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Upper Cretaceous Peritidal Deposits of Olib and Ist Islands (Adriatic Sea, Croatia)

Alan **MORO** and Vladimir **JELASKA**

Key-words: Peritidal sediments, Shallowing-upward cycles, Upper Cretaceous, Sequence stratigraphy

Ključne riječi: peritajdalni sedimenti, ciklusi oplićavanja, gornja kreda, sekvencijska stratigrafija

Abstract

Upper Cretaceous carbonate deposits of Olib and Ist islands are characteristic of peritidal sediments. They consist of shallow subtidal deposits alternating with intertidal laminites (shallowing-upward cycles). Subtidal beds with micritic matrix predominate over peritidal sediments. Determination of the micro- and macrofauna revealed two distinctive assemblages: one of Middle to Upper Cenomanian and the other of Upper Turonian to Lower Santonian age. The relatively high proportion of subtidal over intertidal sediments (subtidal/intertidal ratio 2.72) indicates that the Middle to Upper Cenomanian beds were deposited during a fall in the third order relative sea-level curve (late HST to LST). Sediments of the next carbonate sequence (Upper Turonian to Lower Santonian) with a higher proportion of the subtidal over intertidal sediments (subtidal/intertidal ratio 4.57) indicate deposition during relative sea-level rise (TST) and highstand (HST). Senonian limestones are overlain by sediments of Lower Lutetian age.

Sažetak

Gornjokredne karbonatne naslage otoka Oliba i Ista su peritajdalnih karakteristika. Sastoje se od sedimenata plitkog subtajdala u izmjeni s intertajdalnim laminitima (ciklusi oplićavanja). Unutar peritajdalnih sedimenata prevladavaju subtajdalni vapnenci s mikritnom osnovom. Odredbom mikro i makrofaune utvrđene su dvije različite zajednice: jedna u rasponu od srednjeg do gornjeg cenomana i druga od gornjeg turona do donjeg santona. Relativno veći udio subtajdalnog sedimenta u odnosu na intertajdalni (odnos subtajdal/intertajdal 2.72), ukazuje da su srednje do gornjocenomanske naslage taložene tijekom relativnog pada krivulje trećeg reda (kasni HST do LST) razine mora. Gornjoturonsko-donjosantonski sedimenti slijedeće karbonatne sekvencije su vjerojatno sedimentirani tijekom relativnog rasta (TST) i visoke (HST) razine mora, zbog većeg udjela subtajdalnih u odnosu na intertajdalne sedimente (odnos subtajdal/intertajdal 4.57). Na senonske sedimente transgresivno naliježu sedimenti donjeg lutecija.

1. INTRODUCTION

The islands of Olib and Ist geographically belong to the North-Adriatic group of islands, Northern Dalmatia, Croatia (Fig. 1).

The aim of this paper is to present a detailed analysis of shallow-water environments, and their stratigraphic interpretation.

This study is based on logged sections, determination of lithofacies and microfacies, and interpretation of depositional environments. The Slatinica and Garmina sections are on Olib island and the Mljake profile is on Ist island. The Garmina profile is a composite profile consisting of Cape Slanac, Cape Garmina and Fučinska Cove local profiles (Fig. 1).

Slatinica, Garmina and Mljake profiles belong to the Adriatic carbonate platform (GUŠIĆ & JELASKA, 1990) which extends along the western shore of the Adriatic Sea from the Soča River in the north-west to the present day Montenegrin-Albanian border. To the north-east the platform is overthrust by the Dinaric platform and to the south-west it plunges under the Adriatic Sea, though there are indications that it passes into deeper water pelagic facies (GUŠIĆ & JELASKA, 1993).

MAMUŽIĆ (1970), MAMUŽIĆ & SOKAČ (1973) and MAMUŽIĆ et al. (1970) determined the age range of the Upper Cretaceous beds on these islands as being from the Cenomanian to the Senonian. They are transgressively overlain by Middle Eocene limestones.

The investigated limestone successions are described in the framework of sequence stratigraphy (SARG, 1988; VAN WAGONER et al., 1988). This concept has been further elucidated by TUCKER (1993), and we will follow his model in the proceeding text.

Many carbonate sequences commonly consist of metre-scale shallowing-upward units, termed parasequences, resulting from fourth/fifth order relative sea-level changes. Commonly, parasequences display systematic vertical changes in thickness and facies throughout the sequence. During the transgressive systems tract (TST), when the third-order relative sea-level curve is rising, the parasequences typically show a thickening-upward trend and an increase in the proportion of subtidal facies to intertidal facies. Parasequences deposited during late highstand systems tract (HST) and early lowstand systems tract (LST) will show domination of intertidal facies over subtidal facies and they are generally thinner (TUCKER, 1993).

Department of Geology and Paleontology, Faculty of Science, University of Zagreb, Zvonimirova 8/II, POB 153, 41000 Zagreb, Croatia

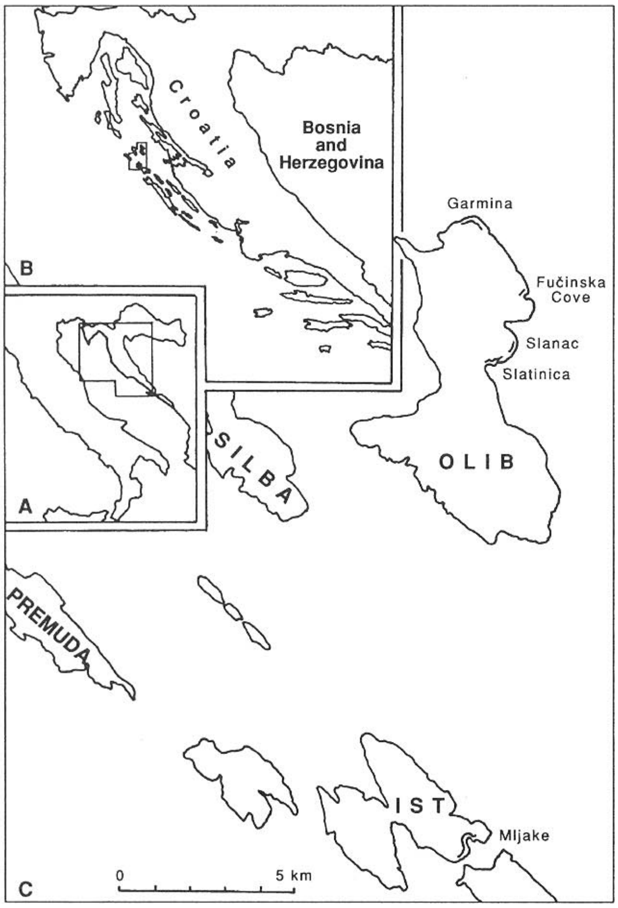


Fig. 1. Situation map. 1 - Slatinica profile, 2 - Garmina profile (local profiles: a - Cape Slanac, b - Cape Garmina and c - Fučinska cove), 3 - Mljake profile.

In the sense of TUCKER & WRIGHT (1990) peritidal carbonates (carbonate sediments formed "around the tides") represent a spectrum of marine environments from shallow subtidal areas adjacent to tidal flats, to the tidal flats themselves, and to supratidal zones including sabkhas, mangrove forests, marshes and coastal "lakes".

The Upper Cretaceous limestones of the studied islands will be correlated with other parts of the Adriatic carbonate platform, i.e. with deposits of Brač and Dugi otok islands.

