu, *Cuneolina* sp.,

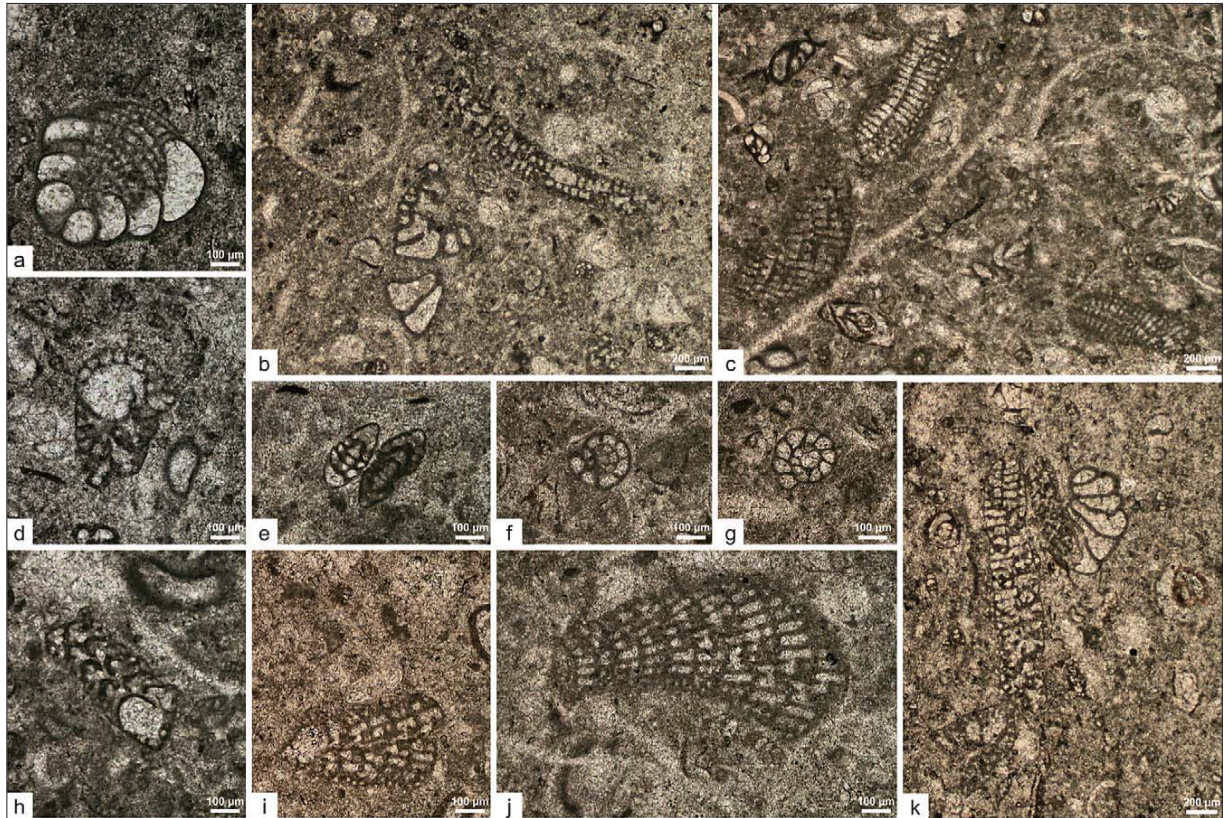


Figure 3. Microphotographs of *C. ketini* and associated benthic foraminifera. a. - *Accordiella conica* Farinacci; b, h., - *Dicyclina schlumbergeri* Munier-Chalmas and *Nezzazatinella* sp (b); c. - *Cuneolina parva* Henson; d, k- *Cuneolina* sp.; i, j. - *Cuneolina ketini* Inan; e - *Moncharmontia compressa* (De Castro); f, g. - *Moncharmontia appenninica* (De Castro)

Dictyoconella minima Henson, *Elazigella?* sp., *Fallotia* aff. *jacquoti* Douvillé, *Loftusia harrisoni* Cox, *Loftusia coxi* Henson, *Loftusia morgani* Douvillé, *Mississippina? binkhorsti* (Reuss), *Nezzazatinella? cf. picardi* (Henson), *Neobalkhania bignoti* Cherchi, Radoičić & Schroeder, *Elphidiella? cretacea* (Pérébaskine), Orbitolinidae indet., *Tarburina zagrosiana* Schlagintweit, Rashidi & Barani, and *Valvulina? sp.* The biostratigraphic age is determined as the Maastrichtian (**Schlagintweit and Rashidi, 2016**).

At localities from the Gavrovo-Tripolitza zone (Greece) (**Fleury, 2014**), *F. adriatica* thrive within an Upper Campanian to Late Maastrichtian inner platform paleoenvironment characterized by the vertical exchange of subtidal and peritidal conditions together with *Cuvillierinella salentina* Papetti & Tedeschi, *Murciella cuvillieri* Fourcade, *Murciella renzi* Fleury, *Cyclopseudedomia smouti* Fleury, *C. hellenica* Fleury, *C. klokovaensis* Fleury, and *Rhapydionina dercourtii* Fleury. In rare places, this paleoenvironment is in a lateral exchange with deeper, more open subtidal conditions with hyaline benthic foraminifera (**Fleury, 2014**).

In the Gosau-type sedimentary succession, *C. ketini* and *F. adriatica* were first mentioned by **Sanders et al. (2004)** from the Campanian deposits of the Central Alps.

