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Microfacies analysis of limestones from the Upper Cretaceous to the Lower Eocene of SW Slovenia (Yugoslavia)

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Abstract

A microfacies analysis of limestone samples from NW Yugoslavia (Slovenia) was carried out. The microscopic observations were complemented with palynological and geochemical data including determination of isotopic ratios. The findings point to a regressive development which took place during the Senonian and culminated in karst and subsequent bauxitization. In a later stage of subaerial exposure, calichification occurred overlapping the karst facies. At the beginning of the Tertiary, a transgression unfolded and the Kozina limestones started to form. Due to sea level changes and climatic factors, these sediments show superimposed palustrine and brackish intertidal to subtidal horizons which were diagenetically altered thus presenting a complicated facies pattern. Overlaying the Kozina limestones, the Late Paleocene Miliolid limestones occur. These are brackish intertidal to subtidal sediments that underwent prolonged periods of subaerial exposure, too. There is a gradual predominance of marine organisms in the vertical sequence that reaches its maximum in the next unit, the Alveolina-Nummulites limestones (Early Eocene). The three stratigraphic units dealt with in this study reflect gradual but important facies changes which are stressed here.

Introduction

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The present study gives a reconstruction of the facies development that took place during the time interval from Upper Cretaceous to Early Eocene in SW Slovenia.

The analysis focuses on the interpretation of the depositional environments and diagenesis of the Tertiary limestones, especially of the limestones that were deposited at the beginning of the Tertiary age, the Kozina limestones.

Several investigators (Stache, 1889; Hamrla, 1960; Pleničar, 1961; Pavlovec, 1963; Drobne et al, 1988) consider these limestones to have been originated under most diverse conditions. Among the proposed depositional settings there are lakes, estuaries and brackish lagoons. The Kozina beds also show marine intercalations rendering the facies spectrum almost complete. This facies complexity is generally taken to be the result of tectonic instability since the Laramian movements of the Alpine orogenesis were still active in the area at the beginning of the Tertiary.

Taken as a whole, the entire Tertiary sequence shows a clear transgressive character which is, of course, unthinkable without tectonics.

Last but not least, the authors refer to the Cretaceous-Tertiary boundary in the studied area which is marked by an unconformity that can be easily recognized in the field. Moreover, this boundary shows some interesting features that may help to interpret the subsequent facies development.

Tectonic structure of the investigated territory

Regarding the broadest geotectonic division of Slovenia, the discussed territory belongs to the Outer Dinarids, the rocks of which originated – from the paleogeographic point of view – on the Dinaric carbonate platform. In the narrow tectonic division this territory makes part of the Materija anticline. The axis of the anticline is directed NW-SE and plunges northwest under a modest angle. In its northern part where profiles 2 (NE of Materija) and 3 (Slivje) are sited, the Cretaceous and the Paleogene beds dip 10 to 30° northeast. In the surroundings of Kozina where profile 1 is sited on the crest of the anticline, the beds dip 40 to 50° west. In the area between Kozina and Slavnik they beds dip steeper southwest; the reach vertical or even overturned position and are scaled in places.

The investigated territory is affected by rare faults. An important fault directed NW-SE runs northeast of Kozina. The same fault can be followed also north of Materija and Markovščina. Along this fault a horizontal slip for about 1,200 m displaced the Paleogene and the Cretaceous beds northeast of Materija. A shorter horizontal displacement can be seen also in Kozina close to profile 1.

The region shows a typical karst topography characterized by numerous dolines. Deep reaching solution weathering which took place especially during the Pleistocene caused the development of subterraneous river systems.

Stratigraphy

The problem of the Cretaceous-Tertiary boundary in the West Dinarides was first studied by the Austrian geologist Stache in the years 1859 to 1889. He introduced the term "Liburnian stage" for the limestone beds which were deposited, according to him, between the uppermost Cretaceous and the lowest Tertiary. The "Liburnian stage" he divided into Lower foraminiferal limestones, Kozina beds and Upper foraminiferal limestones (Stache, 1889).

Instead of "Liburnian stage", Pavlovec and Pleničar (1979) proposed the term "Liburnian formation", since, they argued, the sequence of the beds really extends through several stages. The same authors regard the Lower foraminiferal limestones (which they named "Vreme beds") to be of Maastrichtian age (Pavlovec & Pleničar, 1979), the Kozina beds to be of Lower Paleocene age (Danian) and the Upper foraminiferal limestones (named "Miliolid limestones") to be of Thanetian age. Overlying the Miliolid limestones the so-called Alveolina-Nummulites limestones occur. They belong to the Ilerdian and Cuisian (Drobne & Pavlovec, 1979).

