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Mid Cretaceous orbitolinid (Foraminiferida) record from the islands of Cres and Lošinj (Croatia) and its regional stratigraphic correlation

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The mid Cretaceous shallow-water limestones on the islands of Cres and Lošinj contain abundant and diversified orbitolinid foraminifera. A biostratigraphy, based on the orbitolinid taxa and their chronostratigraphic interpretation, is proposed for the Aptian, Albian and Cenomanian deposits in the area investigated. Four orbitolinid biozones have been recognized: (1) *Palorbitolina lenticularis* Taxon-Range Zone in the Lower Aptian; (2) *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone in the Lower Albian, the body of strata being characterized by a distinctive assemblage of *Orbitolina* (*Mesorbitolina*) *texana*, *O.* (*M.*) *subconcava*, *O.* (*M.*) *parva* and *O.* (*M.*) *pervia*; (3) *'Valdanchella' dercourti* Taxon-Range Zone in the basal Upper Albian; and (4) *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone in the Lower–Middle Cenomanian, a body of strata in which the abundance of the species *Orbitolina* (*Conicorbitolina*) *conica* is significantly greater than is usual in the adjacent parts of the section, regardless of either association or range. The established biozones on the islands of Cres and Lošinj are correlated with orbitolinid biozonations and orbitolinid stratigraphic distributions in the adjacent areas, with emphasis on the Karst Dinarides.

Key Words: mid Cretaceous (Aptian, Albian, Cenomanian); biostratigraphy; orbitolinids; Foraminiferida; Dinarides; Croatia.

1. Introduction

The islands of Cres and Lošinj are situated in the northern Adriatic area (Figure 1). Cretaceous deposits on these islands range in age from early Neocomian to Senonian. They were deposited in a predominantly shallow subtidal environment that was flooded by short-lived pelagic episodes in the Late Cretaceous (Fuček *et al.*, 1995).

During work on the geological map of the Republic of Croatia (1:50 000 scale) the mid Cretaceous shallow-water limestones on the islands of Cres and Lošinj have been found to contain a rather rich foraminiferal association in which orbitolinid forms are especially abundant and diverse. A biostratigraphy, based exclusively on orbitolinid taxa and their chronostratigraphic position, is proposed for the mid Cretaceous deposits on these islands. The biozones are correlated with corresponding zones already established for the Karst Dinarides.

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2. Material

Field investigations of the orbitolinid bearing strata revealed both lateral and vertical facies and thickness variability in the study area. Hence, the stratigraphic distribution of the orbitolinids has required detailed examination of four sections in geographically separated localities, namely Dragozetići (CDB), Petrovski dolac (CPD) and Baldarin (CB) on the island of Cres and Punta (LP) on the island of Lošinj (Figure 1). Additional data were obtained from three other sections on Cres, namely Dragozetići (CDC), Križice (CK) and Punta Križa (PK).

3. Biostratigraphic description and interpretation

3.1. Palorbitolina lenticularis *Taxon-Range Zone*

The sediments underlying the first orbitolinid zone comprise well-bedded alternations of Barremian mudstones and peloid wackestones/packstones with rare benthonic foraminifera and calcareous algae (Figure

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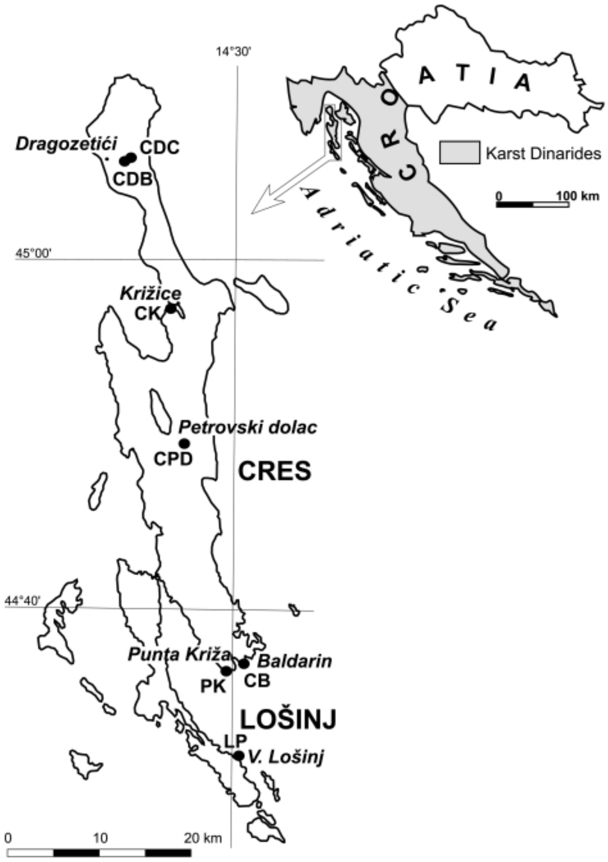


Figure 1. Location map of the sections examined. For explanation of acronyms, see text (Material).

2). They were deposited in a shallow subtidal environment of variable water-energy. Owing to synsedimentary tectonics they were brecciated and intermittently exposed to subaerial weathering. Although microfossils are not very frequent, numerous species have been determined within these strata. The most important are the calcareous algae (Dasycladales) *Salpingoporella muehlbergii* and *S. melitae*, both of which are index fossils for the Barremian in the Dinarides (for authors of these and all other taxa referred to, see Appendix), and *Clypeina solkani*, which ranges in age from Hauterivian to mid-Late Barremian (Sokač, 1996). The total thickness of these deposits (including transitional Hauterivian–Barremian strata) is 130 m. They are overlain by an alternation of yellowish mudstone, wackestone and *Bacinella* oncoid floatstone, which is the typical lithology of the oldest orbitolinid-bearing strata throughout the Dinarides.

The *Palorbitolina lenticularis* Taxon-Range Zone is the body of strata representing the determined range of stratigraphic occurrence of the species *Palorbitolina lenticularis* in the area investigated. These strata correspond to the horizon which is in the wider area of the Karst Dinarides known as Lower Orbitolina Beds, as defined by Velić & Sokač (1976). *Palorbitolina* beds are known from all over Tethys (Vilas *et al.*, 1995) where they are commonly used for mapping purposes, as in the study area.

The observed strata exhibit both vertical and lateral facies variations and thicknesses ranging from 25 to 46 m. They were studied in detail at two localities (Figures 3, 4). The principal feature is the abundance of *Palorbitolina* (subfamily Orbitolininae). On the north of the island of Cres it occurs together with the alga *Bacinella irregularis*. The association of these two taxa is very common in Lower Aptian deposits in the northwest of the Adriatic carbonate platform (Istria), while *Bacinella* gradually becomes more infrequent southwards, as observed in the southern part of the island of Cres and on Lošinj.

The most obvious evidence for the intensive facies differentiation during the early Aptian is the sequence of strata on Lošinj (Figure 4). Unlike the situation in the north, the zone is here characterized by the presence of massive *Palorbitolina* wackestone–floatstone, interbedded every 5–10 cm with 2–10-cm-thick *Palorbitolina* rudstone-tempestites characterized by hummocky and/or swaley cross-stratification (Figure 5).

According to the lithological characteristics of the strata belonging to the *Palorbitolina lenticularis* Taxon-Range Zone, it can be concluded that during the early Aptian the north of the area investigated was dominated by a protected, low-energy subtidal environment. In the south this lagoonal deposition was strongly affected and modified by storm events. Sedimentation of mudstone and wackestone took place during fair weather, while the tempestites were deposited during storms. The massive occurrence of *Palorbitolina lenticularis* is also of importance for interpreting depositional environment. Although reflecting a wide range of environments, it is especially abundant in muddy settings, where it tends to be dominant (Vilas *et al.*, 1995).