The paleoenvironment of *C. ketini* and *F. adriatica* is determined as an external part of the platform. Associated microfauna comprise *Accordiella conica* Farinacci, *Bolivinopsis* sp., *Calveziconus cf. leacalvezae* Caus & Cornella, *Cuneolina* sp., *Dicyclina schlumbergeri* Munier-Chalmas, *Fleuryana* sp., *Lenticulina* sp., *Marssonella oxycona* (Reuss), *Minouxia* sp., *Mississippina* sp., *Orbitoides* sp., *Pseudosiderolites* sp., and *Reticulinella fleuryi* Cvetko, Gušić & Schroeder. Associated macrofossils are Hippuritidae (*Vaccinites vesiculosus* (Woodward), *V. ultimis* (Milovanović), *Hippurites colliciatius* Woodward, Radiolitidae (*Radiolites cf. angeiodes* (Lapeirouse), *Pseudopolyconites* sp. and *Joufia* sp.) as well as fragments of corals, echinoids, coralline algae, brachiopods, non-rudist bivalves, bryozoans, skeletal sponges, and calcareous green algae. The chronostratigraphic range is determined as Late Campanian (**Sanders et al., 2004**).

At Maastrichtian deposits on Brač Island, the paleoenvironment of *F. adriatica* (**De Castro et al., 1994; Korbar et al., 2017**) is subtidal with *Bolivinopsis* sp., *Laffiteina mengaudi* (Astre), primitive “agglutinated” conical foraminifera, abundant miliolids, nezzazatids, Discorbidae, Rotaliidae, Ophthalmidiidae, Valvulinidae, associated with Ostracoda, remains of algae *Thaumatoporella parvovesiculifera* (Raineri) and charophytes, requieniid rudists *Apricardia* sp., and rare planktonic fo-

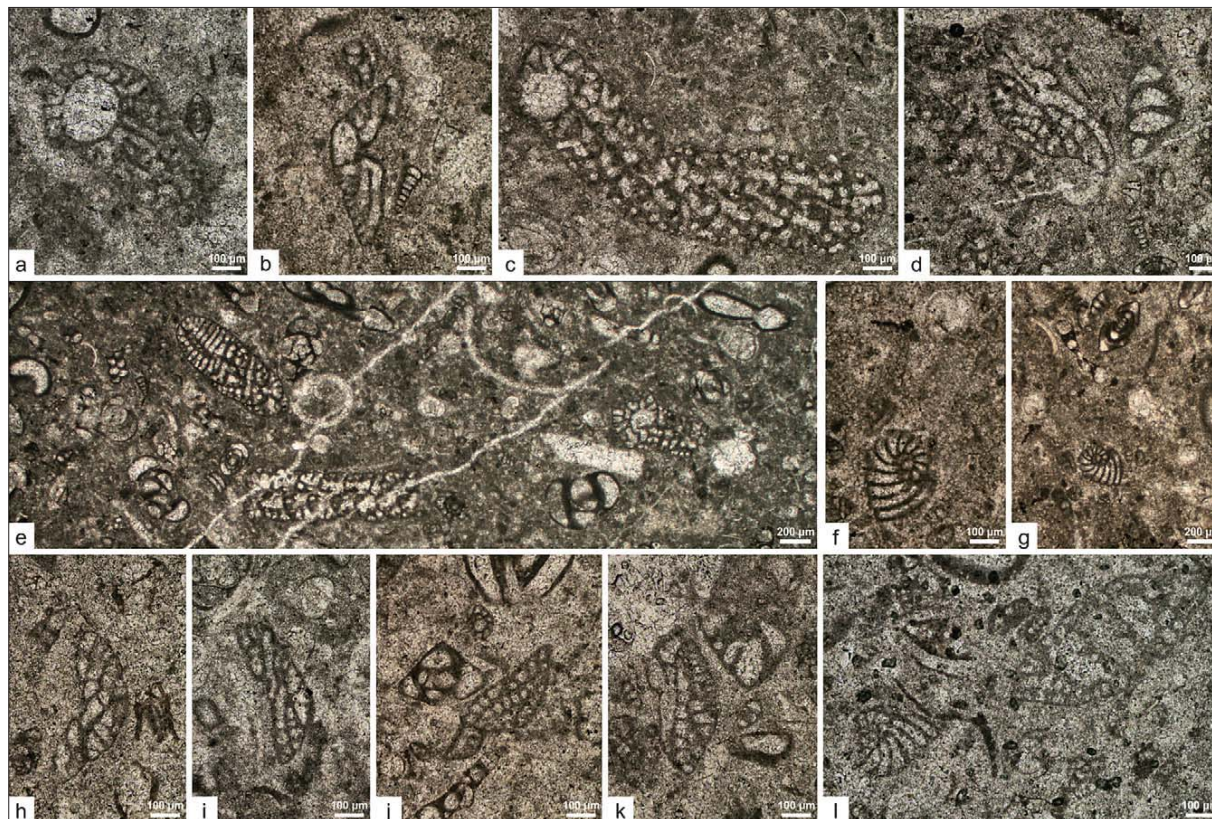


Figure 4. Microphotographs of associated benthic foraminifers. a, e. - *Dicyclina schlumbergeri* Munier-Chalmas; b, d, h. - *Dictyopselloides cuvillieri* (Gendrot); c. - *Cuneolina parva* Henson; f, g, l. - *Peudocyclammina sphaeroidea* Gendrot and *F. adriatica* (g); i, j, k. - *Dictyopsella kiliani* Munier-Chalmas

raminifera and pithonellid calcispheres (Korbar et al., 2017). The chronostratigraphic range is determined by comparison with the type-locality (De Castro et al., 1994), as well as the Sr isotope stratigraphy data of Steuber et al. (2005), which confirm the terminal Maastriichtian age.