Regarding the proposal of a new division of the Paleogene beds (Cavelier

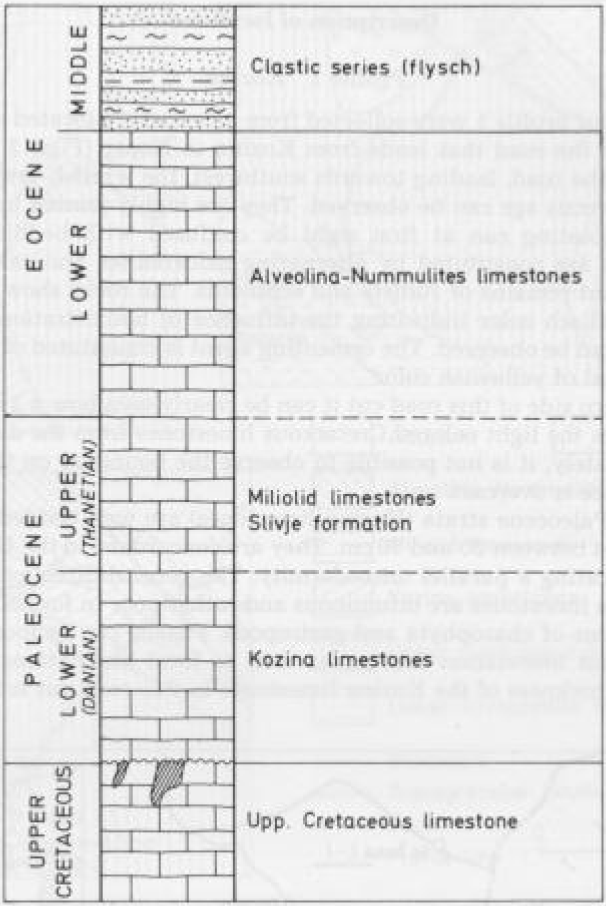


Fig. 1. Schematic profile displaying the stratigraphic units of the studied area

& Pomerol, 1986) in which the Ilerdian is placed into the Upper Eocene and hence lowering the Paleocene-Eocene boundary, the investigated beds can be stratigraphically ranged as follows: the Kozina limestone belongs to the Lower Paleocene or the Danian respectively, the Miliolida limestone to the Upper Paleocene or the Thanetian and the Alveolina – Nummulite limestone to the Lower Eocene (Fig. 1)

The carbonate sequence is overlain by clastic series (flysch) – not analized in this paper – considered to be of Middle Eocene age.

The Vreme beds are not present in the studied localities. Instead, Cretaceous rocks here are constituted by rudistid and micritic limestones which we take to have formed during the Turonian and Senonian. The schematic profile (Fig. 1) shows the stratigraphic units dealt with in the present paper. As we shall discuss later, the stratigraphic subdivision of the Tertiary also reflects important changes of facies. It should be pointed out, however, that the transitions between the carbonate units within the Tertiary sequence are far from being abrupt.

Description of localities

Profile 1 *Kozina*

The samples of profile 1 were collected from an exposure located about 15 km SE from Trieste on the road that leads from Kozina to Koper (Figs. 2 and 3). On the eastern side of the road, leading towards southwest, the whitish-grayish limestones of Upper Cretaceous age can be observed. They are highly jointed in such a regular way that the jointing can at first sight be confused with bedding planes. The limestones here are constituted by alternating calcarenites and calcirudites. They contain abundant remains of rudists and echinoids. The rocks show in some places a brownish-reddisch color indicating the influence of bauxitization. Local brecciation textures can be observed. The cementing agent is constituted of calcareous and bauxitic material of yellowish color.

On the eastern side of this road cut it can be clearly seen how a 3 m thick bauxite pocket separates the light colored Cretaceous limestones from the darker Paleocene beds. Unfortunately, it is not possible to observe the boundary on the western side because the place is overcast.

The Lower Paleocene strata (Kozina limestones) are well bedded having individual thicknesses between 20 and 70 cm. They are concordant to the Upper Cretaceous strata indicating a parallel unconformity. The general direction of dip is W to SW. The Kozina limestones are bituminous and rather poor in fossils. In some places they bear remains of charophyta and gastropods. Pisoids can be locally recognized. Bioturbation and brecciation fabrics, as well as local laminations are commonly observed. The thickness of the Kozina limestones in this road cut totals 61 m.

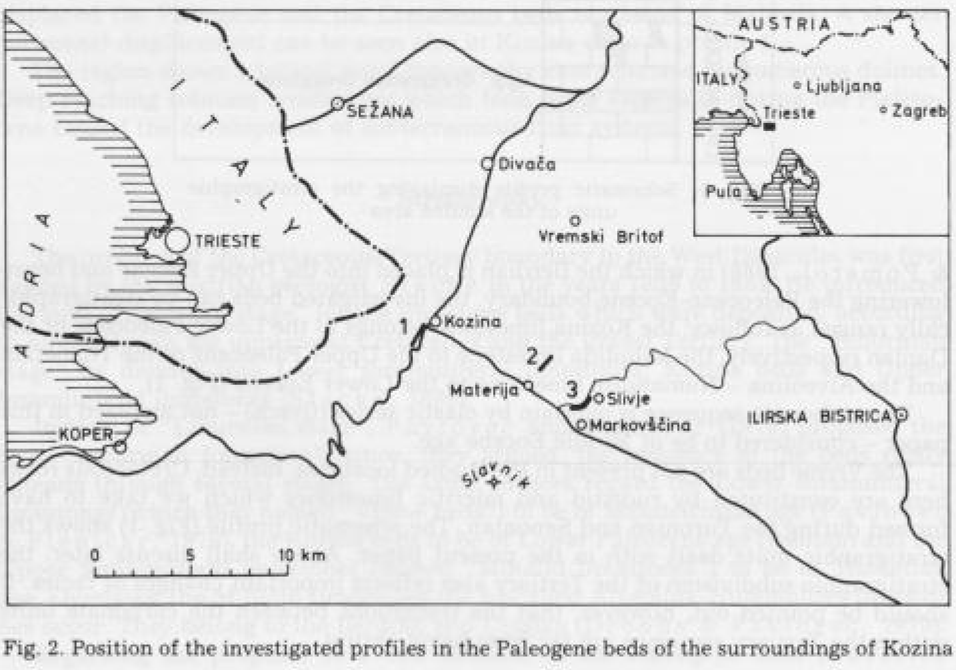


Fig. 2. Position of the investigated profiles in the Paleogene beds of the surroundings of Kozina