A very rich microfossil association (Figures 6, 7) characterizes the *Palorbitolina lenticularis* Taxon-Range Zone. It includes several index foraminifera and many other microfossils (mainly foraminifera) of wider chronostratigraphic range. In addition to *Palorbitolina lenticularis*, these include, in order of their appearance in sections: *Bacinella irregularis*, *Praeorbitolina cormyi*, *Paleodictyoconus* sp., *Sabaudia minuta*, *Vercorsella scarselai*, *V. laurentii*, *Neotrocholina friburgensis*, *N. aptiensis*, *Praeorbitolina wienandsi*, *Orbitolina (Mesorbitolina) lotzei*, *Pfenderina globosa*, *Voloshinoides murgensis*, *Debarina hahounerensis*, *Praechrysalidina infracretacea*, *Sabaudia briacensis*, *Nezzazatinella* sp.

and *Salpingoporella dinarica*. The stratigraphic range of the dominant *Palorbitolina lenticularis* on the Adriatic carbonate platform is Upper Barremian to basal Upper Aptian (Arnaud-Vanneau *et al.*, 1991). However, horizontal prolocular diameters in megalospheric tests of *Palorbitolina lenticularis* found in the area investigated are 0.21–0.36 mm, which according to Gušić (1981) could indicate a late Early Aptian age for the population investigated. Additionally, the occurrence of *Praeorbitolina cormyi* and *P. wienandsi*, which are index fossils for the early Aptian (Schroeder, 1964), is very important. Other index fossils for the early Aptian of the Dinarides are *Orbitolina* (*Mesorbitolina*) *lotzei* (Velić & Sokač, 1983) and *Sabaudia briacensis* (Arnaud-Vanneau *et al.*, 1991).

It is concluded that the strata on the islands of Cres and Lošinj were deposited during the early Aptian in predominantly low-energy lagoonal environments, which, in the southern part of the area investigated, were strongly influenced by storm events.

3.2. Orbitolina (Mesorbitolina) texana *Assemblage Zone*

The early–late Aptian transition, following the last occurrence of *Palorbitolina lenticularis*, corresponds to a major biologic crisis recorded particularly for calcareous algae, benthonic foraminifera and rudists on numerous peri-mediterranean carbonate platforms (Masse, 1989). Thus, the absence of orbitolinids in the Upper Aptian of the islands of Cres and Lošinj might be a result of the regionally well-known emergence, which was of variable duration near the Aptian–Albian transition throughout the Dinarides (e.g., Velić *et al.*, 1989; Gušić & Jelaska, 1993). In the area investigated, this is indicated by breccia that is the product of the interaction of the relative sea-level fall (Haq *et al.*, 1987) and local tectonics (Velić *et al.*, 1989). The most prominent species of late Aptian age is the alga *Salpingoporella dinarica*. Nevertheless, in the Karst Dinarides beds of the *O.* (*Mesorbitolina*) *parva* Zone (late Aptian) and *O.* (*Mesorbitolina*) *parva* & *O.* (*Mesorbitolina*) *texana* Zone (latest Aptian and earliest Albian) continuously overlie *Palorbitolina* beds (Velić, 1988).

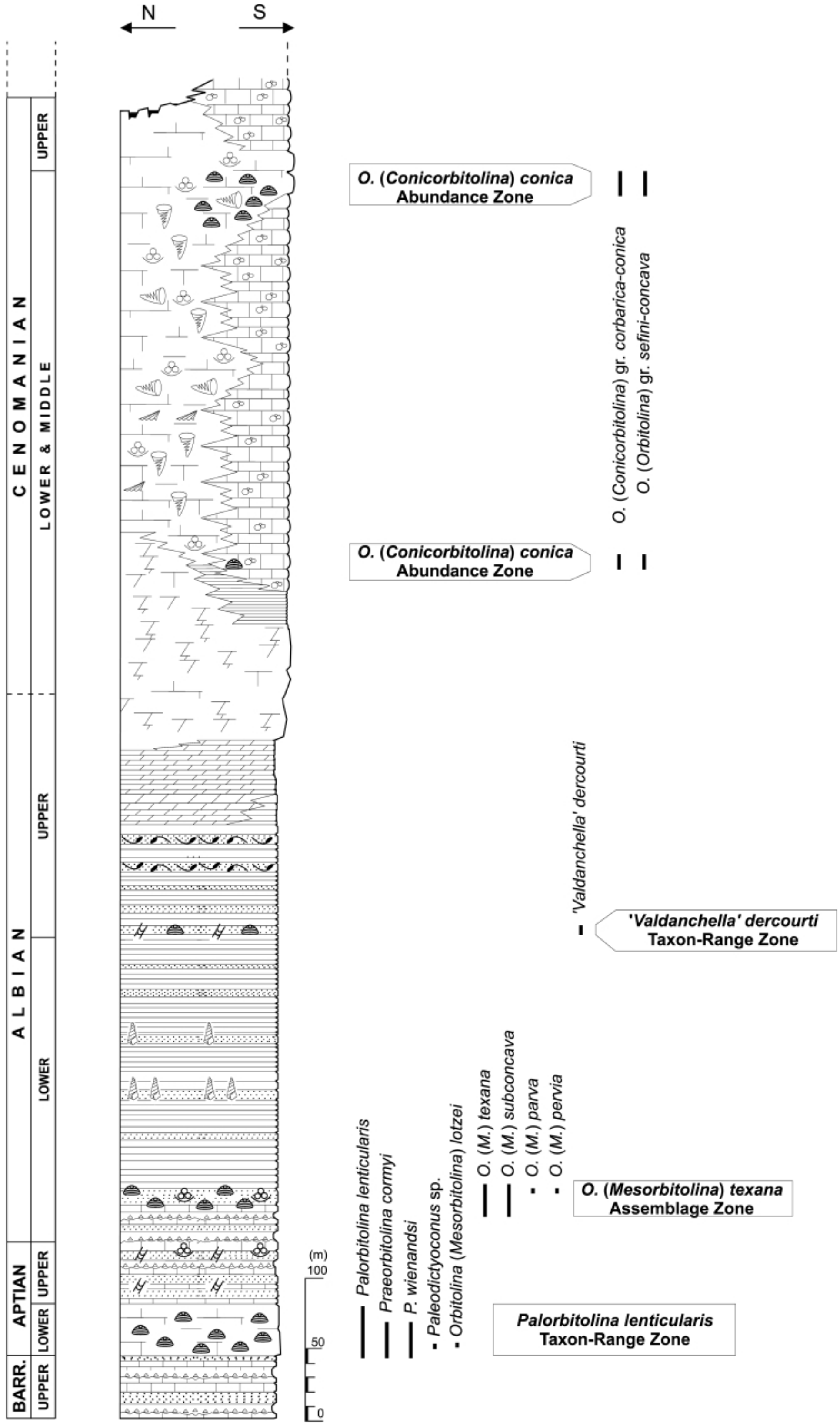
The *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone comprises strata that contain a distinctive assemblage of the following taxa: *Orbitolina* (*Mesorbitolina*) texana, *O.* (*M.*) *subconcava*, *O.* (*M.*) *parva* and *O.* (*M.*) *pervia* (Figures 2, 3, 8).

Owing to a transgressive event and increased water-energy, the base of the Albian is indicated by incomplete coarsening and shallowing-upwards sequences with tempestites. These 80–90-cm-thick cycles, which form the lower part of the zone, consist of the following members, from the bottom to the top: peloid-miliolid wackestone–packstone, fine-grained peloid-packstone, and peloid-foraminiferal packstone–grainstone. Repetition of small-scale shallowing-upward units during transgressive events is rather common in carbonate formations, demonstrating the periodic flooding of platforms (Tucker & Wright, 1992). These cycles are very well developed and frequent in Jurassic and Cretaceous peritidal limestones of the Adriatic carbonate platform (Tišljar *et al.*, 1991). Common coarsening-upwards sequences are the consequence of increased water-energy resulting in the formation of grainstones and infrequent tempestite breccia horizons composed of clasts derived from the neighbouring areas, including reworked black pebbles which are typical for well-emerged limestones (Strasser & Davaud, 1983). The uppermost part of the zone is characterized by an alternation of *Mesorbitolina* rudstone and peloid-foraminiferal grainstone of tempestite origin. The total thickness of beds belonging to the *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone is 36 m, and in contrast to the limestones of the older *Palorbitolina lenticularis* Taxon-Range Zone they exhibit neither lateral nor vertical variations in thickness and facies.

The Albian sequence of strata in the area investigated is marked by the first occurrence of *Pseudonummoloculina heimi*, a taxon that appears at this level throughout the region (Hottinger *et al.*, 1989). The most abundant taxon in the *Mesorbitolina* association is *O.* (*M.*) *texana*, which, according to Velić (1988), has its maximum abundance in the Lower Albian. Additionally, *O.* (*M.*) *subconcava* is considered by the same author to be the index fossil for the Lower Albian in the Karst Dinarides. The first and the last mass occurrences of the association delineate the boundaries of the Zone. The uppermost part of the zone is characterized by the presence of *Archaealveolina reicheli*, a species that is often found with *Salpingoporella dinarica*, and which ranges into the lowermost Albian (De Castro, 1980).