Within the carbonate facies of the Slovenj Gradec succession, characterized by packstone-grainstone and floatstone-rudstone textural types, completely preserved macrofossils are rare and consist of small radiolitic individuals in the succession's lower part. Fossil assemblage comprises the following agglutinated and porcellaneous foraminiferal species: *Accordiella conica* Farinacci, *Calveziconus* cf. *lecalvezae* Caus & Cornella, *Scandonea samnitica* De Castro, *Dicyclina schlumbergeri* Munier-Chalmas, *Dictyopsella kiliani* Munier-Chalmas, *Cuneolina pavonia* D'orbigny and *Peudocyclammina sphaeroidea* Gendrot (Moro et al., 2016). Determined benthic foraminifers indicate the *Calveziconus* cf. *lecalvezae* subzone (Frijia et al., 2015), which chronostratigraphically corresponds to the upper part of the Lower Campanian (Moro et al., 2016). According to the benthic fossil assemblage and textures, the depositional environment can be interpreted as shallow subtidal with moderate water energy.

3. Methods

Thin-section analyses of the limestone cobble as well as the Slovenj Gradec succession include textures and skeletal components and biostratigraphic characteristics. Visual percentage charts were used to estimate the relative abundance of grains (Baccelle and Bosellini, 1965; in Flügel, 2004), and emphasize any differences in microfacies of the carbonate cobble as well as microfacies differences between the cobble and the Slovenj Gradec succession. The taxonomic study of benthic foraminifers is based on randomly orientated sections of tests with observable morphological characteristics of different species. The taxonomic framework used to identify species builds on papers by Inan (1988), De Castro et al. (1994), and Velić (2007).

4. Results

4.1. Microfacies characteristics and chronostratigraphy of the carbonate cobble

The studied cobble is entirely composed of carbonate, with dimensions 20x10 cm. At the macroscopic level, it shows a uniform texture without any visible structure.