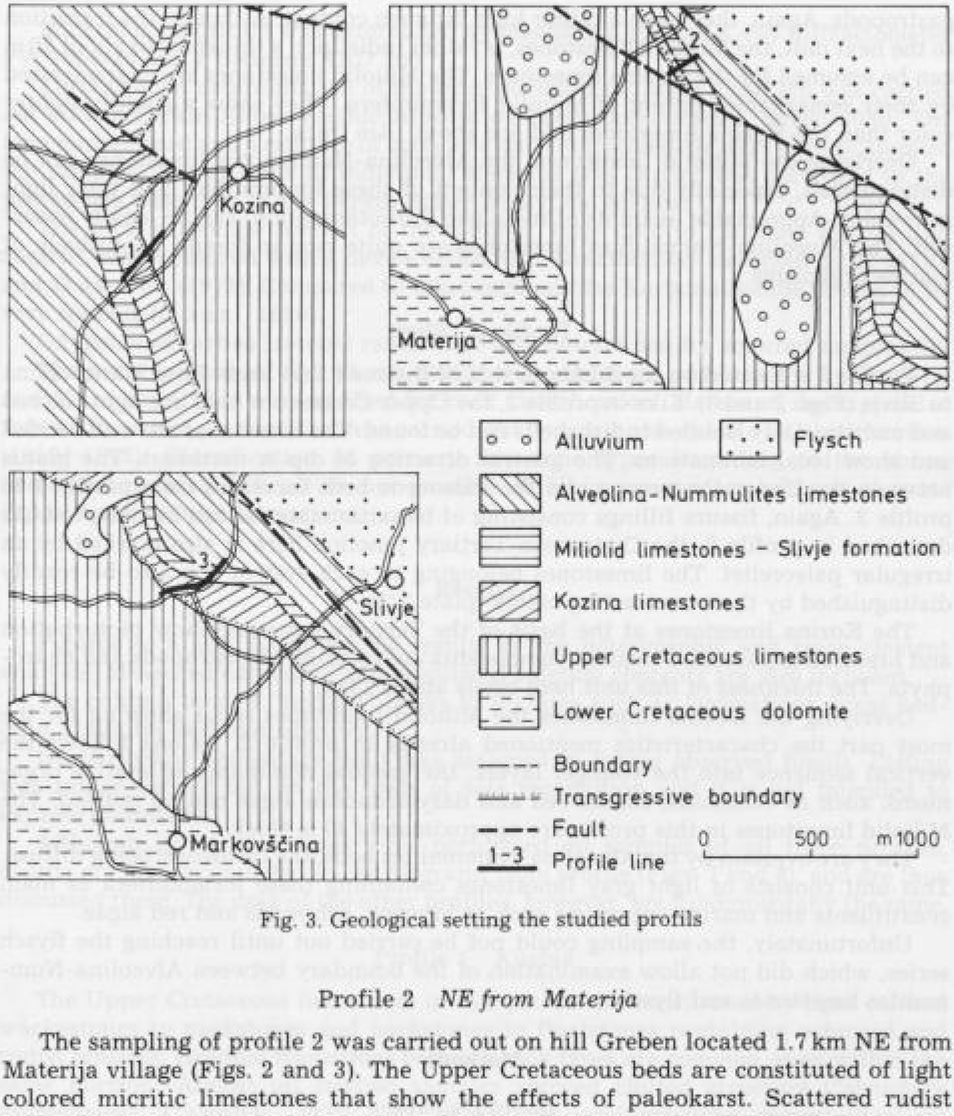


Fig. 3. Geological setting the studied profils

Profile 2 *NE from Materija*

The sampling of profile 2 was carried out on hill Greben located 1.7 km NE from Materija village (Figs. 2 and 3). The Upper Cretaceous beds are constituted of light colored micritic limestones that show the effects of paleokarst. Scattered rudist shells can be found. Like in profile 1 brecciation textures can be locally observed. Again, the cementing material is calcareous and bauxitic. Minor local bauxite intercalations are also present.

The contact between Cretaceous and Tertiary limestones can be readily recognized since the rocks show conspicuous differences in color. Also, the boundary is characterized by an irregular paleorelief exhibiting former solution cavities. These cavities were filled up with dark Lower Paleocene sediments. In profile 2 the Kozina limestones have very much the same apperance as in profile 1. In comparison to the Upper Cretaceous limestones they are obviously the better soil builders as can be seen from the terrain morphology. The beds contain remains of charophyta and gastropods. Again, they have a rather high bitumen content. Although the transition to the next unit, the Miliolid limestones, is rather indistinct, a thickness of about 20 m can be assumed for the Kozina limestones. The Miliolid limestones are characterized by their remarkable content of miliolid foraminifera. They show a slightly lighter color than the Kozina limestones and are about 16 m thick.

Overlying the Miliolid limestones, the Alveolina-Nummulites limestones can be distinguished, especially due to their content of these foraminifera and their light gray color. Appreciable amounts of red algae *(Lithothamnium)* can be locally observed. The Alveolina-Nummulites limestones are quite rich in fossils, exclusively of marine organisms.

Profile 3 *Slivje*

Profile 3 is located on the northern side of the road that leads from Markovščina to Slivje (Figs. 2 and 3). Like in profile 2, the Upper Cretaceuos beds are light colored and micritic. Only isolated rudist shells can be found. The limestones are well bedded and show local laminations. The general direction of dip is northeast. The hiatus between the Upper Cretaceous and the Paleocene beds increases from profile 1 to profile 3. Again, fissure fillings consisting of bauxitic material can be observed. As described in profile 2, the Cretaceous-Tertiary junction here is also marked by an irregular paleorelief. The limestones belonging to each system can also be readily distinguished by their contrasting colors (plate 7/1).

The Kozina limestones at the basis of the Tertiary sequence show bioturbation and brecciation fabrics. Frequent components are remains of gastropods and charophyta. The thickness of this unit here totals about 73 m.