In addition to the species mentioned above, this zone includes the following taxa, in order of first appearances up-section: *Cuneolina pavonia*, *Vercorsella scarselai*, *V. arenata*, *V. laurentii*, *Sabaudia* sp., *Debarina hahounerensis*, *Sabaudia minuta*, *S. auruncensis*, *Paracoskinolina* sp., *Praechrysalidina infracretacea*, *Nezzazatinella* sp., *Mayncina bulgarica*, *Sabaudia capitata*, *Cuneolina parva*, ?*Charentia cuvillieri*, ?*Daxia* sp., *Hemicyclammina sigali* and *Pseudocyclammina* sp.

In conclusion, the body of strata established as the *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone reflect deposition during the early Albian in a


N
S
CENOMANIAN
UPPER
LOWER & MIDDLE
ALBIAN
UPPER
LOWER
APTIAN
UPPER
LOWER
BARR.
UPPER
O. (Conicorbitolina) conica
Abundance Zone
O. (Conicorbitolina) gr. corbarica-conica
O. (Orbitolina) gr. sefini-concava
O. (Conicorbitolina) conica
Abundance Zone
'Valdanchella' dercourti
'Valdanchella' dercourti
Taxon-Range Zone
O. (M.) texana
O. (M.) subconcava
O. (M.) parva
O. (M.) pervia
O. (Mesorbitolina) texana
Assemblage Zone
Palorbitolina lenticularis
Praeorbitolina cormyi
P. wienandsi
Paleodictyoconus sp.
Orbitolina (Mesorbitolina) lotzei
Palorbitolina lenticularis
Taxon-Range Zone
(m)
100
50
0

moderate to high water-energy, shallow, subtidal environment that periodically emerged above sea level.

3.3. 'Valdanchella' dercourti *Taxon-Range Zone*

Overlying the *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone are the youngest early Cretaceous deposits on the island of Cres. They are represented by an early–late Albian subtidal alternation of mudstone and miliolid wackestone–packstone. Within these shallow-water deposits only incomplete coarsening and shallowing-upwards cycles, composed of mudstones overlain by packstones/grainstones, are identified. These cycles are the result of aggradation and lateral progradation of facies belts in a shallow platform realm.

The *'Valdanchella' dercourti* Taxon-Range Zone is the body of strata delineated by the stratigraphic range of the nominate species in the study area. The associated microfossil assemblage is rather sparse (Figure 8; see also Figure 3), both in terms of number of taxa and number of individuals, which is a common tendency in the Dinarides (Velić & Sokač, 1978). In order of their appearance up-section it consists of: *Salpingoporella turgida*, *Pseudonummoloculina heimi*, *Vercorsella scarselai*, *Cuneolina pavonia* and *Mayncina bulgarica*. Primitive '*Valdanchella*' *dercourti* is the only orbitolinid. The thickness of strata attributable to the zone is only 30 cm, its boundaries being indicated by the first and the last occurrences of the taxon. In common with other members of the subfamily Dictyoconinae, the occurrence of '*V.*' *dercourti* is linked to very shallow environments (Masse, 1976; Arnaud-Vanneau, 1979, 1980).

Both mud and grain-supported subtidal limestones of this biozone contain the alga *Salpingoporella turgida*, which in association with the other species mentioned is very frequent in deposits of earliest late Albian age in the Karst Dinarides (e.g., Velić & Sokač 1979, 1983; Velić *et al.* 1979, 1989; Velić, 1988).

3.4. Orbitolina (Conicorbitolina) conica *Abundance Zone*

The underlying deposits consist of dolomitized laminated limestones and an irregular alternation of massive, late-diagenetic dolomites and recrystallized limestones that are devoid of fossils. As a result, they can be dated only on the basis of superpositional relations as latest Albian–early-mid Cenomanian.

The *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone is the body of strata in which the abundance of the species *Orbitolina* (*Conicorbitolina*) *conica* is significantly greater than is usual in adjacent parts of the section, regardless of either association or range. Deposition in a shallow-water environment with variable water-energy is indicated by the bioclastic-peloid-skeletal packstones–grainstones with numerous fragments of rudists and rare bioclasts of other molluscs, hydrozoans and bryozoans. Shallow-water bioclastic material was transported during storms and deposited in deeper water characterized by pelagic sedimentation.

Major facies differentiation took place during the Cenomanian, similar to that of the neighbouring area of Istria (Vlahović *et al.*, 1994; Tišljar *et al.* 1995, 1998). Hence, the strata were examined at two localities, each representing typical environments. In the Petrovski dolac (PD) area, situated in the central part of Cres, the strata belonging to the *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone are located at the base (lowermost 4.30 m) of an almost 250-m-thick sequence of calcisphere-rich limestones indicating pelagic sedimentation. The bioclastic material is

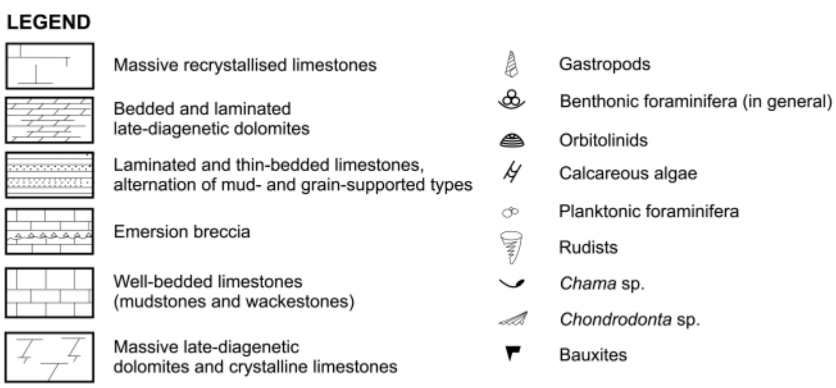


Figure 2. Schematic geological column of the study area (modified from Fuček *et al.*, 1995) with stratigraphic distribution of the orbitolinid taxa.

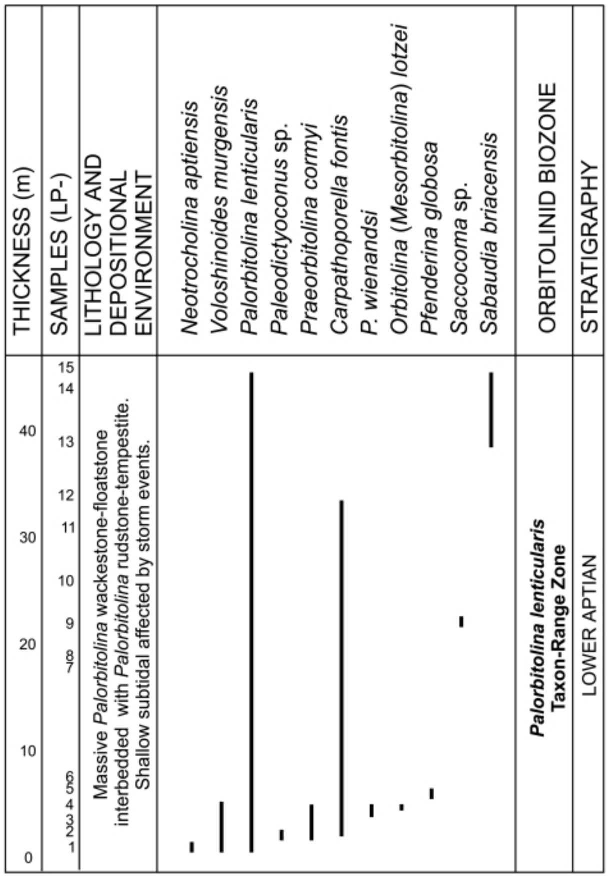


Figure 4. Stratigraphic distribution of Lower Aptian index microfossils in the Punta (LP) section.

not autochthonous, but transported from shallower environments. The following microfossils have been determined, in order of their appearance up-section (Figure 9A): *Orbitolina* (*Conicorbitolina*) gr. *corbarica-conica*, *O.* (*Orbitolina*) gr. *sefini-concava*, *Favusella washitensis*, *Hedbergella planispira*, *Pithonella sphaerica*, *P. ovalis*, *P. innominata*, *Bonetocardiella conoidea*, *Heterohelix* sp., *Rotalipora* sp., *Nodosaria* sp. and different undetermined benthonic forms, echinoid spines and mollusc fragments.

This association of foraminifera (both benthonic and planktonic) and calcisphaerulids at the Petrovski dolac locality (Figure 10) implies a Vraconian–middle Cenomanian age. However, according to the regional stratigraphy of the Karst Dinarides (e.g., Velić, 1988; Velić & Vlahović, 1994) an early–middle Cenomanian age seems more probable.