2. FACIES AND FOSSILS

2.1. SLATINICA PROFILE (MIDDLE TO UPPER CENOMANIAN)

In the Slatinica profile (Figs. 2 and 3), four limestone types alternate in vertical succession: (1) Foraminiferal-peloidal wackestone-packstone, (2) *Chondrodonta* coquinas, (3) microbial laminites, and (4) wackestone with remnants of pelagic biota at the top of the profile. Sparitic cement was found only in one bed, as pelsparite within a *Chondrodonta* coquina, in the base of the profile.

In the vertical succession there is a regular repetition of the various facies types, which produce sedimentary cycles. Each cycle begins with foraminiferal-peloidal wackestone-packstone with a thickness of 0.4 - 5.5 m. Chondrodonts, which are mostly orientated parallel to the bedding planes, are commonly in alternation with these beds. The upper part of each cycle consists of laminated limestone with a thickness ranging from 0.3 - 1.3 m, which is mostly dolomitized. The average thickness of the cycles is 2.83 m. Thicknesses measured within all 43 shallowing upward cycles are presented in Table 1.

(1) In thin-sections of the foraminiferal-peloidal limestones (Pl. I, Fig. 1) peloids are the most abundant non skeletal particles. Biogenic remains are represented by benthic foraminifera, *Thaumatoporella* and rare *Aeolisaccus*. Lime mud is often recrystallized into microsparite. Late diagenetic dolomitization is indicated by rhombohedral dolomite crystals.

(2) *Chondrodonta* coquinas (= floatstone) consist of *Chondrodonta* shells, which are commonly orientated parallel to the bedding plane. The matrix is lime mud with the same characteristic as the foraminiferal-peloidal limestones. In the basal part of the Slatinica profile there is a *Chondrodonta* coquina with pelsparite matrix. Most of the pellets belong to *Favreina* sp.

(3) Laminated limestones (Pl. I, Fig. 3) are mostly dolomitized, hence the laminated structure is visible on weathered surfaces. In thin-sections micritic laminae are coloured in different shades of grey. Remains of

Thickness (m)			
Subtidal		**Intertidal**	
1.9	1.5	0.4	0.8
5.5	2.0	0.6	1.0
0.5	1.3	0.7	0.8
0.4	1.5	0.5	0.5
2.0	1.9	0.4	0.6
4.0	4.5	0.7	0.9
4.7	4.4	0.5	0.6
1.7	1.1	1.0	0.9
0.7	1.0	0.3	0.8
0.5	3.4	0.4	0.8
1.5	2.3	0.5	0.7
1.4	1.2	1.3	0.5
0.8	2.1	0.3	0.5
1.1	1.5	0.3	0.4
5.1	1.3	1.0	0.6
3.4	4.2	0.3	0.6
1.2	2.1	0.4	0.6
1.1	1.8	1.0	0.8
1.1	2.3	0.5	0.4
2.4	1.1	0.5	0.5
2.1	3.2	0.6	0.7
0.5		0.7	
Sum	89.3	Sum	32.9
Avr.	2.07	Avr.	0.76

Table 1. Thickness of the subtidal and intertidal units in the Slatinica profile (43 shallowing upward cycles measured). Ratio between average thickness of the subtidal and intertidal units is 2.72.

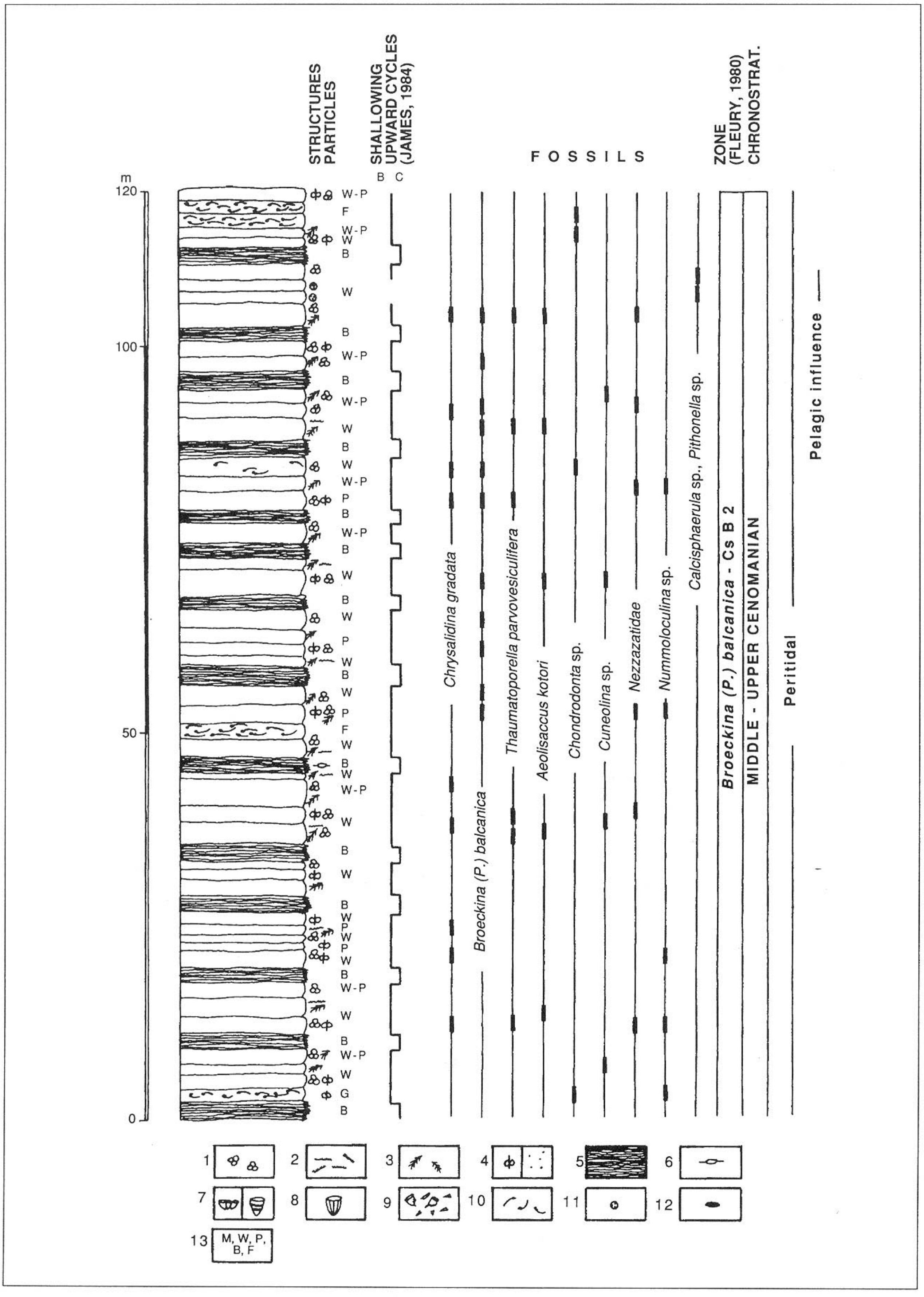


Fig. 2. Stratigraphic section of the Slatinica profile. Shallowing-upward cycles are schematically shown (not to scale). 1 - benthic foraminifera, 2 - Aeolisaccus, 3 - Thaumatoporella, 4 - peloids, 5 - peritidal laminite, 6 - bird-eye structures, 7 - radiolitid thickets and radiolitids, 8 - Hippurites, 9 - rudist floatstones, 10 - Chondrodonta shells, 11 - calcispheres and pithonellas, 12 - Palaeogene foraminiferas, 13 - structural type.