Overlying the Kozina limestones the Miliolid limestones occur showing for the most part the characteristics mentioned already in profile 2. As one follows the vertical sequence into the younger layers, the gradual dominance of marine organisms, such as echinoids, corals, red and dasycladacean algae can be noticed. The Miliolid limestones in this profile are approximately 47 m thick.

They are overlain by the Alveolina-Nummulites beds, the transition being diffuse. This unit consists of light gray limestones containing these foraminifera as main constituents and marine organisms such as bryozoa, echinoids and red algae.

Unfortunately, the sampling could not be carried out until reaching the flysch series, which did not allow examination of the boundary between Alveolina-Nummulites limestones and flysch.

Methods

David Delvalle

A total of 154 samples was collected from the localities described above. All samples were cut at right angles to bedding planes, and the more suitable halves were selected for the preparation of acetate peels according to the method described by McCrone (1963). The remaining material was ground and kept for mineralogical and geochemical analysis.

Acetate peels were examined with a microfiche reading device which allowed a maximal 42-fold enlargement and proved to be most useful for observation.

Thin sections were made from selected samples in order to solve special problems such as recrystallization, cement types and optic orientation of crystals.

Mineral composition was determined by means of a Philips X-ray diffractometer PW 1050/25 and a Siemens XRD 500.

Furthermore, determination of the trace elements Sr, Mg, Fe and Mn was carried out with a Perkin Elmer Atomic Absorption Spectrophotometer, model 3030. The long burner head and a mixture of acetylene and compressed air were used to atomize the samples. The analysis of individual elements was carried out according to the procedures described in the Perkin Elmer Analytical Manual.

The total carbonate content of the samples, later used to calculate the calcium content, was measured with a device called »Karbonatbombe« designed by Müller and Gastner (1971). Compared to other methods the Karbonatbombe proved to be very reliable (Dunn, 1980).

Oxygen and carbon isotopic ratios were also determined for selected samples (9).

The nomenclature of Dunham (1962) with additions put forward by Embry and Klovan (1972) were applied for rock classification. Moreover, description of thin sections (see photoplates) was carried out by using also the Folk classification (1959, 1962). Classification of primary limestone types according to the above nomenclature was difficult or not possible at all in some cases because of post-depositional texture alterations.

Results

Figures 4, 5 and 6 display the results of the petrographic and trace element analysis. Measured carbonate and calculated calcium contents are also included.

The column termed "texture" refers to features such as laminations, cross bedding, stylolites and bioturbation.

No particular percentage limit was assumed in listing observed fossils. Listing was rather carried out on the basis of sole recognition and it is not intended to express quantities.

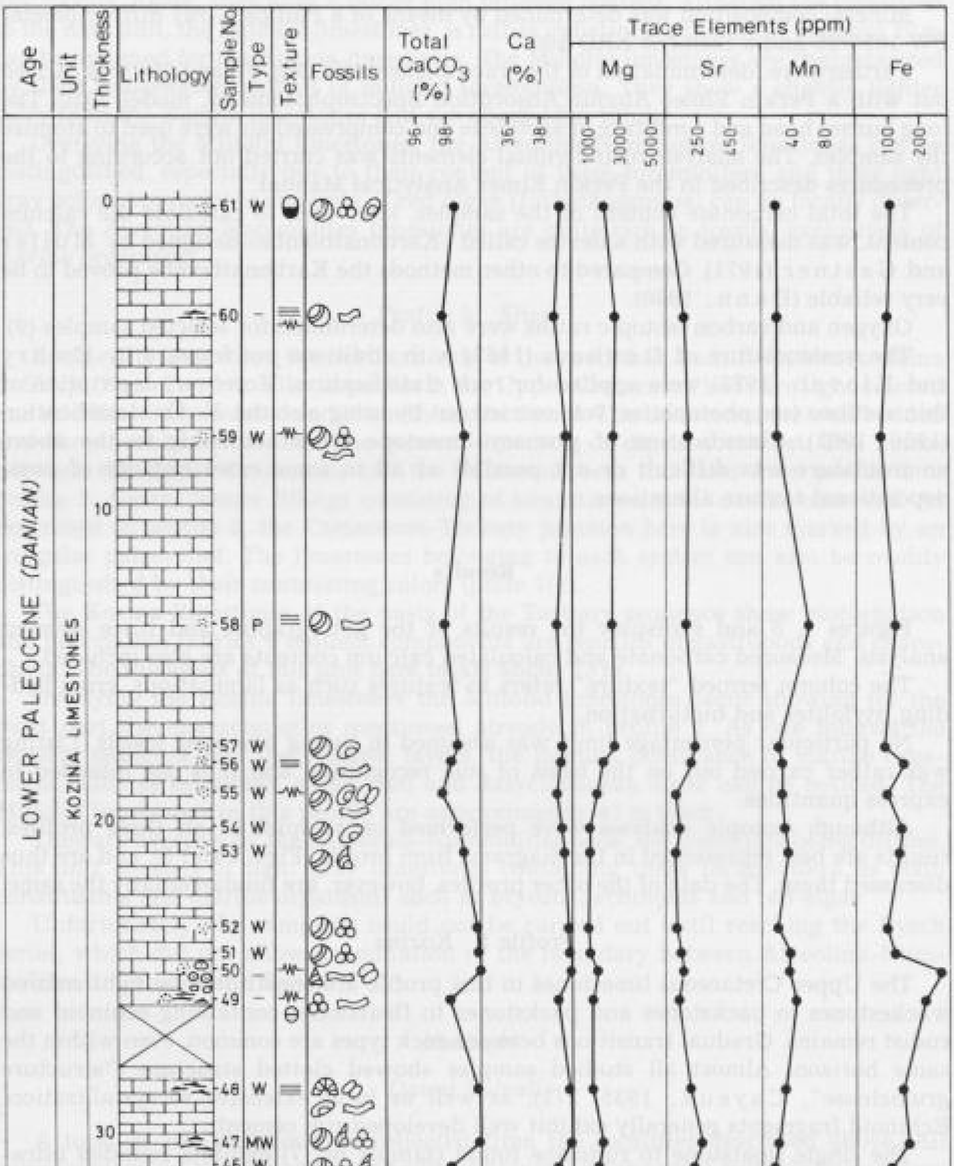
Although isotopic analyses were performed on samples of all three profiles, results are best represented in the diagrams from profile (Figs. 7 and 8), and are thus discussed there. The data of the other profiles, however, are fundamentally the same.