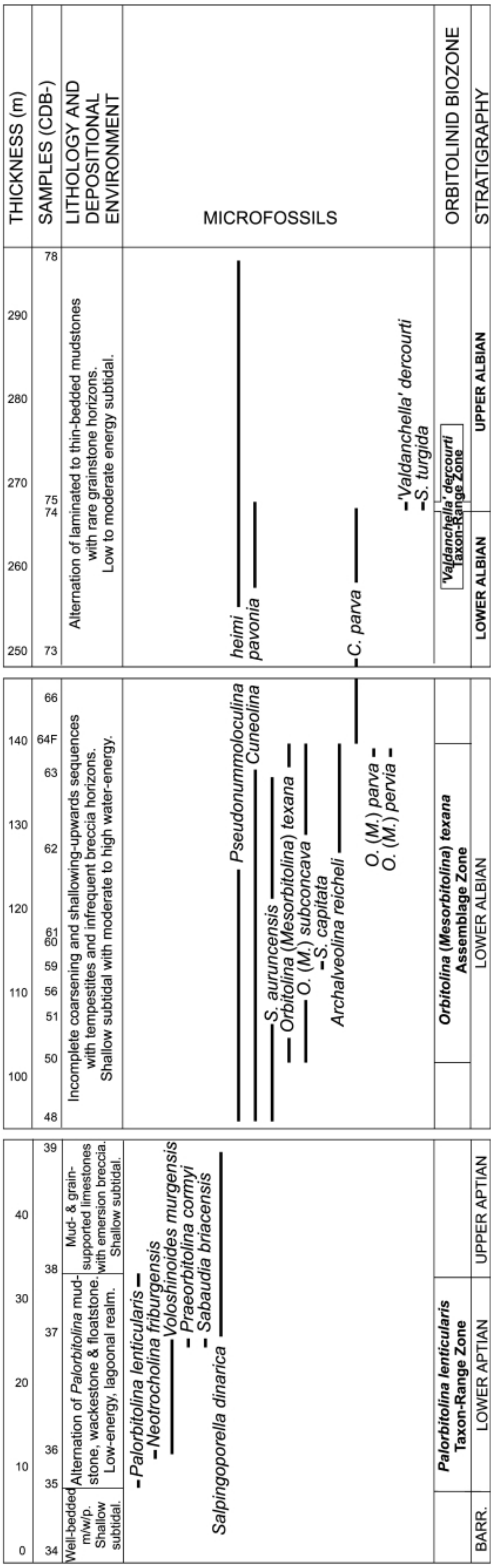


Figure 3. Stratigraphic distribution of index microfossils in the orbitolina-bearing intervals of the Dragozetići (CDB) section (Upper Barremian–Upper Albian).

Figure 5. *Palorbitolina* tempestite (lens cap is 52 mm in diameter).

At the Baldarin locality (CB), situated in the vicinity of the southern cape of Cres (see Figure 1), the strata are represented by porcellaneous, recrystallized limestones with smaller or larger fragments of rudists. The biozone is here characterized by an abundance of foraminifera, especially orbitolinids (Figure 9B). The boundaries of the zone, encompassing 13.60 m of section, are biohorizons of significant change in abundance of *Orbitolina* (*Conicorbitolina*) *conica*. In addition to this species this zone yields the following taxa in order of their appearance up-section: *Broeckina* (*Pastrikella*) *balcanica*, *Nezzazata gyra*, *N. simplex*, *N. conica*, *Cuneolina pavonia*, *C. parva*, *Peneroplis turonicus*, *Biplanata peneropliformis*, *Trochospira avnimelechi*, *Nummoloculina regularis*, *Pseudonummoloculina heimi*, *Pseudorhapydionina dubia*, *Pseudolituonella reicheli*, *Merlingina cretacea*, *Spiroloculina* sp., *Scandonea phoenissa*, *Scandonea* sp., *Nezzazatinella picardi* and *Chrysalidina gradata*. Different Cenomanian rudists have also been recorded, namely *Ichthyosarcolites poljaki*, *I. bicarinatus*, *I. tricarinatus*, *Schiosia carinatoformis*, *Orthopthychus striatus*, *Durania* sp., *Sauvagesia* sp. and numerous radiolitid forms, as well as rather rare fragments of molluscs that are probably referable to *Chondrodonta*.

The determined microfossil association of benthonic foraminifera at the Baldarin locality (Figure 10) corresponds to the late Middle Cenomanian biozone CEN-4 in the neighbouring Istrian peninsula (Velić & Vlahović, 1994), although in Istria contemporaneous deposits contain no orbitolinids. By contrast, orbitolinids are very abundant in the study area, especially *Orbitolina* (*Conicorbitolina*) *conica*, which is the index fossil for the early–middle Cenomanian (Schroeder & Neumann, 1985). The *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone is overlain by a similar microfossil association lacking orbitolinids, but containing the species *Vidalina radoicicae*, which is the index fossil for the late Cenomanian (Cherchi & Schroeder, 1985). Therefore, it may be concluded that the zone at the Baldarin locality is of late Middle Cenomanian age.

In Istria the same orbitolinid forms have been found only in the early Middle Cenomanian deposits of CEN-3a biozone (Velić & Vlahović, 1994), i.e., between two appearances determined on the island of Cres. This is the consequence of different environments during the early and middle Cenomanian in the northern Adriatic realm (Vlahović *et al.*, 1994; Tišljar *et al.*, 1998), since Cenomanian orbitolinids have been found exclusively in deposits that intermittently record higher energy environments: foreshore barrier bars (Istria) and reworked shallow-water deposits (Cres).

4. Regional correlation with emphasis on Karst Dinarides

Orbitolinids have been found at numerous localities in the Karst Dinarides. They are often very abundant,