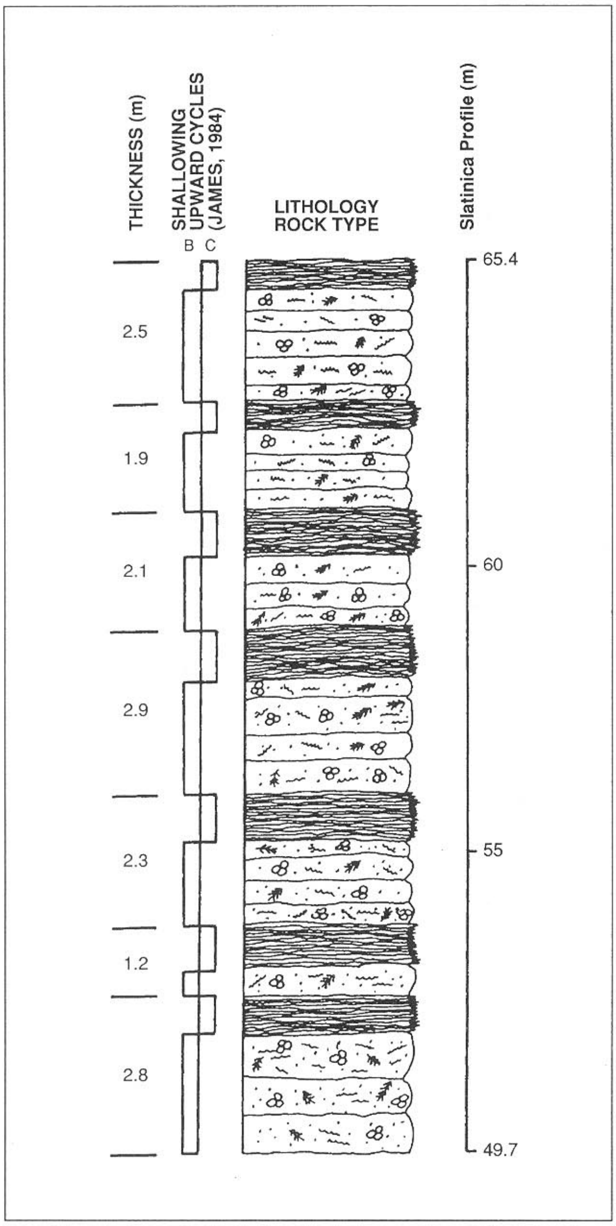


Fig. 3. Part of the Slatinica profile with the typical shallowing-upward cycles.

Thaumatoporella and *Aeolisaccus* are rare and mostly compacted. Bird-eye structures are rare, regular and horizontally arranged.

(4) Within the uppermost 10 m of the Slatinica profile, there are 80 cm thick beds of wackestones characterised by planktonic particles: calcispheres and pithonellas, echinoderm fragments and undefined small-sized calcite debris (Pl. I, Fig. 2).

Foraminiferal-peloidal wackestones and *Chondrodonta* coquinas contain a rich microfossil assemblage (Pl. I, Fig. 1). Stratigraphically, the most important forms are *Broeckina (Pastrikella) balcanica* CHERCHI, RADOIČIĆ & SCHROEDER and *Chrysalidina gradata* d'ORBIGNY. In addition, there are *Nezzazata simplex* OMARA, *Nummoloculina* sp., *Cuneolina* sp., *Nezzazatinella (= Valvulammina) picardi* (HENSON), *Thaumatoporella parvovesiculifera* RAINERI and *Aeolisaccus kotori* RADOIČIĆ. Among the macrofauna, *Chondrodonta* sp. and undetermined radiolitid fragments have been found. In the wackestones from the uppermost 10 m of the Slatinica profile small calcispheres and pithonellas have been determined.

Determination of a Middle to Upper Cenomanian age is based on microfossils of FLEURY'S (1980) CsB2 zone with *Broeckina (Pastrikella) balcanica, Chrysalidina gradata* and *Chondrodonta* sp. The upper boundary of the Slatinica profile is marked by faulting.

2.2. GARMINA AND MLJAKE PROFILES (UPPER TURONIAN - LOWER SANTONIAN)

In the vertical succession of the Garmina and Mljake profiles (Figs. 4 and 5), there is also regular repetition of four different facies which form sedimentary cycles. The subtidal part of the cycles is represented by (1) foraminiferal-peloidal wackestones-packstones in alternation with (2) *Aeolisaccus* and *Thaumatoporella* wackestone, and, especially in the Garmina profile, (3) rudist floatstones. The upper part and top of each cycle is represented by (4) laminated limestones. The thickness of the subtidal members ranges between 0.8 - 5.9 m, and intertidal laminates from 0.3 - 0.9 m. The average thickness of each cycle is 3.27 m, and thicknesses measured within all 47 shallowing upward cycles of the Garmina profile are presented in Table 2.

(1) In the foraminiferal-peloidal wackestones-packstones (Pl. II, Figs. 3 and 5) peloids are the most abundant allochems, and *Aeolisaccus*, *Thaumatoporella* and benthic foraminifers are the most abundant fossil remains. Lime mud is often recrystallized into microsparite. Rare rhombohedral crystals of late diagenetic dolomite are present.

(2) *Aeolisaccus* and *Thaumatoporella* are the most abundant fossil remains in *Aeolisaccus* and *Thaumatoporella* wackestone and *Aeolisaccus* laminites (Pl. II, Figs. 1 and 4). Lime mud is often recrystallized into microsparite.

(3) Rudist floatstones consist of fragments and whole right valves of radiolitids and rare hippuritids (Pl. III, Fig. 4). In the Garmina profile the upper boundary of the floatstone is marked by radiolitid thickets (Pl. III, Figs. 2, 3 and 6) in growth position, overlain with laminite.

(4) Laminated limestones are mostly dolomitized, and laminated structure is visible on weathered surface (Pl. III, Fig. 1). In thin sections micritic laminae are coloured in different shades of grey. They are totally barren of fossils or contain very rare *Aeolisaccus*. In the field work rudist fragments were observed in the lower part of laminites. Regular bird-eyes are present in the laminites of the lower part of the Garmina profile.

The age of the Garmina and Mljake profiles is based on the following genera and species (Pl. II, Figs. 1, 3, 4 and 5): *Scandonea samnitica* DE CASTRO, *Moncharmontia apenninica* (DE CASTRO), *Pseudocyclammina sphaeroidea* GENDROT, *Nummoloculina* sp., *Cuneo-*