Profile 1 *Kozina*

The Upper Cretaceous limestones in this profile are constituted by light colored wackestones to packstones and packstones to floatstones containing echinoid and rudist remains. Gradual transitions between rock types are common, even within the same horizon. Almost all studied samples showed clotted structure ("structure grumeleuse", Cayeux, 1935, 271), as well as local extensive recrystallization. Echinoid fragments generally exhibit well developed rim cement.

The single floatstone to rudstone found (sample no. 7) exhibits rounded intraclasts ("grapestones") in addition to rudist and echinoid fragments. Two cement generations can be observed, however, the A cement is almost entirely obliterated (plate 1/1).

The total carbonate content of the Upper Cretaceous limestones varies between 98 and 100 percent. Some samples (e. g. no. 6A and 11) show lower values due to the influence of bauxitic material. Mg values oscillate between 1000 and 2000 ppm. The remaining elements show rather low values: Sr (50 to 130 ppm); Mn (up to 40 ppm); Fe (30 to 70 ppm).


Age
Unit
Thickness
Lithology
SampleNo
Type
Texture
Fossils
Total CaCO3 (%)
Ca (%)
Trace Elements (ppm)
Mg
Sr
Mn
Fe
96
98
36
38
1000
3000
5000
250
450
40
80
100
200
LOWER PALEOCENE (DANIAN)
KOZINA LIMESTONES
0
10
20
30
61 W
60 –
59 W
58 P
57 W
56 W
55 W
54 W
53 W
52 W
51 W
50 –
49 –
48 W
47 MW
46 W
45 W
44 P
43 WP

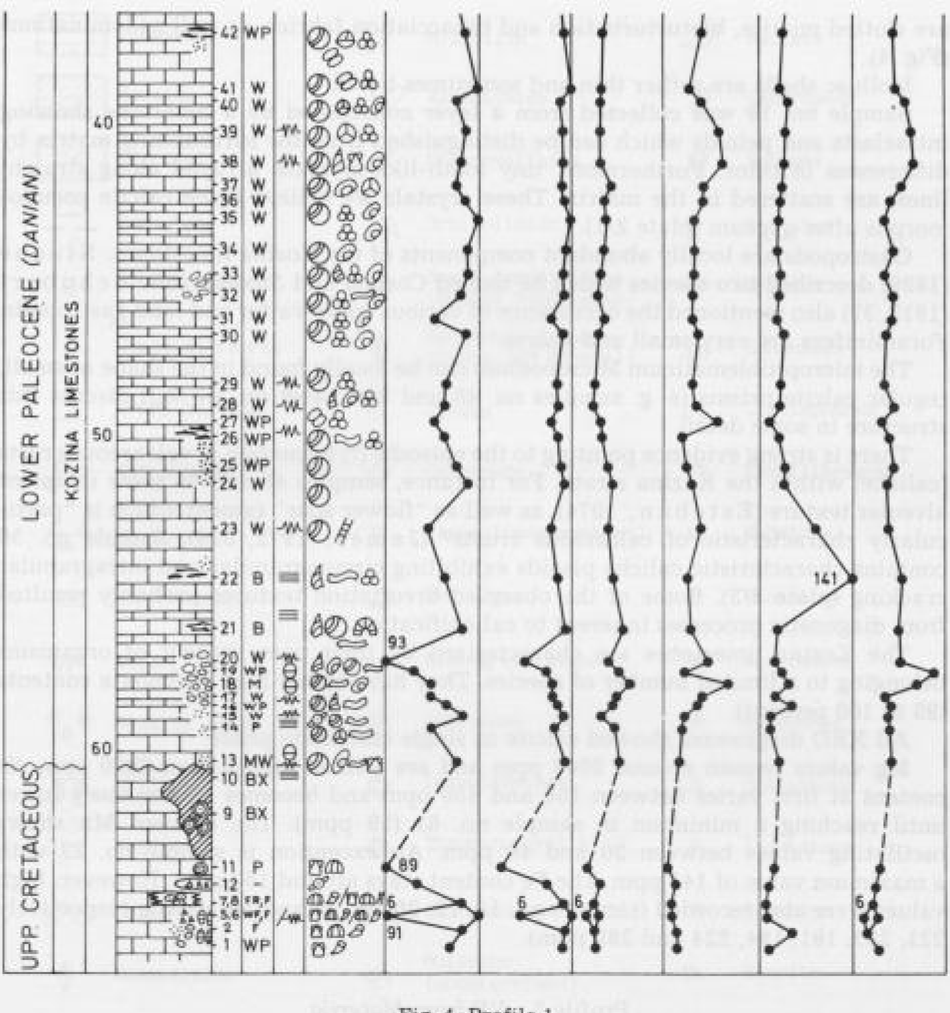


Fig. 4. Profile 1

The sample collected from the bauxite pocket shows a texture type which Carrozi (1960) termed "oolitic". Individual ooids exhibit diameters up to 0.5 mm, reveal a brown-reddish color under the microscope and are clearly zoned. Such ooids formed, of course, diagenetically (plate 1/4).