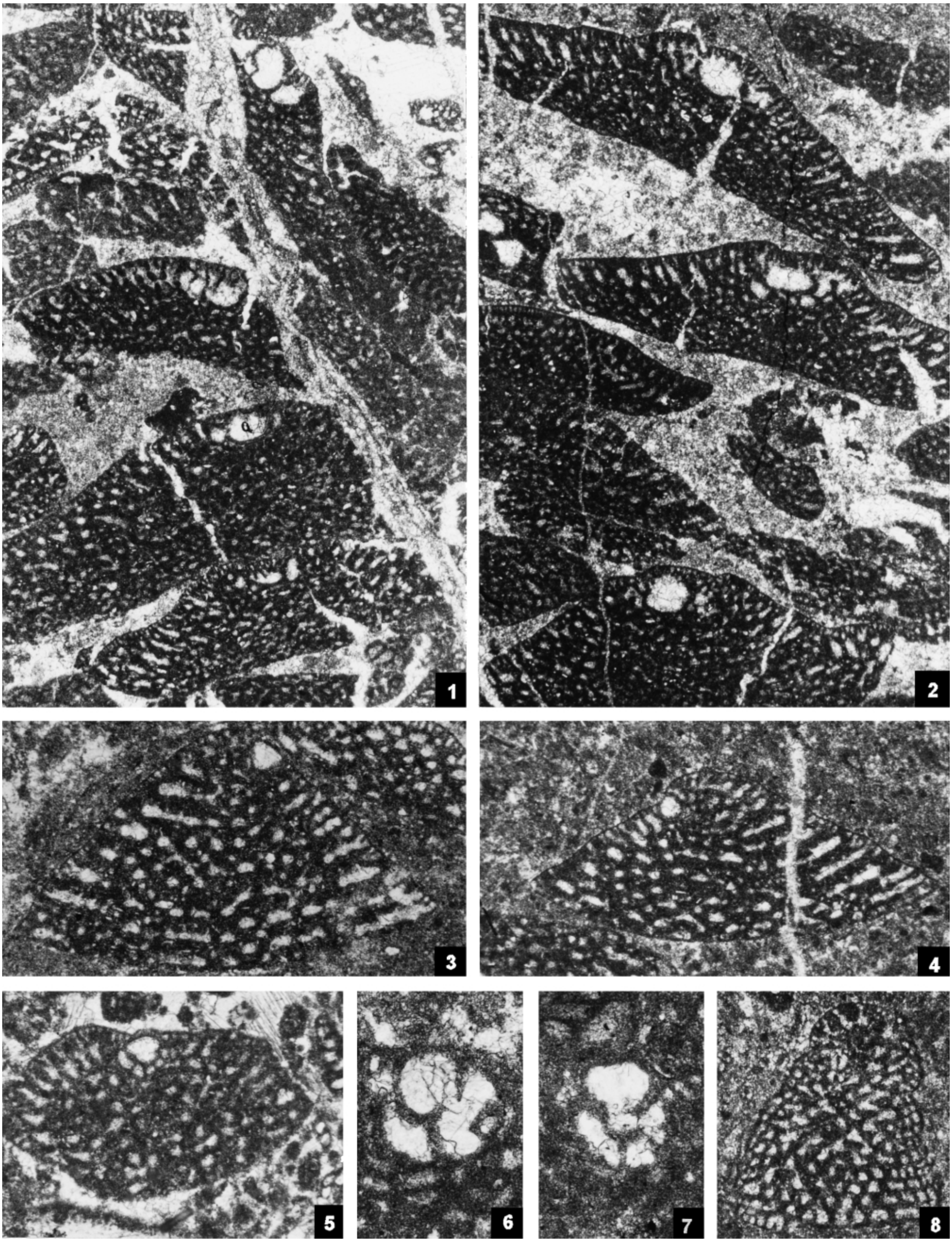


Figure 6. *Palorbitolina lenticularis* Taxon-Range Zone, early Aptian. 1, 2, *Palorbitolina* tempestite with more axial sections through megalospheric embryonic apparatuses, Križice (CK) section, × 32. 3, 4, *Praeorbitolina cormyi*; axial section through megalospheric embryonic apparatus, Križice (CK), × 54. 5, 6, *Praeorbitolina wienandsi*; axial section through megalospheric embryonic apparatus, Punta (LP) (5, × 54; 6, × 135). 7, *Orbitolina* (*Mesorbitolina*) *lotzei*; axial section through megalospheric embryonic apparatus, Punta (LP), × 135. 8, *Paleodictyoconus* sp; subaxial section, Križice (CK), × 54.

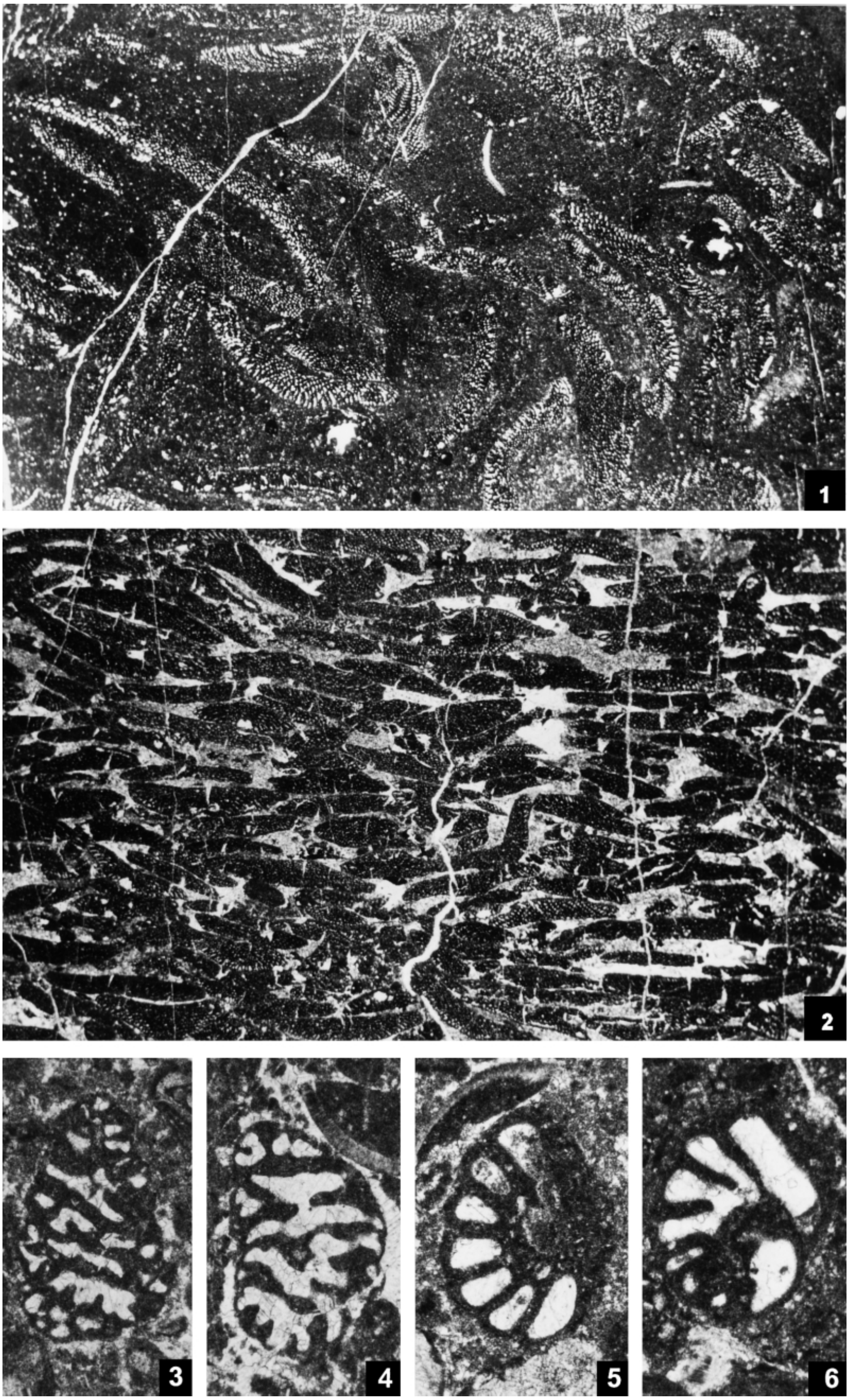


Figure 7. *Palorbitolina lenticularis* Taxon-Range Zone, early Aptian. 1, *Palorbitolina* wackestone deposited in a low-energy, lagoonal-type environment, Punta (LP) section, × 8. 2, *Palorbitolina* grainstone–tempestite, Križice (CK), × 8. 3, 4, *Voloshinoides murgensis*; oblique section, Punta (LP), × 54. 5, 6, ?*Pfenderina globosa*; oblique section, Punta (LP), × 54.