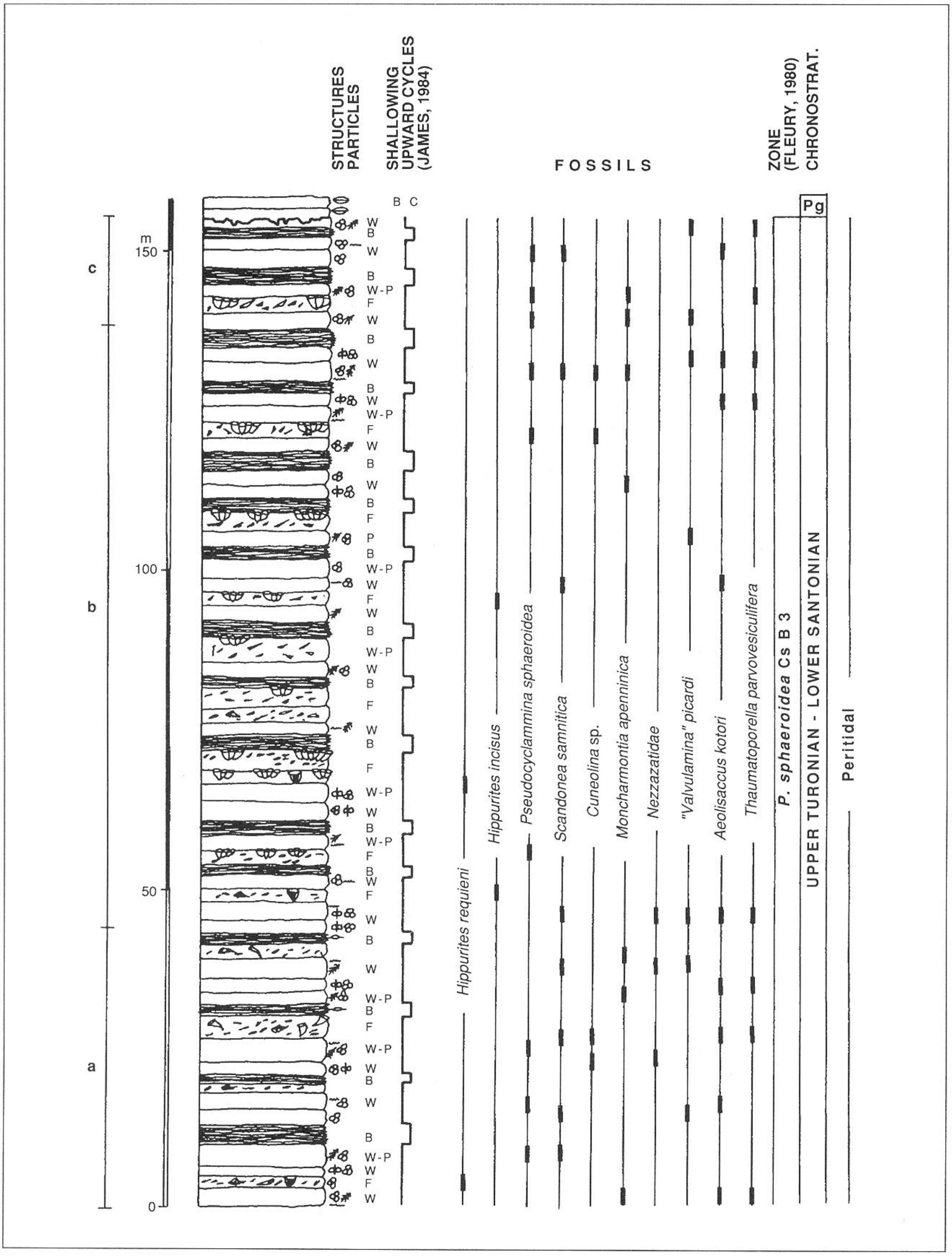


Fig. 4. Stratigraphic section of the Garmina profile (local profiles: a-Cape Slanac, b-Cape Garmina and c-Fučinska cove). Shallowing-upward cycles are schematically shown (not to scale).

lina sp., *Nezzazatinella (= Valvulammina) picardi* (HENSON), *Nezzazata* sp., *Aeolisaccus kotori* RADOIČIĆ and *Thaumatoporella parvovesiculifera* RAINERI. In rudist floatstones of the Garmina profile *Hippurites requieni* MATHERON and *Hippurites incisus* DOUVILLE were found.

The above listed microfossils suggest correlation with FLEURY'S (1980) CsB3 zone with *Pseudo-*

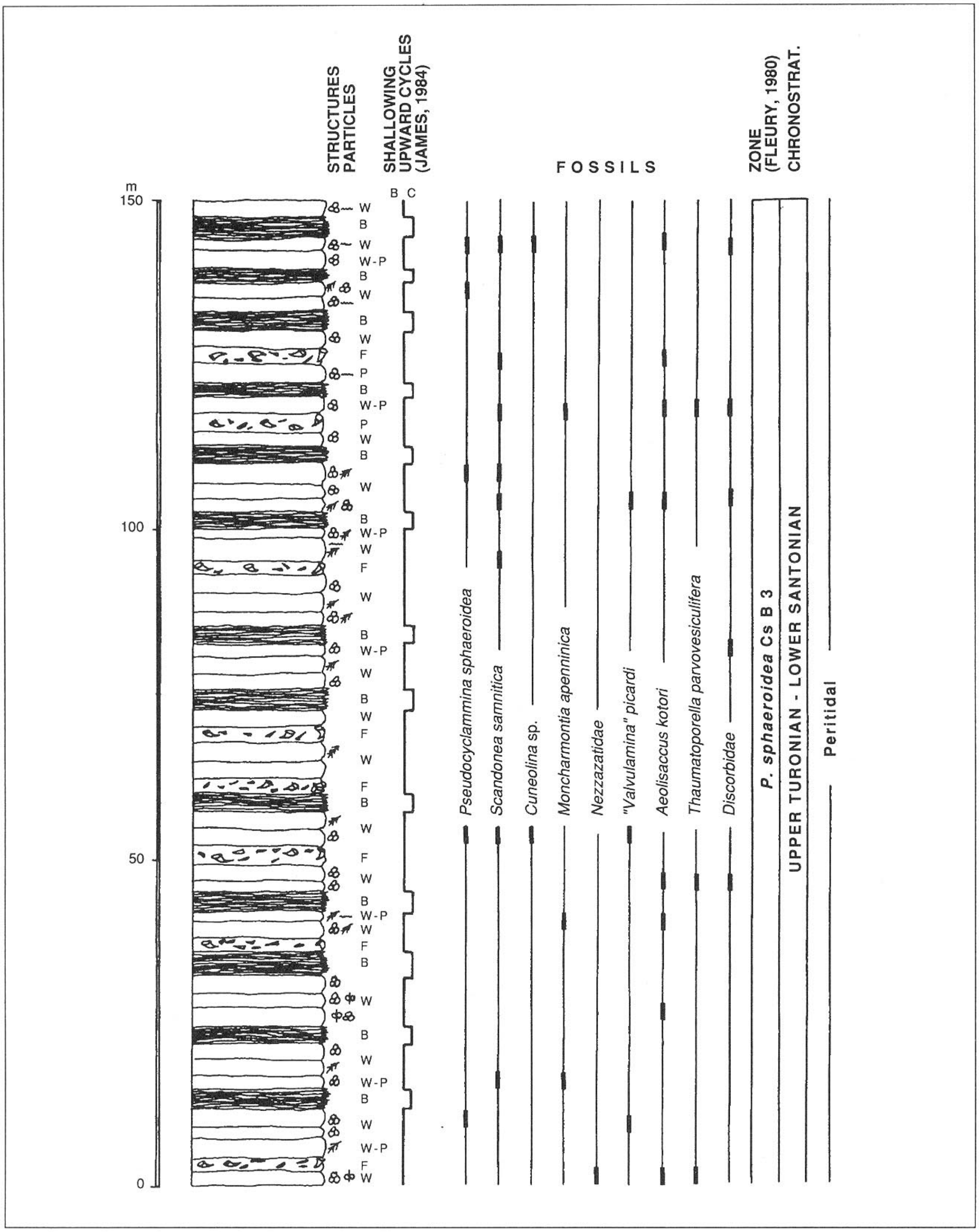


Fig. 5. Stratigraphic section of the Mljake profile. Shallowing-upward cycles are schematically shown (not to scale).

cyclammina sphaeroidea. According to POLŠAK (1965, 1967) *Hippurites requieni* is characteristic for the subzone C of III rudist cenozone, and *Hippurites incisus* for the beginning of the IV rudist cenozone. Therefore, chronostratigraphically, this fossil assemblage corresponds to the Upper Turonian-Lower Santonian range.

Upper Cretaceous beds of the Garmina profile are transgressively overlain with Lower Lutetian beds, while the upper boundary of the Mljake profile is marked by faulting.