Sample no. 10, also collected from the pocket, has a rather conglomeratic fabric. The rock fragments are constituted by limestones exhibiting rounded micritic bodies ("glaebules") cemented with microspar (plate 1/5).

At the basis of the Tertiary sequence the Kozina limestones occur consisting of dark bituminous mudstones to wackestones, wackestones to packstones and packstones that underwent, however, local post-depositional texture alterations. Most samples contain abundant peloids, remains of charophyta (oogonia and gyrogonites), blue-green algae and sparse minute ostracods. Important features of these limestones are clotted micrite, bioturturbation and breacciation fabrics, as well as laminations (Fig. 4).

Mollusc shells are rather thin and sometimes bored.

Sample no. 19 was collected from a layer constituted by a limestone showing intraclasts and peloids which can be distinguished from the surrounding matrix by differences in color. Furthermore, tiny tooth-like crystals, arrayed along straight lines, are scattered in the matrix. These crystals we believe to be calcite pseudomorphs after gypsum (plate 2/1).

Gastropods are locally abundant components of the Kozina limestones. Stache (1889) described two species which he named *Cosinia* and *Stomatopsis*. Schubert (1912, 37) also mentioned the occurrence of various fresh watter and land gastropods. Foraminifera are very small and sparse.

The microproblematicum Microcodium can be locally found in the shape of small, regular calcite prisms (e. g. samples no. 48 and 50). Later on, we will discuss this structure in some detail.

There is strong evidence pointing to the episodic (?) formation of calcareous crusts (caliche) within the Kozina strata. For instance, samples 48 and 49 show incipient alveolar texture (Esteban, 1974), as well as "flower spar" cement which is "particularly characteristic of calcareous crusts" (James, 1972, 826). Sample no. 50 contains characteristic caliche pisoids exhibiting circumgranular and intragranular cracking (plate 3/3). Some of the observed brecciation textures probably resulted from diagenetic processes inherent to calichification.

The Kozina limestones are characterized by their poor content of organisms belonging to a limited number of species. They have rather high carbonate contents (95 to 100 percent).

All XRD diagramms showed calcite as single carbonate phase.

Mg values remain around 2000 ppm and are seldom higher than 3000 ppm. Sr content at first varies between 150 and 450 ppm and becomes continuously lower until reaching a minimum in sample no. 61 (59 ppm). The element Mn shows oscillating values between 20 and 40 ppm. An exception is sample no. 22 with a maximum value of 141 ppm. The Fe content stays around 150 ppm. However, high values were also recorded (samples no. 18, 19, 20, 38, 49 and 50, having respectively 221, 253, 191, 194, 224 and 289 ppm).

Profile 2 *NE from Materija*

The Upper Cretaceous limestones of profile 2 are constituted by whitishgrayish wackestones, in places changing to packstones and floatstones (Fig. 5). Rudist shells are not as common as in the profile 1. Frequent components are foraminifera (miliolids, rotalids, orbitolinids), echinoid fragments and algae *(Thaumatoporella parvovesiculifera)*. Furthermore, locally abundant tiny, round to elliptical objects can be observed which we take to be planktonic foraminifera of the species *Pithonella* (plate 4/2).

Miliolids are rather small and often show recrystallized tests.

The limestones are occasionally brecciated (e.g. samples no. 2 and 6K). Such breccias can be clearly observed, even with the microscope (microbreccia). The fissures are not always cemented with sparite but partly filled with micritic and siltsized material (plate 4/3).

In general, the limestones have a micritic matrix showing recrystallized areas.