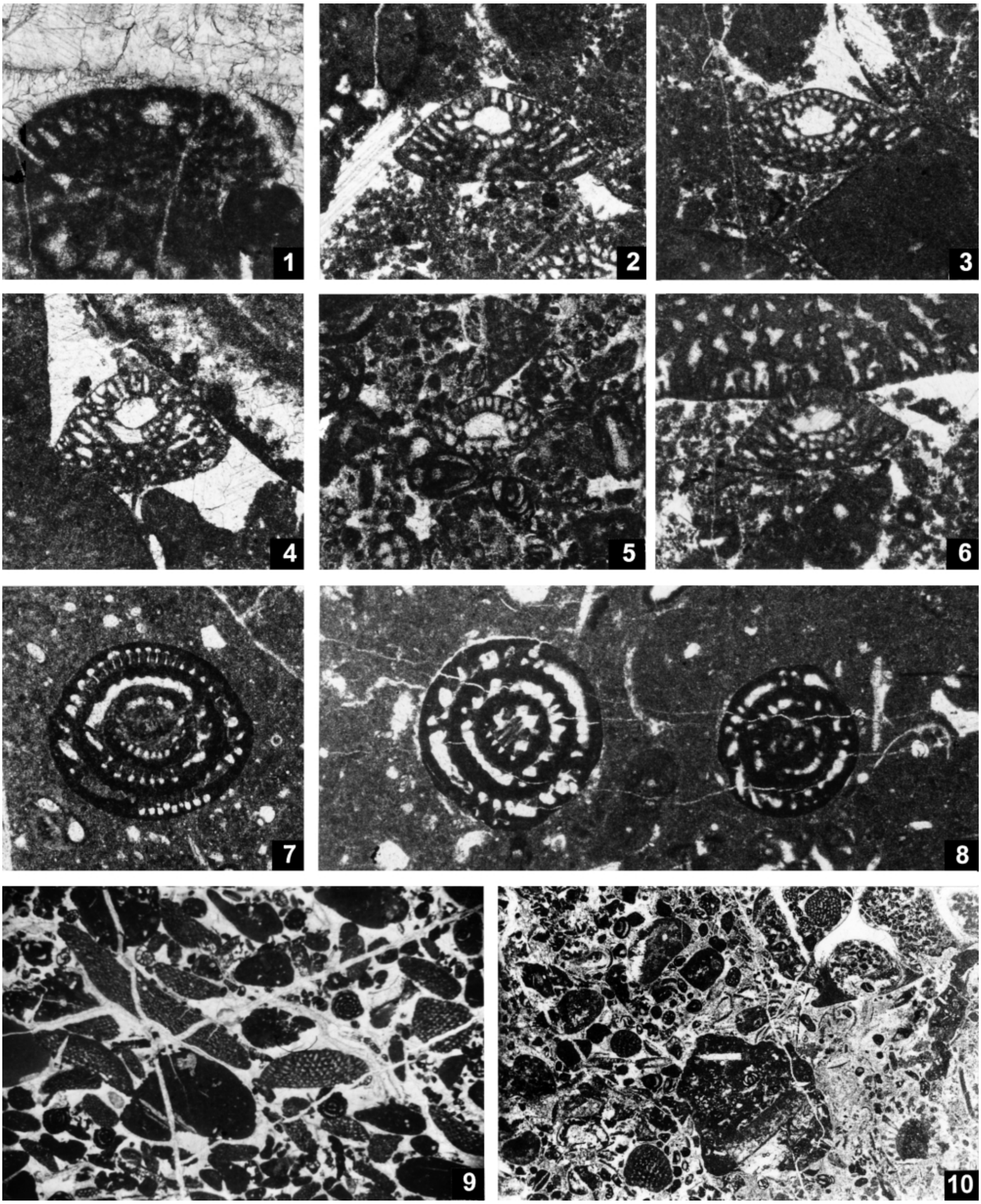


Figure 8. *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone, early Albian (Photographs 1–9). 1, *Orbitolina* (*Mesorbitolina*) *parva*; axial section through megalospheric embryonic apparatus, Dragozetići (CDC) section, × 54. 2–4, *Orbitolina* (*Mesorbitolina*) *texana*; axial section through megalospheric embryonic apparatus, Dragozetići (CDB), × 42. 5, *Orbitolina* (*Mesorbitolina*) *pervia*; axial section through megalospheric embryonic apparatus, Dragozetići (CDB), × 42. 6, *Orbitolina* (*Mesorbitolina*) *subconcava*; axial section through megalospheric embryonic apparatus, Dragozetići (CDB), × 42. 7, 8, *Archaealveolina reicheli*; subaxial section, Dragozetići (CDB), × 42. 9, *Mesorbitolina*–*Archaealveolina* grainstone–tempestite, Dragozetići (CDB), × 9. '*Valdanchella*' *dercourti* Taxon-Range Zone, late Albian. 10, skeletal-peloid packstone–grainstone with various sections of '*Valdanchella*' *dercourti* and *Salpingoporella turgida*, Dragozetići (CDB), × 9.

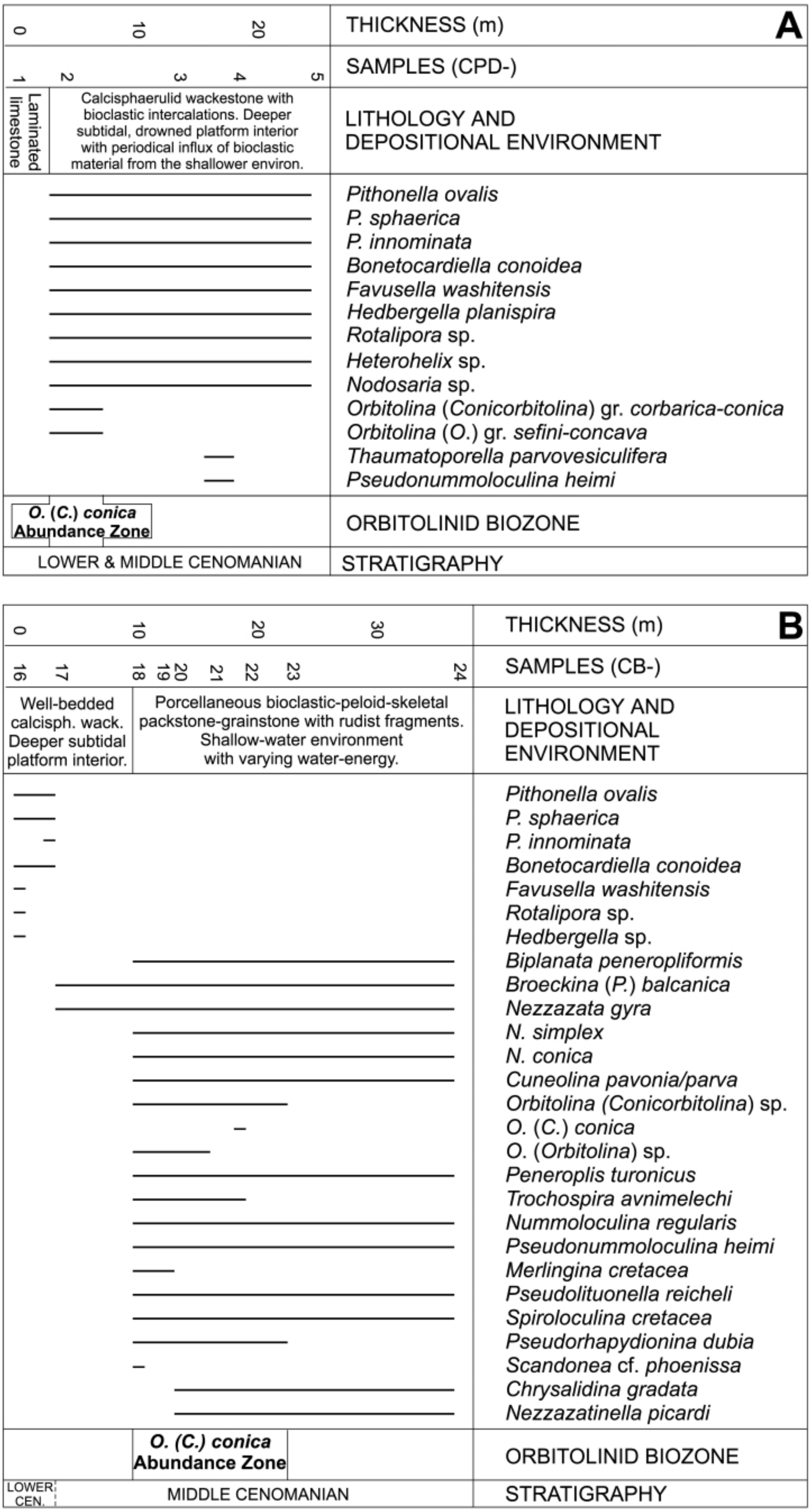


Figure 9. A, stratigraphic distribution of microfossils in the lower part of the Petrovski dolac (CPD) section. B, stratigraphic distribution of microfossils in the upper part of the Baldarin (CB) section.