Thickness (m)			
Subtidal		**Intertidal**	
2.1	4.8	0.5	0.4
2.3	2.6	0.6	0.6
1.9	5.5	0.7	0.7
3.2	1.7	0.9	0.5
1.7	2.0	0.8	0.8
2.4	2.8	0.6	0.5
1.5	3.6	0.4	0.7
2.0	1.6	0.5	0.6
5.7	3.2	0.6	0.6
4.2	1.3	0.8	0.9
3.6	1.6	0.4	0.5
3.0	1.1	0.6	0.5
2.4	4.3	0.5	0.6
1.0	3.7	0.6	0.8
2.0	2.6	0.4	0.7
3.2	0.8	0.6	0.5
4.1	1.1	0.7	0.3
3.5	5.9	0.5	0.8
4.5	3.1	0.6	0.4
2.5	1.5	0.5	0.3
1.7	2.0	0.6	0.7
3.1		0.4	
2.2		0.8	
2.3		0.7	
1.4		0.3	
1.9		0.6	
Sum	126.2	Sum	27.6
Avr.	2.685	Avr.	0.587

Table 2. Thickness of the subtidal and intertidal units in the Garmina profile (47 shallowing upward cycles measured). Ratio between average thickness of the subtidal and intertidal units is 4.57.

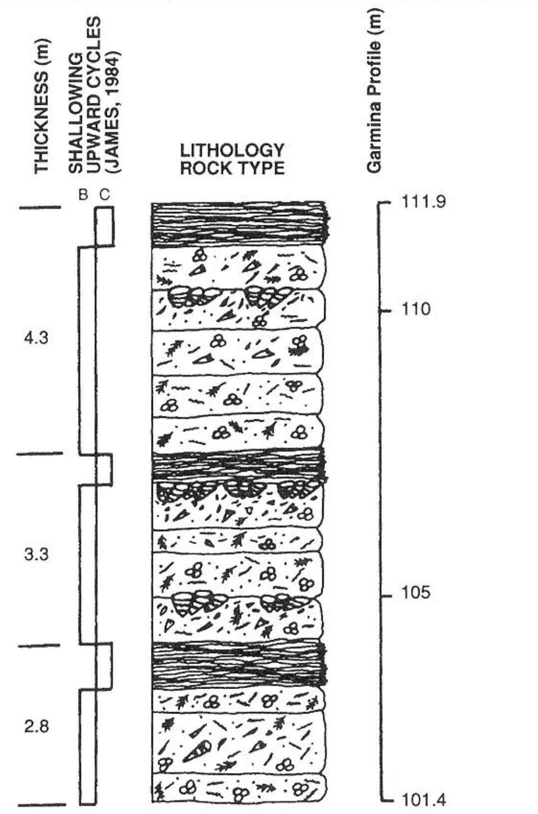


Fig. 6. Part of the Garmina profile with the typical shallowing-upward cycles.

3. DISCUSSION

3.1. SHALLOWING-UPWARD CYCLES

In the vertical succession of the Slatinica profile, there is a repetition of subtidal deposits, i.e. foraminiferal-peloidal wackestones with *Chondrodonta* coquinas, in alternation with intertidal laminites (Fig. 3). These subtidal and intertidal sediments have characteristics of the B and C units within the carbonate shallowing-upward cycles described by JAMES (1984). In the concepts of sequence stratigraphy, the shallowing upward cycles are termed parasequences, which result from fourth/fifth order relative sea-level changes (TUCKER, 1993). Parasequences of the Slatinica profile (Fig. 3) have a relatively high proportion of subtidal facies over intertidal facies (subtidal/intertidal ratio 2.72; Table 1, Fig. 7). This indicates that peritidal sediments of the Slatinica profile were deposited during late HST to LST, when third order relative sea level curve was falling. In the upper part of the Slatinica profile lithofacies and biotic change occur, which are marked by the occurrence of limestones with planktonic organisms. These limestones probably represent the beggining of TST within the next sequence, which in the study area is partly represented in the Garmina and Mljake profiles.

Upper Turonian - Lower Santonian shallowing-upward cycles of the Garmina and Mljake profiles consist of B and C units, similar to the Upper Cenomanian Slatinica profile (Fig. 6). The subtidal B unit consists of two motifs. One is foraminiferal-peloidal and *Aeolisaccus-Thaumatoporella* wackestone, and the other is rudist (mainly radiolitid) floatstone with a wackestone matrix. In the Garmina profile, at the top of rudist floatstones, radiolitid thickets are common, mostly overlain by laminated limestones which correspond to the intertidal C unit. Laminites without desiccation cracks probably represent the end of an incomplete shallowing-upward cycle. Regular and horizontally arranged bird-eyes ("fenestral fabric") indicate lower intertidal environments (JAMES, 1984).

Rare hippuritids which are found in growth position within floatstones presumably lived in a deeper subtidal environment, and therefore they are not found in contact with laminites. Radiolitids probably lived in thickets in the upper subtidal realm on muddy bottoms. Contrary to the hippuritids, such radiolitid thickets are often directly overlain by laminite (as in the Sumartin Formation of Maastrichtian age, Brač Island; GUŠIĆ & JELASKA, 1990).

Shallowing-upward cycles (parasequences) of the Upper Turonian - Lower Santonian Garmina and

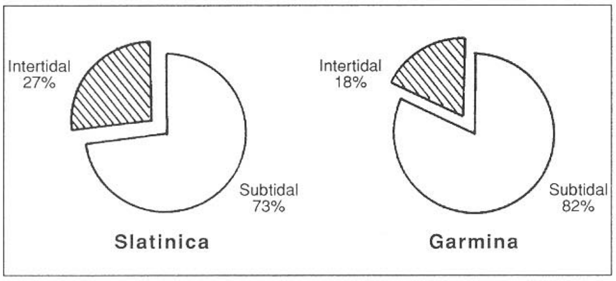
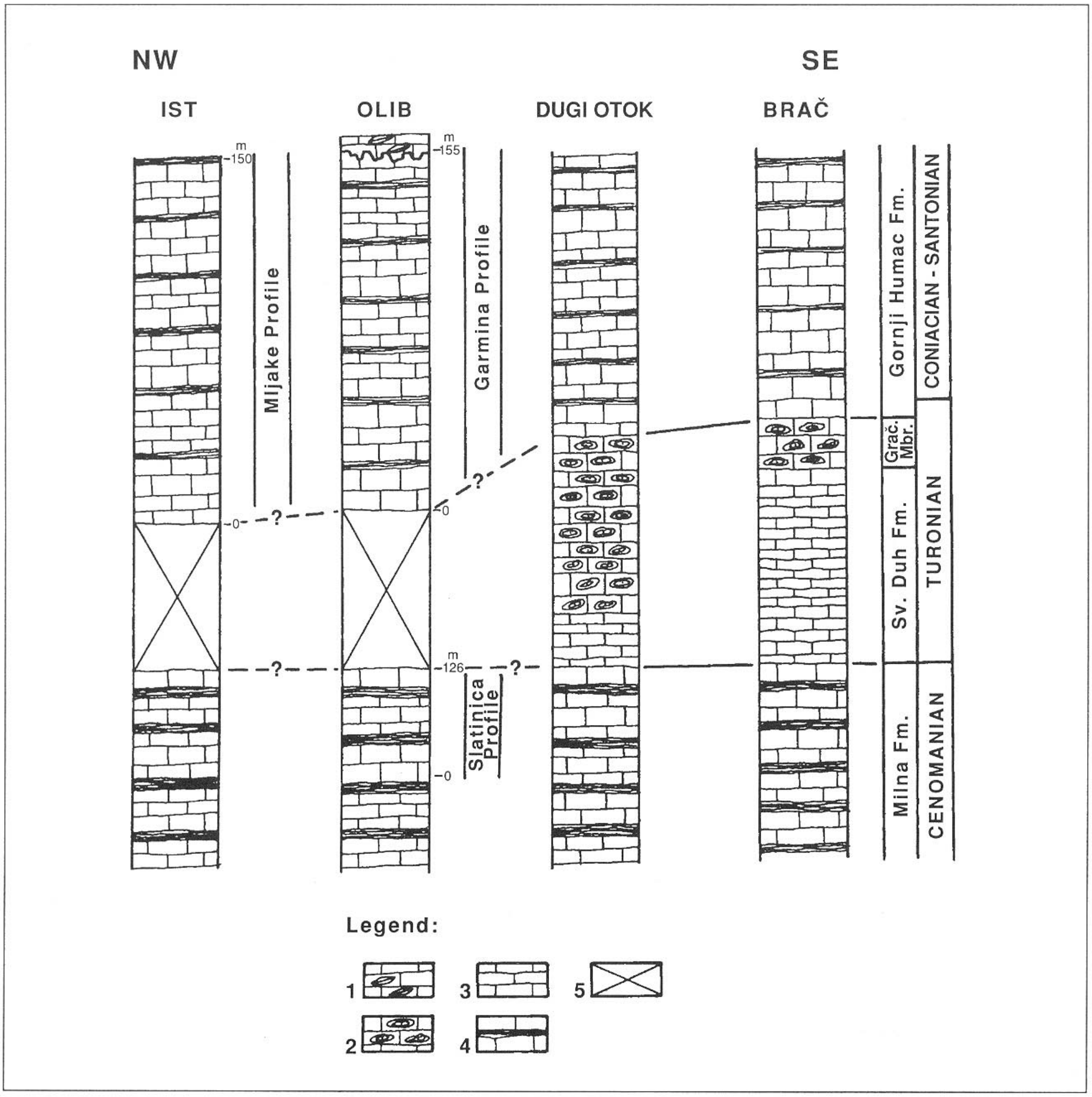