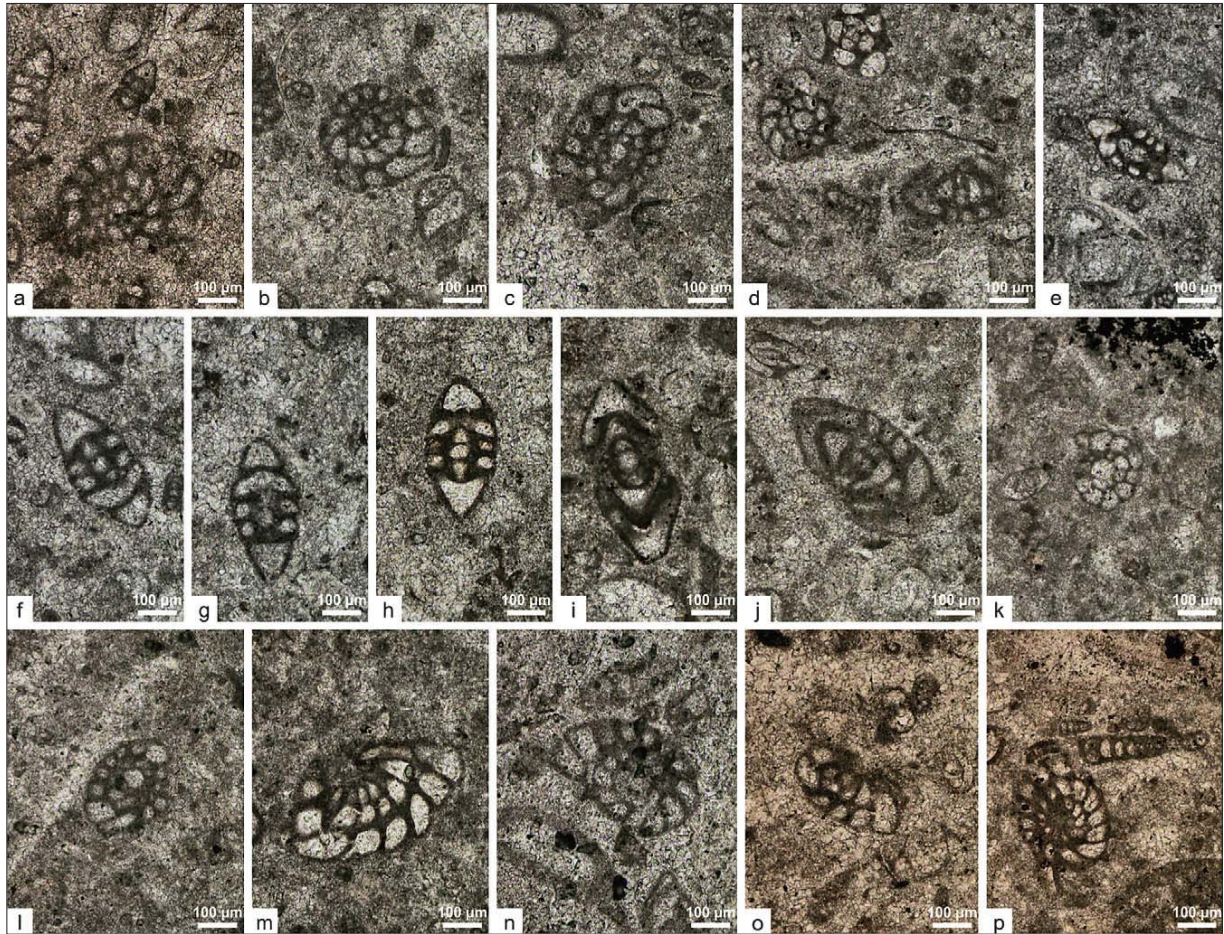


Figure 5. *Fleuryana adriatica*. Axial (e, f, g, h, i), equatorial (a, b, d, k, l), and oblique (c, j, m, n, o, p) sections

Macroscopic two cross-sections of Gosau-type gastropods are visible (see **Figure 1**), determined as *Trochactaeon giganteus* (Sowerby) and *Trochactaeon* cf. *goldfussi* (d'Orbigny). A detailed description of the mollusk fauna is given in **Mikuž et al. (2012)**. Thin sections, 56 in total, reveal shallow-water non-skeletal and skeletal particles, including pellets, peloids, benthic foraminifers, and fragments of macrofossils, presented through two textural types: packstone-grainstone and floatstone-rudstone (see **Figure 2**), which appears randomly throughout the thin sections. Packstone-grainstone characterizes bioclasts (10-20%) with similar frequencies of shallow water macrofossil fragments (5-10%) and whole microfossils (5-10%). Within the microfossil assemblage, miliolids (2.5-5%) predominate over cuneolinas and rare dicyclinans (1 to 2.5%). The frequency of small nezzazatids (*Fleuryana* and *Moncharmontia*: **Loeblich and Tappan, 1988**; **Kaminski, 2004**, included within the family Charentiidae) ranges up to 1%. The frequency of *Nezazatinella* is also up to 1%, as well as test sections of undetermined benthic forams (see **Figure 4l**) with a frequency of up to 1%. Within estimated frequency ranges, some foraminifera species are present rarely:

Accordiella conica and *Moncharmontia compressa* represented by a single specimen, *Peudocyclammina sphaeroidea* and *Cuneolina ketini* by two specimens, and *Moncharmontia appenninica* by three specimens.

The microfossil assemblage is composed of the following agglutinated and porcellaneous foraminiferal species (see **Figures 3 to 7**): *Accordiella conica* Farinacci, *Cuneolina ketini* Inan, *Fleuryana adriatica* De Castro, Drobne & Gušić, *Dicyclina schlumbergeri* Munier-Chalmas, *Dictyopsella kiliani* Munier-Chalmas, *Dictyopselloides cuvillieri* (Gendrot), *Cuneolina parva* Henson, *Moncharmontia appenninica* (De Castro), *M. compressa* (De Castro) and *Peudocyclammina sphaeroidea* Gendrot.

The determined benthic foraminifers as well as the microfossil assemblage of the nearby Slovenj Gradec section indicate the *Calveziconus* cf. *lecalvezae* subzone (**Frija et al., 2015**), which chronostratigraphically correspond to the upper part of the Lower Campanian (**Moro et al., 2016**) (see **Figure 8**). According to the benthic fossil assemblage, structures, and textures, the depositional environment can be interpreted as shallow subtidal with moderate water energy.