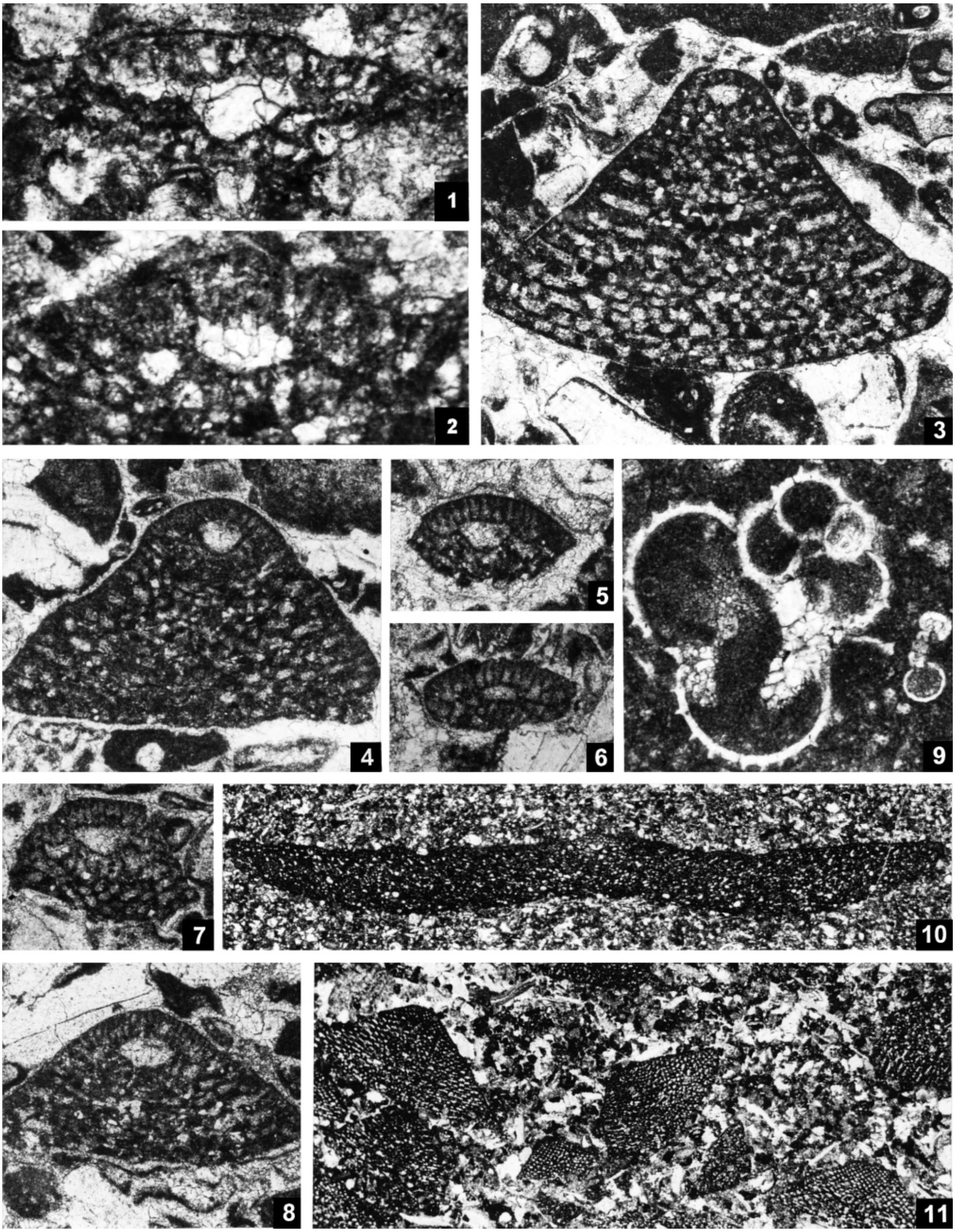


Figure 10. *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone, early and middle Cenomanian. 1, *Orbitolina* (*Orbitolina*) gr. *sefini-concava*; axial section through megalospheric embryonic apparatus, Petrovski dolac (CPD) section, × 135. 2, *Orbitolina* (*Conicorbitolina*) gr. *corbarica-conica*; axial section through megalospheric embryonic apparatus, Petrovski dolac (CPD), × 135. 3–8, *Orbitolina* (*Conicorbitolina*) *conica*; axial section through megalospheric embryonic apparatus, Petrovski dolac (CPD), × 42. 9, *Favusella washitensis* and *Hedbergella planispira*; oblique section, Petrovski dolac (CPD), × 135. 10, calcisphaerulid wackestone–packstone with orbitolinids, Petrovski dolac (CPD), × 16. 11, bioclastic-peloid-skeletal grainstone with orbitolinids, Punta Križa (PK), × 8.

sometimes forming the bulk of a deposit. Typical examples are the regions of Istria and Mt. Velika Kapela in Croatia, where biozonations have been established on the basis of orbitolinid taxa and their stratigraphic distribution (Figure 11). Velić (1988) proposed a biostratigraphic zonation for the entire area of the Karst Dinarides. The biozones established herein for the islands of Cres and Lošinj correspond to the orbitolinid biozonations and orbitolinid stratigraphic distributions of the adjacent areas:

The *Palorbitolina lenticularis* Taxon-Range Zone corresponds to the biozones already established in Croatian regions of Istria (Velić *et al.*, 1995) and Mt. Velika Kapela (Velić, 1977; Velić & Sokač, 1978), which yield an assemblage of *Palorbitolina* and *Praeorbitolina* that may be regarded as indicating an early Aptian age. The genus *Palorbitolina* is recorded from Tethyan carbonate platforms of late Barremian age, but when in association with the genus *Praeorbitolina* it indicates early–earliest Late Aptian (Pantoja-Alor *et al.*, 1994).

The *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone corresponds to the Cenozone *Orbitolina* (*Mesorbitolina*) ex gr. *texana* known from Mt. Velika Kapela (Velić, 1977; Velić & Sokač, 1978). By contrast to the Dinaric area where the chronostratigraphic range of this taxon is considered to be latest Aptian–early Albian, in the other parts of Tethys its range varies considerably. In the Apennines (e.g., Chiocchini & Mancinelli, 1977; Cherchi *et al.*, 1978; Cherchi, 1979), Atlas Mountains (e.g., Schroeder *et al.*, 1974; Masse, 1984) and in the Middle East (e.g., Simmons & Hart, 1987; Pratt & Smewing, 1993) it is typical for the late Aptian, whereas in the Hellenides (e.g., Decrouez & Moullade, 1974), Pyrenees (e.g., Peybernès, 1976; Bilotte *et al.*, 1978) and on the Iberian Peninsula (e.g., García *et al.*, 1993) it is characteristic for the late Albian. These deviations reflect ecological changes that occurred during the late Aptian and Albian in the broad Tethyan realm.

The '*Valdanchella*' *dercourti* Taxon-Range Zone corresponds to the biozones of the same name established for deposits of late Albian age in the adjacent areas of Istria (Velić *et al.*, 1995) and Mt. Velika Kapela (Velić, 1977; Velić & Sokač, 1978). In other parts of Tethys this taxon also occurs in younger, early Cenomanian successions, as in the Apennines (e.g., Chiocchini *et al.*, 1984) and the Hellenides (e.g., Decrouez & Moullade, 1974).

The *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone corresponds to the CEN-3a Biozone of the Middle Cenomanian of Istria (Velić & Vlahović, 1994), which is characterized by containing *Chrysalidina gradata* in association with orbitolinids, and to the *Orbitolina* (*Conicorbitolina*) *cuvillieri-conica* Zone, which is known from the Lower Cenomanian of the Dinarides (Velić, 1988). It also corresponds to the *Orbitolina* (*Conicorbitolina*) *conica* Biozone, which is known from Vraconian–Middle Cenomanian of the Pyrenees (e.g., Bilotte, 1978; Bilotte *et al.*, 1978), and the *Orbitolina* cf. *conica* Zone, known from the Middle Cenomanian of the Atlas Mountains (Schroeder *et al.*, 1974).

5. Conclusions

A rich foraminiferal, especially orbitolinid, association has been determined within Aptian, Albian and Cenomanian limestone deposits on the islands of Cres and Lošinj. Four biostratigraphic zones have been established based on the orbitolinid taxa and their stratigraphic distribution.

The *Palorbitolina lenticularis* Taxon-Range Zone encompasses strata representing the determined stratigraphic range of the named species. The strata reflect deposition during the early Aptian in predominantly low-energy lagoonal-type environments that were strongly influenced by storm events on the southern part of the island of Cres. Besides *P. lenticularis*, the following orbitolinids have been identified: *Praeorbitolina cormyi*, *P. wienandsi*, *Orbitolina* (*Mesorbitolina*) *lotzei* and *Paleodictyoconus* sp.

Strata referable to the *Orbitolina* (*Mesorbitolina*) *texana* Assemblage Zone are characterized by yielding a distinctive assemblage of the following taxa: *Orbitolina* (*Mesorbitolina*) *texana*, *O.* (*M.*) *subconcava*, *O.* (*M.*) *parva* and *O.* (*M.*) *pervia*. Deposition in a moderate to high water-energy, shallow subtidal environment that periodically emerged above sea level is indicated. Coarsening and shallowing-upwards cycles are the result of transgression and an increase in water-energy during the early Albian.

The overlying '*Valdanchella*' *dercourti* Taxon-Range Zone encompasses both mud and grain-supported subtidal limestones that contain the alga *Salpingoporella turgida* which, in association with '*V.*' *dercourti*, indicates the earliest late Albian.

The *Orbitolina* (*Conicorbitolina*) *conica* Abundance Zone encompasses strata in which the abundance of the named taxon is markedly greater than is usual in adjacent parts of the succession in the study area. *O.* (*Conicorbitolina*) gr. *corbarica-conica* and *O.* (*Orbitolina*) gr. *sefini-concava* also occur. Deposition in a shallow-water environment of varying water-energy during the early–middle Cenomanian is indicated. During storms, bioclastic material was transported from shallow to deep-water environments that were dominated by pelagic sedimentation.