Fig. 7. Proportions of subtidal and intertidal sediments in 122.2 m of the Slatinica profile and 153.8 m of the Garmina profile

Mljake profiles, were presumably sedimented during upper part of TST and early HST, due to the fact that thick subtidal sediments are more dominant over thin intertidal laminites than in the Slatinica profile (subtidal/intertidal ratio 4.57 compared to 2.72 respectively; Tables 1 and 2, Fig. 6 and 7, Pl. III, Fig. 1).

3.2 CORRELATION WITH PERITIDAL DEPOSITS OF BRAČ AND DUGI OTOK ISLANDS

On the basis of the lithological and fossil characteristics, the Slatinica profile is correlatable with the Milna Formation of Brač Island (GUŠIĆ & JELASKA, 1990) and the Mir profile of Dugi Otok Island (FUČEK et al., 1990) (Fig. 8). These are overlain by micrites with planktonic biota. These pelagic limestones represent a sedimentary record of global transgression which occurred around the Cenomanian-Turonian boundary (HAQ et al., 1987). Consequently, limestones with calcisphaerulids of the Slatinica profile are, in facies and stratigraphy, correlatable with the beginning of the Sveti Duh Formation of Brač Island (GUŠIĆ & JELASKA, 1990). Sediments of the Lower to Middle Turonian age are missing in the study area due to tectonic reduction. Penecontenporaneous sediments in the broader area of the Adriatic carbonate platform (Brač and Dugi



Otok islands) are represented by the deeper-water Sveti Duh Formation, which is in turn, overlain by the oncoid-bearing shallow-water Gračišće Member (GUŠIĆ & JELASKA, 1990; FUČEK et al., 1990).

Upper Turonian to Lower Santonian peritidal limestones of the Garmina and Mljake profiles correspond in facies and stratigraphy to the Gornji Humac Formation of Brač Island (GUŠIĆ & JELASKA, 1990) and the upper part of the Jaz profile of Dugi Otok Island (FUČEK et al., 1990).

The upper boundary of the Upper Turonian - Lower Santonian peritidal deposits in the study area is clearly marked by emersion. The interruption in sedimentation presumably occurred in the Santonian, prior to the *Murgella lata* level.

4. CONCLUSION

The Upper Cenomanian peritidal deposits with a relatively high proportion of subtidal over intertidal sediments correspond to the late HST to LST. Massive micrites with planktonic biota at the top of the Upper Cenomanian Slatinica profile represent the first impulses of global transgression which occurred around the Cenomanian-Turonian boundary (HAQ et al., 1987). They also indicate the beginning of the TST, which is partly represented in Garmina and Mljake profiles in the study area.

Lower to Middle Turonian sediments are not present in the study area as a result of tectonism.

The higher proportion of the subtidal over intertidal sediments within the younger sequence, compared to the Slatinica profile (Middle to Upper Cenomanian), indicates that peritidal sediments of the Upper Turonian-Lower Santonian age have TST and early HST characteristics.

Senonian limestones of the Olib and Ist islands are older than the *Murgella lata* level. They are transgressively overlain by Lower Lutetian beds.

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Fig. 8. Correlation of the study area profiles with Dugi otok (FUČEK et al., 1990) and Brač island (GUŠIĆ & JELASKA, 1990). Lithostratigraphic subdivision after GUŠIĆ & JELASKA (1990). 1 - Paleogene beds, 2 - Oncolite bearing facies, 3 - Sv. Duh Formation, 4 - Peritidal deposits, 5 - Stratigraphic gap.

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PLATE I

1 Foraminiferal-peloidal wackestone with *Chrysalidina gradata* D'ORBIGNY and *Broeckina (Pastrikella) balcanica* CHERCI, RADOIČIĆ & SCHROEDER. Muddy matrix partly recrystallized to microsparite. Subtidal B unit of the shallowing-upward cycle. Slatinica profile. Scale bar 1.6 mm.

2 Wackestone with pithonellas, calcispheres and undefined calcitic debris. Slatinica profile. Scale bar 0.4 mm.

3 Micritic laminae with different shades of grey. Intertidal C unit of the shallowing-upward cycle. Slatinica profile. Scale bar 0.4 mm.

PLATE II

1 *Aeolisaccus* wackestone with muddy matrix partly recrystallized to microsparite. Subtidal B unit of the shal lowing-upward cycle. Garmina profile. Scale 0.8 mm.

2 Micritic laminae in different shades of grey, which correspond to the intertidal C unit of the shallowing-upward cycle. Garmina profile. Scale bar 0.4 mm.

3 *Aeolisaccus-Thaumatoporella* laminite. Subtidal B unit of the shallowing-upward cycle. Garmina profile. Scale bar 0.8 mm.

4 *Scandonea samnitica* (DE CASTRO). Mljake profile. Scale bar 0.8 mm.