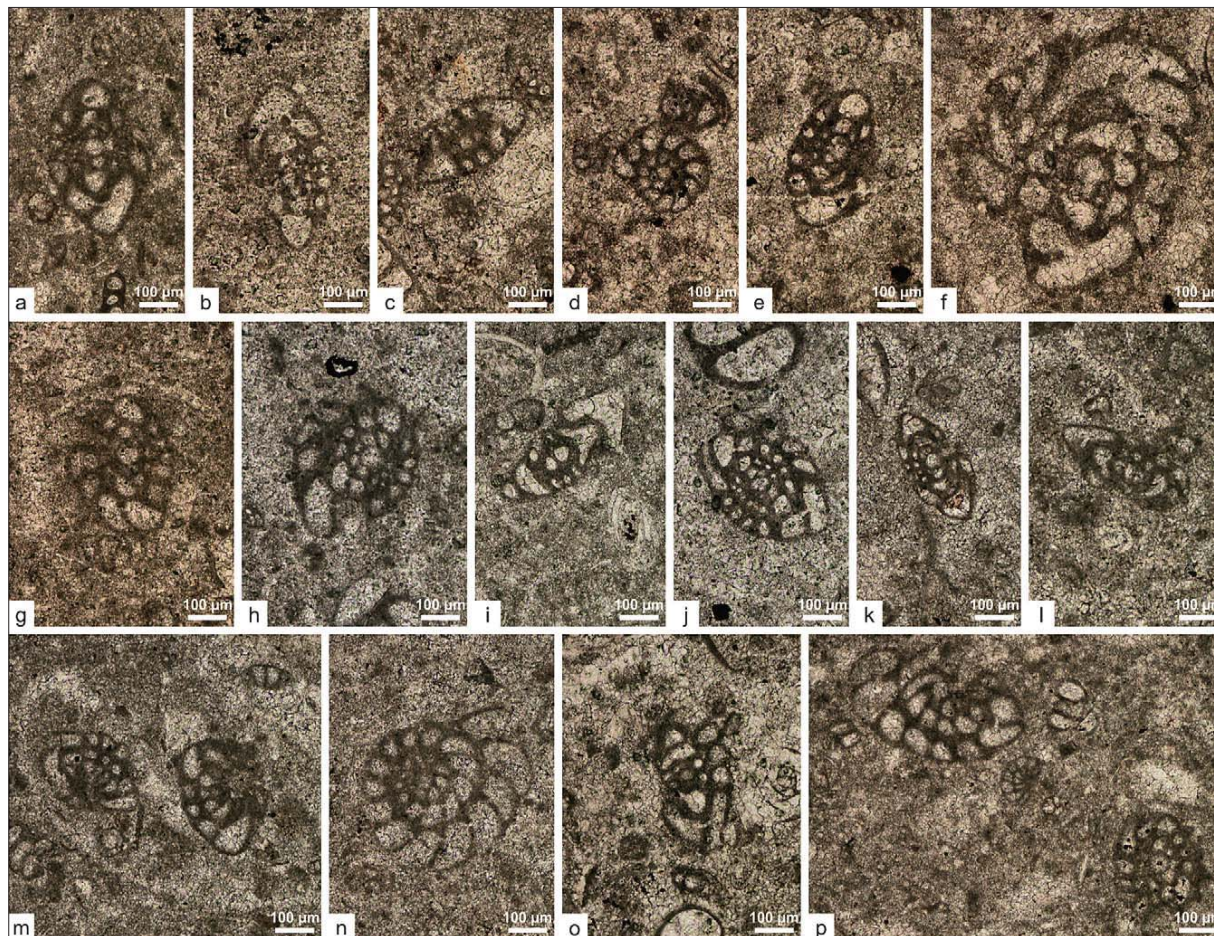


Figure 6. *Fleuryana adriatica*. Axial (n), equatorial (d, i, k) and oblique (a, b, c, d, e, f, g, h, j, l, m, o, p) sections

4.2. Microfacies characteristics of the Slovenj Gradec succession

The carbonate facies of the Slovenj Gradec succession are packstone-grainstone and floatstone-rudstone, with both lithotypes distributed randomly throughout the succession. Completely preserved macrofossils are rare and consist of small radiolitid individuals up to 4 cm in height and 0.8 cm in diameter in the succession's lower part. Thin sections, 28 in total, reveal shallow-water non-skeletal and skeletal particles, including peloids, benthic foraminifers, and fragments of macrofossils. Within the packstone-grainstone, the estimated frequency of bioclasts is 2.5 to 20%, where fragments of macrofossils are present with a frequency of 5 to 20%, while microfossils are present with a frequency of up to 2.5%, with a random domination of miliolids or cuneolinas and rare dicyclinids. Other microfossils (such as small nezazatinellids, *Accordiella conica*, *Calveziconus* cf. *lecalvezae*, *Dictyopsella kiliani* and previously undetermined *Nezzazatinella* sp.) are present in small numbers, from 1 to 4 specimens. Within the floatstone-rudstone variates, the estimated frequency of bioclasts, rarely

lithoclasts, is between 50 and 60%. Fragments of radiolitids predominate while microfossils are present with a small number of miliolids and nezazatinids.

5. Paleoniche of *Fleuryana adriatica*

The subtidal carbonate paleoenvironment with "typical" biostratigraphically important, mostly epiphytic (Murray, 2006), porcelaneous-agglutinated-hyaline foraminifers (such as *Scandonea*, *Moncharmontia*, *Accordiella*, *Calveziconus*, *Dicyclina*, *Dictyopsella*, *Orbitoides*, *Praesiderolites*) and rudists, appears at the Tethyan realm during the Campanian-Maastrichtian in textural types, ranging mostly from floatstone-rudstone to wackestone-packstone (Gušić and Jelaska, 1990; Moro et al., 2002, 2016; Chicchini and Mancinelli, 2001; Steuber et al., 2005; Velić, 2007; Schlagintweit and Rashidi, 2016; Solak et al., 2017). Although there are 10 cycle boundaries, i.e. beginnings and terminations of sequences towards the end of the Cretaceous (see Figure 8), which could allow the possibility of the development of shallow-water paleoenvironments with the above-mentioned benthic foraminifers, probably a tectonic