*May be often regarded as brecciation textures

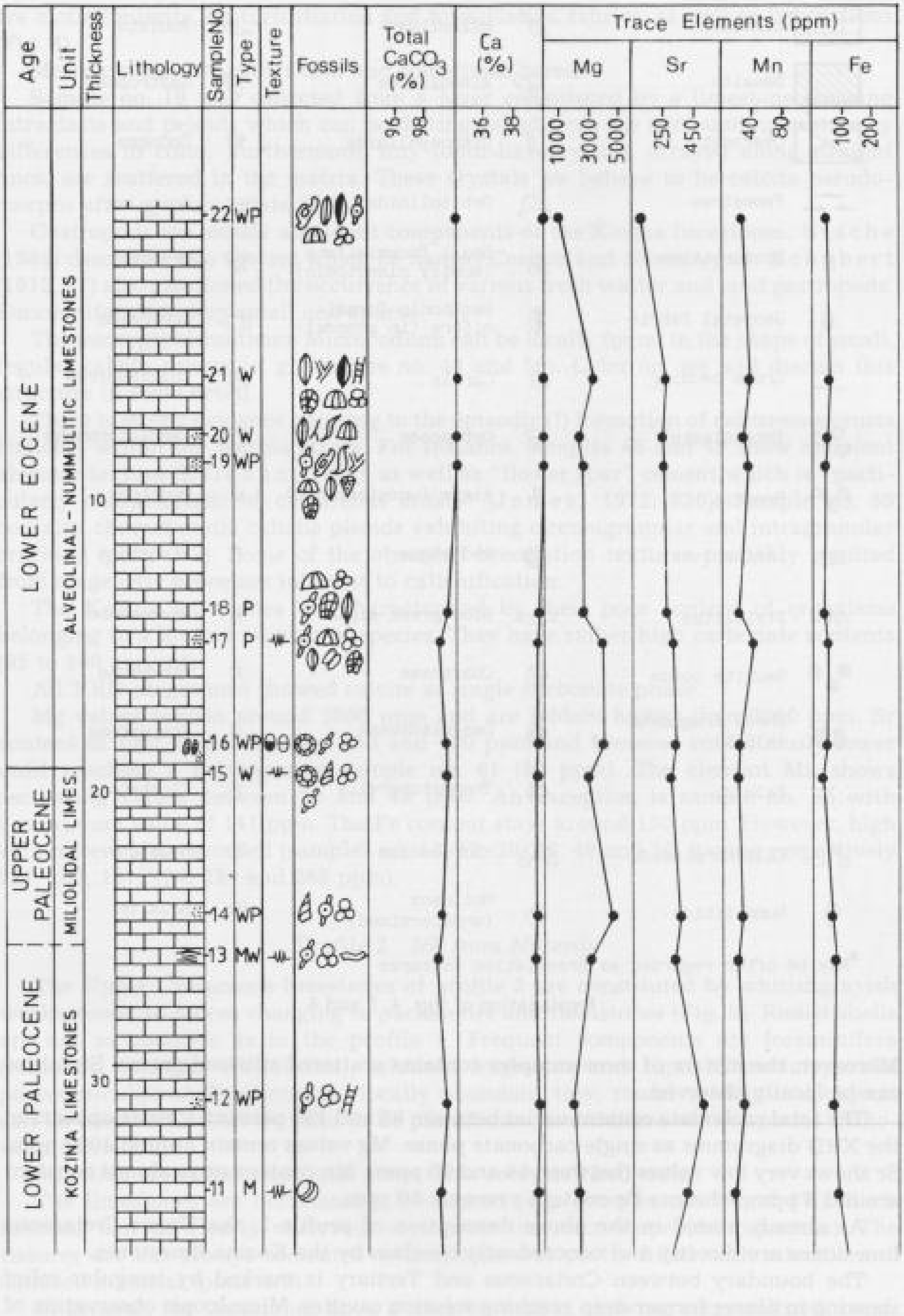
Explanation of figs. 4, 5 and 6

Moreover, the matrix of some samples contains scattered siltsized grains. Stylolites can be locally observed.

The total carbonate content varies between 98 and 100 percent. Calcite appears in the XRD diagramms as single carbonate phase. Mg values remain around 1000 ppm. Sr shows very low values (between 50 and 90 ppm). Mn content stays almost constant around 8 ppm, whereas Fe content averages 50 ppm.

As already stated in the above description of profile 2, the Upper Cretaceous limestones are directly and concordantly overlain by the Kozina limestones.

The boundary between Cretaceous and Tertiary is marked by irregular relief showing in places former deep reaching solution cavities. Microscopic observation of


Age
Unit
Thickness
Lithology
SampleNo.
Type
Texture
Fossils
Total CaCO3 (%)
Ca (%)
Trace Elements (ppm)
Mg
Sr
Mn
Fe
96
98
36
38
1000
3000
5000
250
450
40
80
100
200
LOWER EOCENE
ALVEOLINAL-NUMMULITIC LIMESTONES
UPPER PALEOCENE
MILIOLIDAL LIMES.
LOWER PALEOCENE
KOZINA LIMESTONES
10
20
30
22 WP
21 W
20 W
19 WP
18 P
17 P
16 WP
15 W
14 WP
13 MW
12 WP
11 M

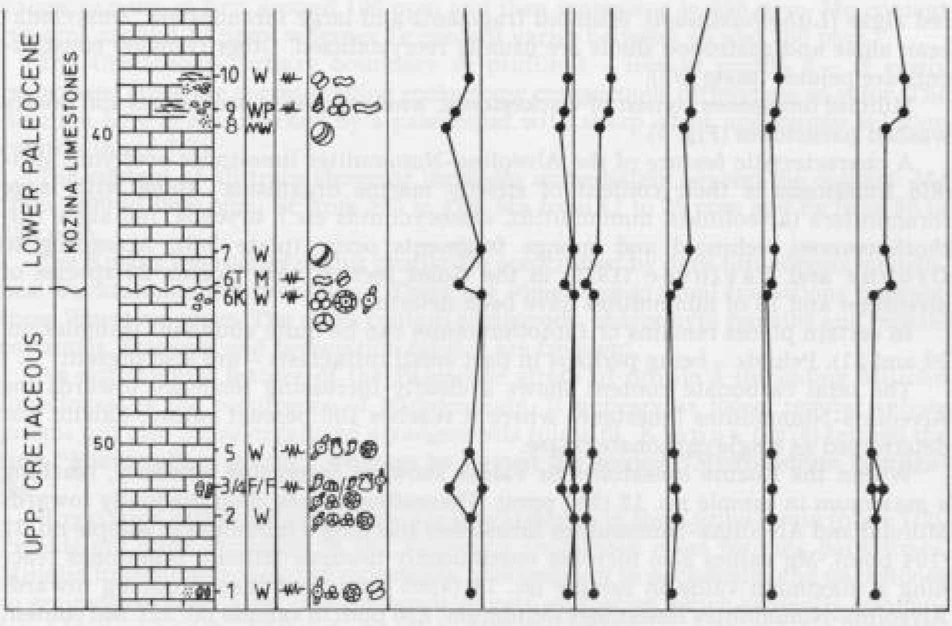


Fig. 5. Profile 2

the contact reveals that it is overprinted by stylolites. The Kozina limestone at the contact is constituted by a mudstone showing calcified filaments of an indefinite origin (calcified root filaments ?). Siltsized grains are scattered in the matrix.

Only a slight decrease of $CaCO_3$ content can be recorded in the corresponding Upper Cretaceous and Paleocene rocks present at the boundary (from 100 to 98 percent). Furthermore, with the exception of Mg (1170 to 960 ppm), the content of remaining elements increases: Sr from 80 to 120 ppm; Fe from 60 to 110 ppm; Mn from 4 to 12 ppm.

Profile 2 – unlike profile 1 – covers all three limestone units mentioned in section 3.

The Kozina limestones have quite the same appearance as described in profile 1, showing, however, an even lower fossil content. They are constituted by dark bituminous mudstones, mudstones to wackestones, wackestones and wackestones to packstones (Fig. 5).