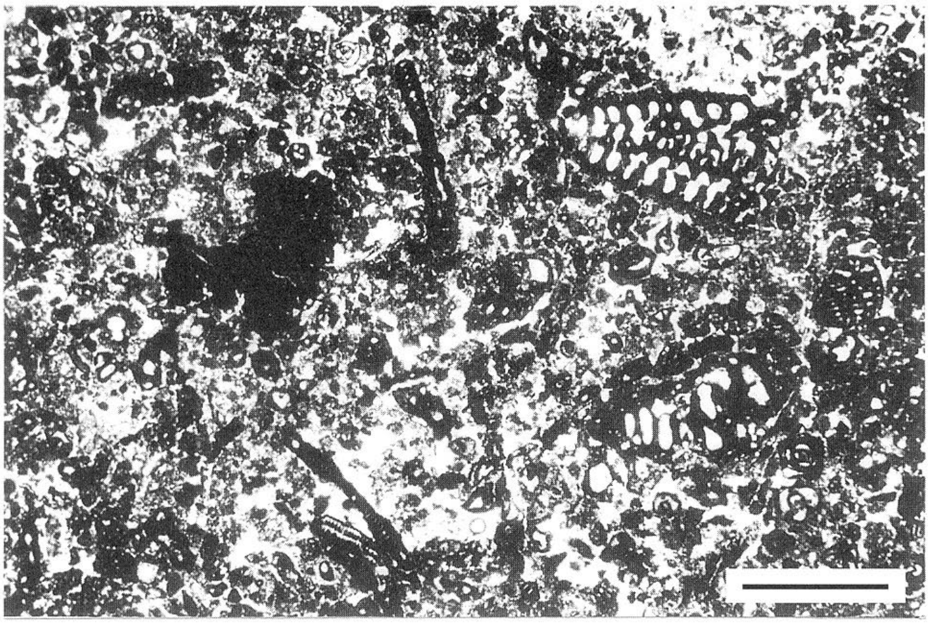
5 Foraminiferal-peloidal wackestone with *Pseudocyclammina sphaeroidea* GENDROT and *Moncharmontia apeninnica* (DE CASTRO). Muddy matrix partly recrystallized to microsparite. Subtidal B unit of the shal lowing-upward cycle. Garmina profile. Scale bar 0.8 mm.

PLATE III

1 Shallowing-upward cycles with B and C units. Garmina profile.

2, 3 Upper bedding planes of the floatstone with Radiolitid thicket in growth position. Garmina profile.

4 Upper bedding plane of the rudist floatstone with Radiolitids and a Hippurites. Garmina profile.



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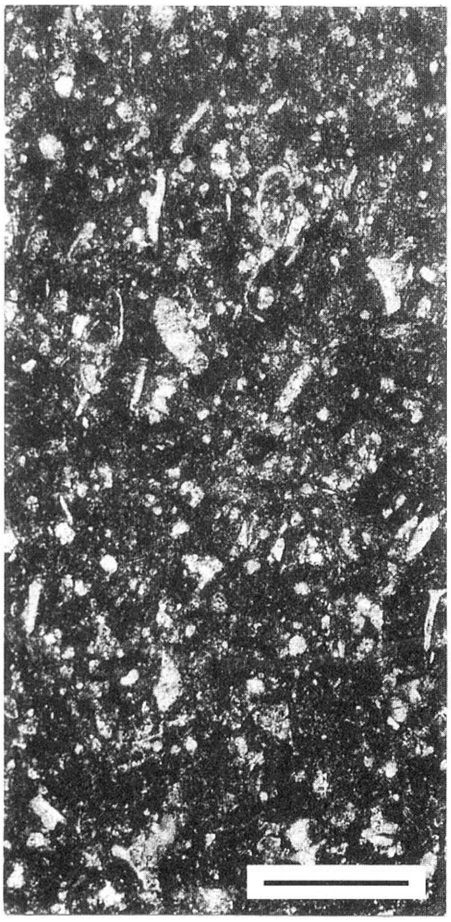

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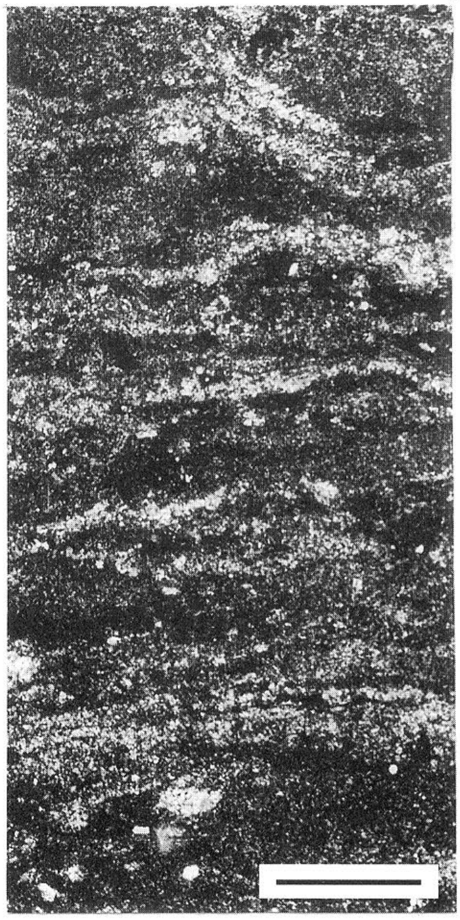

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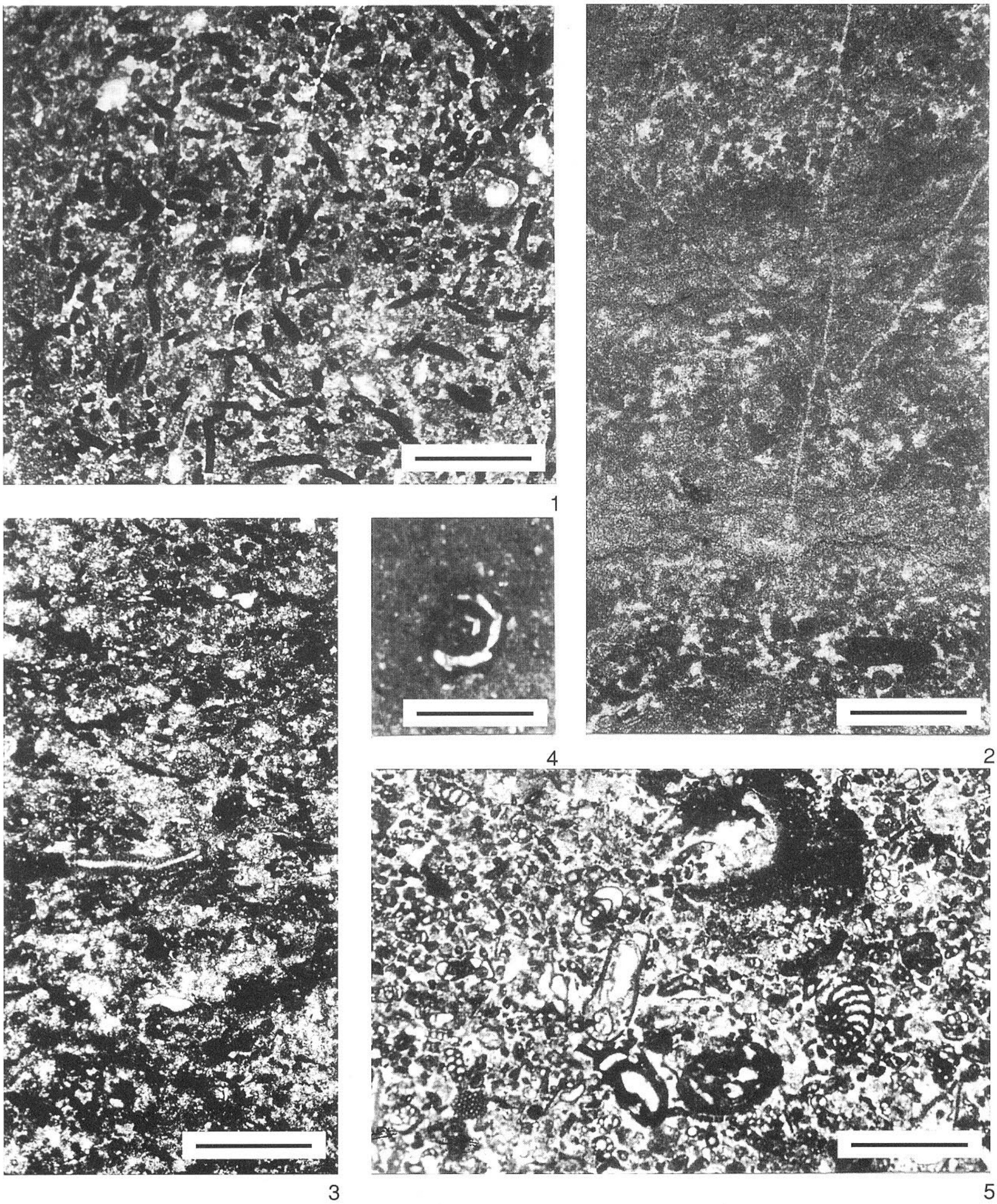
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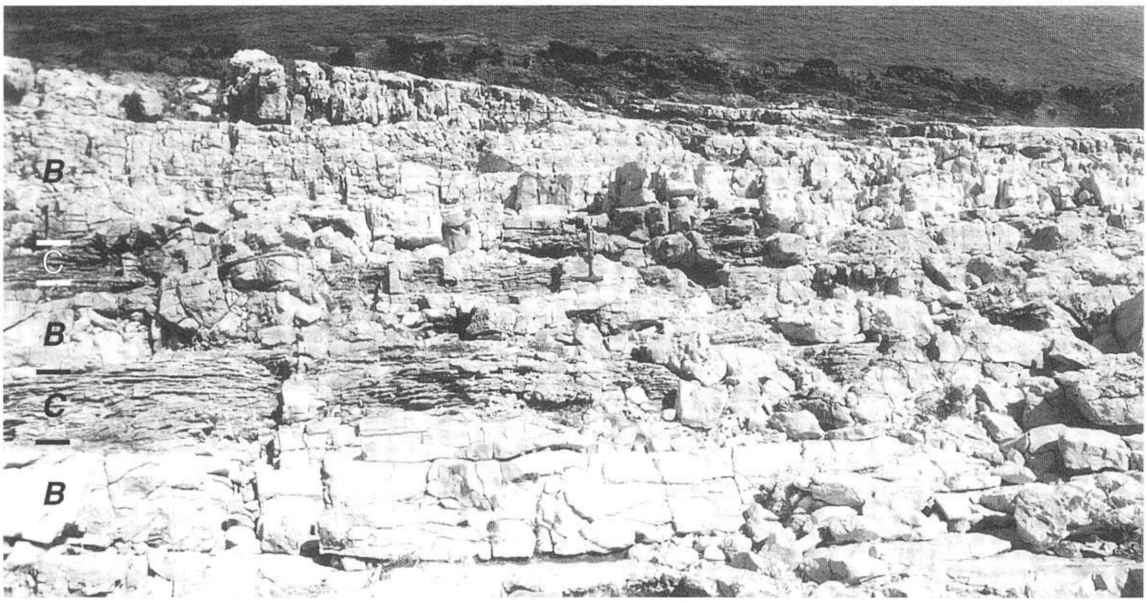