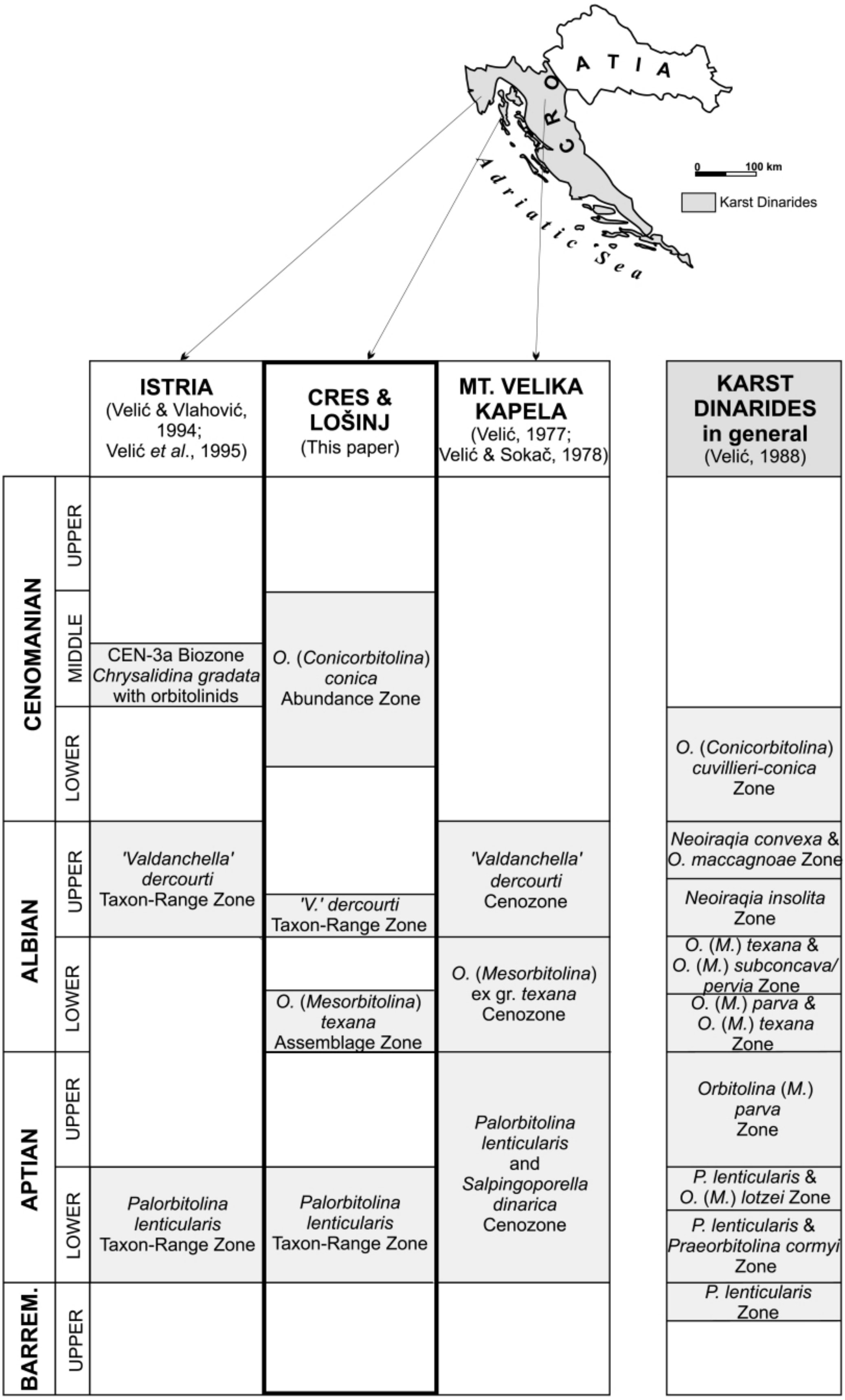


Figure 11. Mid Cretaceous orbitolinid biozonations in the Karst Dinarides.

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Appendix

List of species mentioned in the text with author attributions and dates.

Benthonic foraminifera
Archaealveolina reicheli (De Castro, 1966)
Biplanata peneropliformis Hamaoui & Saint-Marc, 1970
Broeckina (*Pastrikella*) *balcanica* Cherchi, Radoičić & Schroeder, 1976
Charentia cuvillieri Neumann, 1965
Chrysalidina gradata D'Orbigny, 1839
Cuneolina parva Henson, 1948
Cuneolina pavonia D'Orbigny, 1846
Daxia sp.
Debarina hahounerensis Fourcade, Raoult & Villa, 1972
Hemicyclammina sigali Maync, 1953
Mayncina bulgarica Laug, Peybernès & Rey, 1980
Merlingina cretacea Hamaoui & Saint-Marc, 1970
Neotrocholina aptiensis (Iovcheva, 1962)
Neotrocholina friburgensis Guillaume & Reichel, 1957
Nezzazata conica (Smout, 1956)
Nezzazata gyra (Smout, 1956)
Nezzazata simplex Omara, 1956
Nezzazatinella picardi (Henson, 1948)
Nezzazatinella sp.
Nodosaria sp.
Nummoloculina regularis Philippson, 1887
Orbitolina (*Conicorbitolina*) *conica* (D'Archiac, 1837)
Orbitolina (*Conicorbitolina*) gr. *corbarica* Schroeder, 1985-*conica* (D'Archiac, 1837)
Orbitolina (*Mesorbitolina*) *lotzei* Schroeder, 1964
Orbitolina (*Mesorbitolina*) *parva* Douglass, 1960
Orbitolina (*Mesorbitolina*) *pervia* Douglass, 1960
Orbitolina (*Mesorbitolina*) *subconcava* Leymerie, 1878
Orbitolina (*Mesorbitolina*) *texana* (Roemer, 1849)
Orbitolina (*Orbitolina*) gr. *sefini* Henson, 1948-*concava* (Lamarck, 1816)
Paleodictyoconus sp.
Palorbitolina lenticularis (Blumenbach, 1805)
Peneroplis turonicus Said & Kenawy, 1957
Paracoskinolina sp.
Pfenderina globosa Foury, 1968
Praechrysalidina infracretacea Luperto-Sinni, 1979
Praeorbitolina cormyi Schroeder, 1964
Praeorbitolina wienandsi Schroeder, 1964
Pseudocyclammina sp.
Pseudolituonella reicheli Marie, 1952
Pseudonummoloculina heimi (Bonet, 1956)
Pseudorhapydionina dubia (De Castro, 1965)
Sabaudia auruncensis (Chiocchini & Di Napoli Alliata, 1966)
Sabaudia briacensis Arnaud-Vanneau, 1980
Sabaudia capitata Arnaud-Vanneau, 1980
Sabaudia minuta (Hofker,1965)
Sabaudia sp.
Scandonea phoenissa Saint-Marc, 1974
Scandonea sp.
Spiroloculina sp.
Trochospira avnimelechi Hamaoui & Saint-Marc, 1970
'*Valdanchella*' *dercourti* Decrouez & Moullade, 1974
Vercorsella arenata Arnaud-Vanneau, 1980
Vercorsella laurentii (Sartoni & Crescenti, 1962)
Vercorsella scarselai (De Castro, 1963)
Vidalina radoicicae Cherchi & Schroeder, 1985
Voloshinoides murgensis Luperto-Sinni & Masse, 1993

Planktonic foraminifera
Bonetocardiella conoidea (Bonet, 1956)
Favusella washitensis (Carsey, 1926)
Hedbergella planispira (Tappan, 1940)
Hedbergella sp.
Heterohelix sp.
Rotalipora sp.

Algae
Bacinella irregularis Radoičić, 1959
Clypeina solkani Conrad & Radoičić, 1972
Salpingoporella dinarica Radoičić, 1959
Salpingoporella melitae Radoičić, 1967
Salpingoporella muehlbergii (Lorenz, 1902)
Salpingoporella turgida (Radoičić, 1964)

Calcisphaerulids
Pithonella innominata (Bonet, 1956)
Pithonella ovalis (Kaufmann, 1865)
Pithonella sphaerica (Kaufmann, 1865)

Bivalves
Chama sp.
Chondrodonta sp.
Durania sp.
Ichthyosarcolites bicarinatus (Gemmellaro, 1865)
Ichthyosarcolites poljaki Polšak, 1964
Ichthyosarcolites tricarinatus Parona, 1921
Orthopthychus striatus Futterer, 1892
Sauvagesia sp.
Schiosia carinatoformis Polšak, 1967