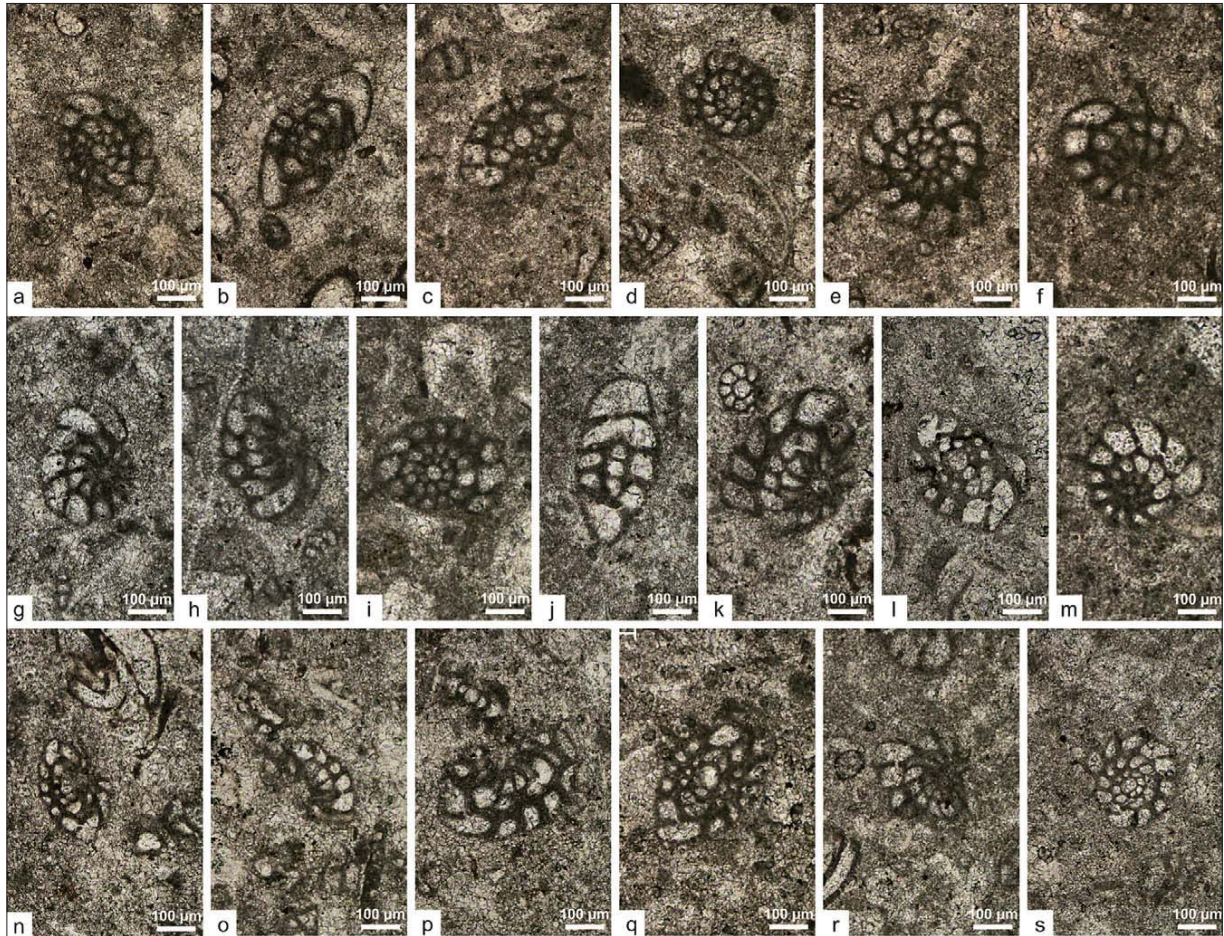


Figure 7. *Fleuryana adriatica*. Axial (b, j), equatorial (a, c, d, e, g, i, l, m, r, t) and oblique (f, h, k, n, o, p, s) sections

overprint of the sea-level change resulted in the regional development of paleogeographically and biostratigraphically more or less extended subtidal paleoenvironments during the Campanian and Maastrichtian (Gušić and Jelaska, 1990; De Castro et al., 1994; Chiocchini and Mancinelli, 2001; Moro et al., 2002, 2016; Vlahović et al., 2005; Steuber et al., 2005; Steuber and Schüter, 2012; Schlagintweit and Rashidi, 2016; Korbar et al., 2017; Solak et al., 2017). Somewhere within that paleoenvironment is paleoniche where *F. adriatica* thrived.

Similarly to the distribution of benthic foraminifers (Hottinger, 1983), elevator rudist morphotypes thrive in soft muddy substrate environments, which range from the shallowest subtidal with a pure radiolitid assemblage over a relatively deeper (absence of shallowing upward cycles) subtidal with a mixed radiolitid-hippuritid assemblage towards a subtidal with relatively rare vaccinitid individuals (Gušić and Jelaska, 1990; Moro, 1997; Moro and Čosović, 2000; Moro et al., 2002, 2016; Steuber et al., 2005; Korbar et al., 2009). Exceptions are radiolitids, which could also thrive in shallow-water, moderate-energy paleoenvironments as clingers (Ross and Skelton, 1993; Skelton and Gili, 2002).

The rudist assemblage, which thrives in a subtidal paleoenvironment as elevators or occasionally as clingers (radiolitids) (Skelton and Gili, 2002) with mostly epiphytic porcelaneous-agglutinated foraminifers (Murray, 2006), could also have laterally overlapped with hyaline foraminifers (Gušić and Jelaska, 1990; Sanders et al., 2004; Schlagintweit and Rashidi, 2016; Solak et al., 2017; Wilmsen et al., 2018) on a harder substrate (Hottinger, 1983).

The presence or absence of *F. adriatica* and associated microfossils within that kind of shallow subtidal environment (Inan, 1988; De Castro et al., 1994; Chiocchini and Mancinelli, 2001; Sanders et al., 2004; Velić, 2007; Fleury, 2014; Schlagintweit and Rashidi, 2016; Solak et al., 2017; Korbar et al., 2017; Wilmsen et al., 2018) (see Figure 9) is presumably the result of the lateral presence of a relatively harder substrate (Hottinger, 1983), more adequate for epiphytic benthic foraminifers (Murray, 2006). This lateral variation could be the result of slightly pronounced uplifts or relatively steeper parts of the paleorelief within a more open subtidal. This kind of substrate (sea floor) even includes peritidal paleoenvironments with shallowing upward cy-