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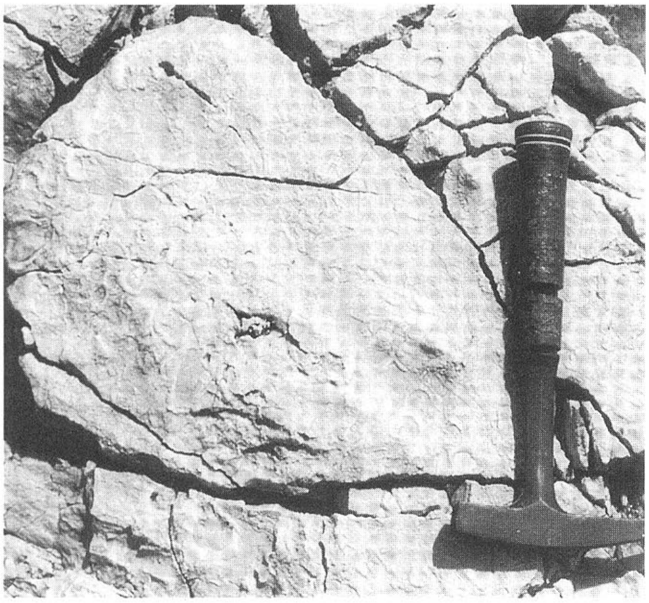

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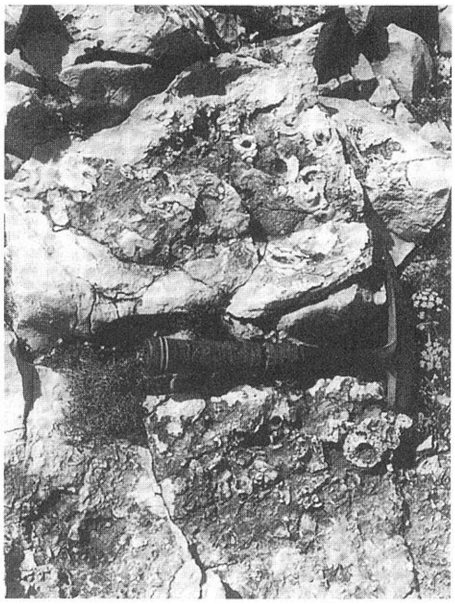

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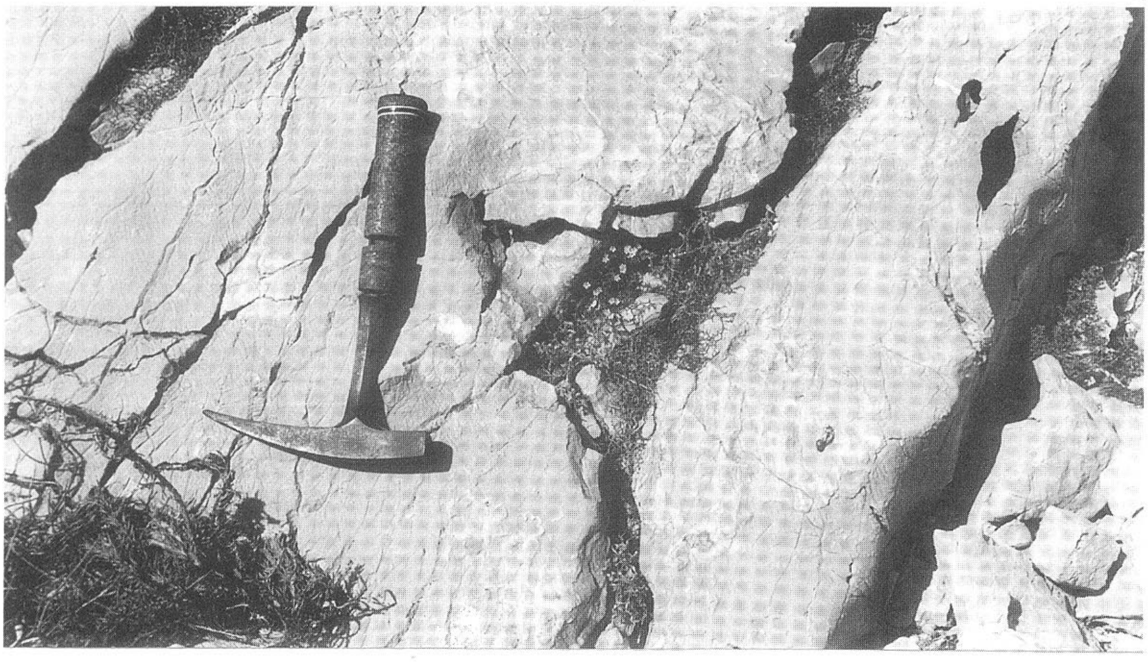

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