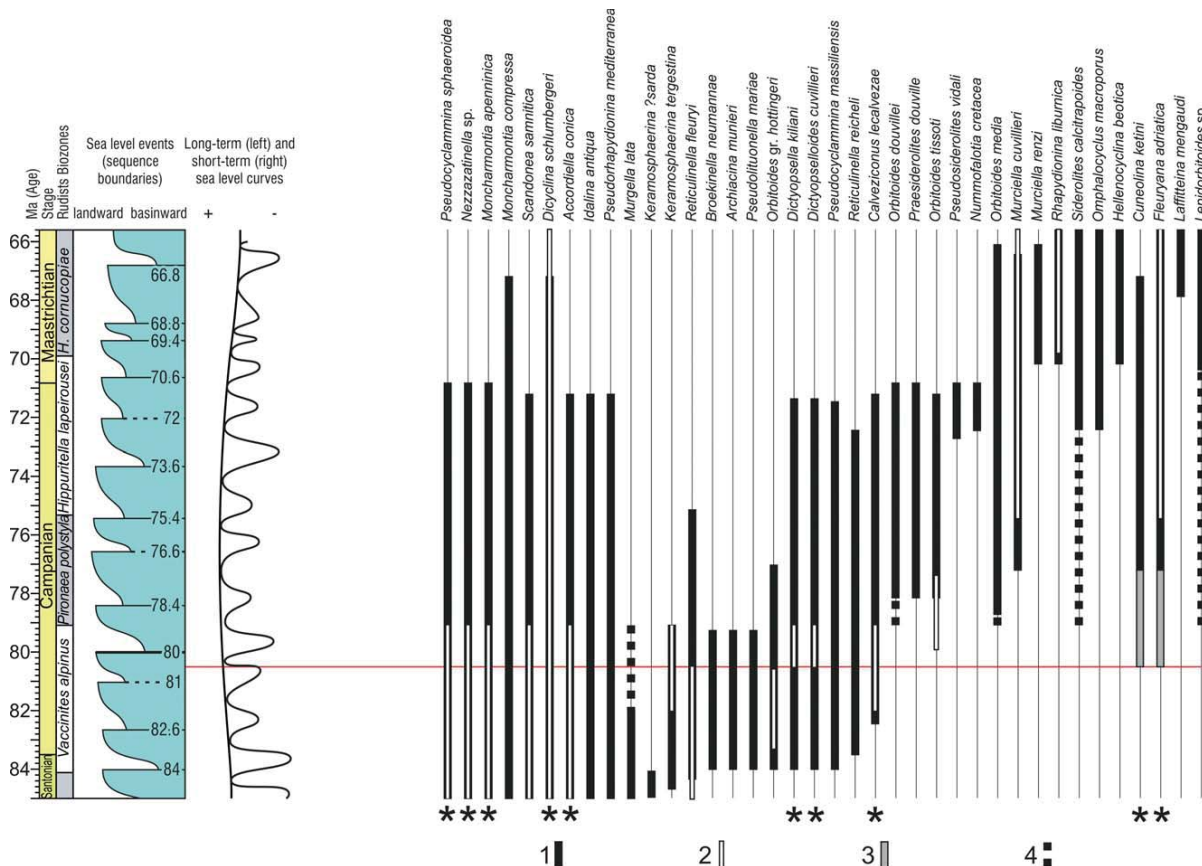


Figure 8. Biostratigraphic and chronostratigraphic ranges of microfossils. Legend: 1 – Biostratigraphic ranges after Velić (2007), Solak et al. (2017) and Wilmsen et al. (2018). 2 – Chronostratigraphic ranges after Steuber et al. (2005), Frijia et al. (2015) and Moro et al. (2016). 3 – Extended biostratigraphic ranges of *F. adriatica* and *C. ketini* (this paper). 4 – Chronostratigraphically extended ranges on genera level after Moro et al. (2016). The horizontal line indicates the beginning of the transgression of the Slovenj Gradec succession (after Moro et al. 2016). Sea-level curve and sequences after Haq (2014). Rudist biozones after Steuber and Schlüter (2012). Microfossils determined in the carbonate cobble and the S. Gradec succession are marked with a star.

cles and a sea floor hard enough for the presence of hyaline benthos (Schlagintweit and Rashidi, 2016; Solak et al., 2017). The moderate hydrodynamically energized packstone-grainstone texture enables the shifting of epiphytic (Murray, 2006) hyaline foraminifers towards shallower parts of the subtidal (Hottinger, 1983; Hohenegger, 1999; Hohenegger, 2000) (see Figure 9) where they overlap with the porcelaneous-agglutinated benthic assemblage (Velić, 2007). Similarly, sediment dwelling rudists are pushed towards the mud-prevailing shallower parts of the subtidal (Sanders et al., 2004; Schlagintweit and Rashidi, 2016; Solak et al., 2017; Wilmsen et al., 2018). Moreover, *F. adriatica* paleo-niche is laterally absent from protected paleoenvironments with soft muddy substrate and a relatively high carbonate sedimentation rate, colonized with elevator radiolites and hippuritids (Gušić and Jelaska, 1990; Chiocchini and Mancinelli, 2001; Wilmsen et al., 2018) as well as from the relatively higher water energy paleoenvironments characterized by hard grainstone-

rudstone substrate (Gušić and Jelaska, 1990; Schlüter et al., 2008; Wilmsen et al., 2018).

Besides the type of substrate, salinity, turbidity, and nutrient supply could also be controlling factors for the macro and microfauna of the Upper Cretaceous Tethyan realm with subtropical conditions (Camoïn et al., 1993). The abundant presence of miliolids (De Castro et al., 1994; Chiocchini and Mancinelli, 2001; Solak et al., 2017; Korbar et al., 2017) and gastropods, typical of shallow-water environments, could also indicate elevated (Murray, 2006) meso to euhaline conditions (Kollmann, 1965; Herm, 1977; Sohl and Kollmann, 1985). The lateral presence of brackish to fresh-water Characean algae (Korbar et al., 2017) suggests at least the occasional influence of fresh water, while the rare planktonic foraminifera and calcispheres indicate a more open depositional environment (Korbar et al., 2017; Solak et al., 2017). Their presence could exclude salinity as a limiting factor. Turbidity is less likely a controlling factor within moderate-energy shallow-water environments

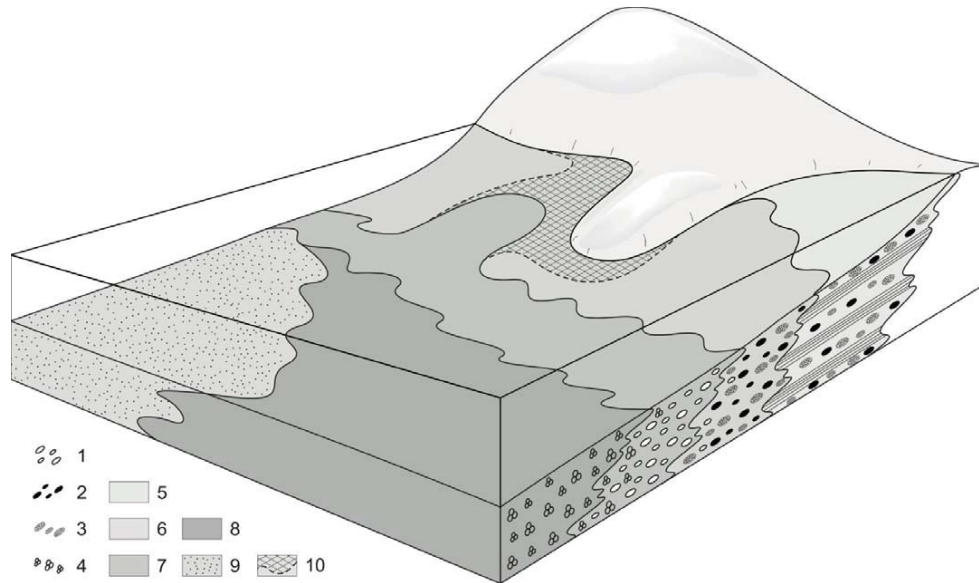


Figure 9. Block diagram with reconstructed paleoniche of *Fleuryana adriatica*. Not to scale. Explanation: 1-3 benthic foraminifers: 1.- hyaline, 2.- porcelaneous, 3.- agglutinated, 4.- planktonic foraminifers, 5-9 depositional environments: 5.- peritidal, 6.- shallow subtidal, 7.- deeper subtidal, 8.- deepwater (pelagic), 9.- deepwater marly sediments, 10.- paleoniche of *F. adriatica*.

where gastropods, rudists, and corals once thrive (Sanders and Baron Szabo, 1997; Moro et al., 2016). In shallow-water environments of the Tethyan realm, rudists predominate as carbonate producers, generally indicating oligotrophic conditions (Gili et al., 1995). Exceptions are successions with the presence of red algae (Sanders et al., 2004; Wilmsen et al., 2018) which may indicate, together with the large benthic foraminifers, a moderate nutrient supply (Acker and Leptoukh, 2007; Coletti et al., 2017). Although the rare local siliciclastic intercalations could reinforce nutrition as a controlling factor, as well as fragments of bryozoans (more eutrophic), corals and rudists as predominantly oligotrophic carbonate producers (Gili et al., 1995), together with the microfossil assemblage (Murray, 2006), could exclude nutrition as a controlling factor.

The presence of *F. adriatica* and other biostratigraphic important benthic foraminifers (see Figure 8) gave them the opportunity to be incorporated into a chronostratigraphic framework of rudist biozones and used in cases where fossil remnants of rudists are laterally absent.

6. Conclusions

The following conclusions may be drawn based on the microfacies analysis of the cobble from Slovenj Gradec, as well as the correlation with other localities comprising *F. adriatica* and associated microfossils within the Tethyan realm.

1. The paleoniche in which *F. adriatica* thrive is the shallowest part of the subtidal, close to peritidal conditions. The relatively harder substrate is a result of the

laterally more pronounced paleorelief. It is rare and narrow, resulting from the shifting of hard grainstone-rudstone substrate with hyaline benthic foraminifers towards the shallowest part of the subtidal. Moreover, it is laterally absent from protected paleoenvironments with soft muddy substrate and relatively high carbonate sedimentation rate, as well as from relatively higher water energy, more open paleoenvironments with hard grainstone-rudstone substrate.

2. According to the benthic microfossils and determined chronostratigraphic range of nearby successions (obtained by previous investigations), the regional biostratigraphic range of *F. adriatica* and *C. ketini* could be extended to the upper part of the Lower Campanian (80.5 Ma). Incorporated in rudist biozones and together with the ranges of other stratigraphically important foraminifers, these extended ranges could be useful in cases where fossil remnants of rudists are laterally absent.

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