Most common components are peloids. Gastropods are not as frequent as in profile 1 but when present, they show micritic envelopes. Again, common features are bioturbation and brecciation textures (plate 5/1).

A gradual transition leads to the Miliolid limestones which show the following miliolid species (Drobne, 1974): *Idalina*, *Periloculina* and *Fabularia*, as well as conical forms like *Fallotella*, *Coskinolina* and other. Moreover, foraminifera with discoidal shapes *(Broeckinella, Discocyclina)* have been also reported (Drobne, 1979). According to Drobne and Pavlovec (1979), first alveolinids appear in the upper part of the Miliolid limestones *(Glomalveolina primaeva)*.

As pointed out before, a gradual dominance of typically marine organisms can be ascertained the younger the beds get. Such organisms include dasycladacean algae, red algae *(Lithothamnium)*, echinoid fragments and large foraminifera. Dasycladacean algae and gastropod shells are usually recrystallized. Other common constituents are peloids (plate 5/2).

Miliolid limestones consist of wackestones, wackestones to packstones and poorly washed packstones (Fig. 5).

A characteristic feature of the Alveolina-Nummulites limestones overlying Miliolid limestones is their content of strictly marine organisms. Along with large foraminifera (alveolinids, nummulitids, discocyclinids etc.), bryozoa, red algae *(Lithothamnium)*, echinoid and sponge fragments occur (plate 5/3). According to Drobne and Pavlovec (1979) in the Golež section near Kozina 29 species of alveolines and 13 of nummulites have been determined.

In certain places remains of *Lithothamnium* can be quite abundant (samples no. 20 and 21). Peloids – being perhaps in part small intraclasts – are also present.

The total carbonate content shows a clearly increasing tendency towards the Alveolina-Nummulites limestones where it reaches 100 percent values. Calcite was determined as single carbonate phase.

Within the Kozina limestones Sr values show an increasing tendency, reaching a maximum in sample no. 12 (532 ppm). Thereafter, values drop gradually towards Miliolid and Alveolina-Nummulites limestones reaching a minimum in sample no. 22 (104 ppm). Mg values also increase continuously towards Miliolid limestones reaching a maximum value in sample no. 14 (4500 ppm) and then dropping towards Alveolina-Nummulites limestones (minimum: 830 ppm in sample no. 22). Mn content varies rather irregularly between 10 and 35 ppm. Fe values also show irregular variations between 40 and 150 ppm. However, highest contents occur within Kozina limestones.

Profile 3 *Slivje*

Compared to corresponding strata in the other profiles the Upper Cretaceous limestones of profile 3 (Fig. 6) have the lowest fossil content. With one exception (sample no. 4) the limestones consist of light colored mudstones and mudstones to wackestones. The following fosils were observed: small foraminifera (miliolids and other), algae (*Thaumatoporella*), and isolated rudist and echinoid fragments. Sample no. 4 was collected from a bed constituted by floatstone.

The limestones usually show clotted structure. Laminations, sometimes associated with fenestral fabrics, can be observed (e. g. sample no. 5). Rudist shells are rather small and, especially near the boundary, completely recrystallized.

Occasionally, rudist shells filled with micritic material can be encountered (internal sediment). Recrystallized areas are present, however, as in sample no. 6, not affecting lamination. This same sample also contains scattered bauxite ooids.

Thaumatoporella algae sometimes exhibit geopetal fabrics. Miliolids are small and have often recrystallized shells.

Small and irregular bauxite intercalations can be found within the Upper Cretaceous limestones. From such an intercalation sample no. 3 was collected. It has oolitic texture and is composed of the minerals boehmite, goethite, kaolinite, and anatase, as the XRD diagram shows (see figure 7).

The total carbonate content varies between 98 and 100 percent. XRD diagrams indicate calcite as single carbonate phase.

Mg values oscillate at first around 1000 ppm, increasing suddenly, before reaching the boundary, to 3400 ppm. The analysis of Sr results in similar evidence, the values varying at first around 100 ppm and then increasing to 230 ppm. Mn content remains around 13 ppm, whereas Fe content varies between 60 and 200 ppm.

The Cretaceous-Tertiary boundary in profile 3 – like in profile 2 – is easily recognized since the corresponding rocks show conspicuous differences in color. The junction here is also marked by a paleorelief with sharp edges and former solution cavities (plate 7/1).

The content of all trace elements increases immediately beyond the contact: Mg from 3400 to 3900 ppm; Sr from 335 to 470; Mn from 11 to 25 ppm and Fe from 60 to 230 ppm.

The Kozina limestones of this profile are constituted by dark bituminous mudstones, wackestones and packstones. There are sometimes gradual transitions between these limestone types. The rocks contain gastropods, charophyta remains and minute ostracods. Burrows and brecciation fabrics are frequent.

An outstanding feature of the Paleocene strata of profile 3 (including Miliolid limestones) is the occurrence of Microcodium. It appears as loose, regular calcite prisms but also forms organized arrangements (plate 6). Klappa (1978) termed the first "Microcodium grains", whereas he named the second "Microcodium aggregates".

Brecciation and alveolar textures are very common in the Kozina strata (plate 7/2). Peloids are quite abundant in the Paleocene limestones often forming packstones. Miliolid limestones consisit of mudstones, wackestones to packstones and packstones to grainstones. The latter contain fossils of various species which evidently accumulated by current action after death (plate 6/3). Such biocalcarenites also show cross-bedding (e.g. sample no. 41).

In the younger Miliolid strata remains of marine organisms gradually predominate. Among these, there are echinoids, corals, dasycladacean algae (see also Buser & Radoičić, 1987), coralline algae and sponge fragments.

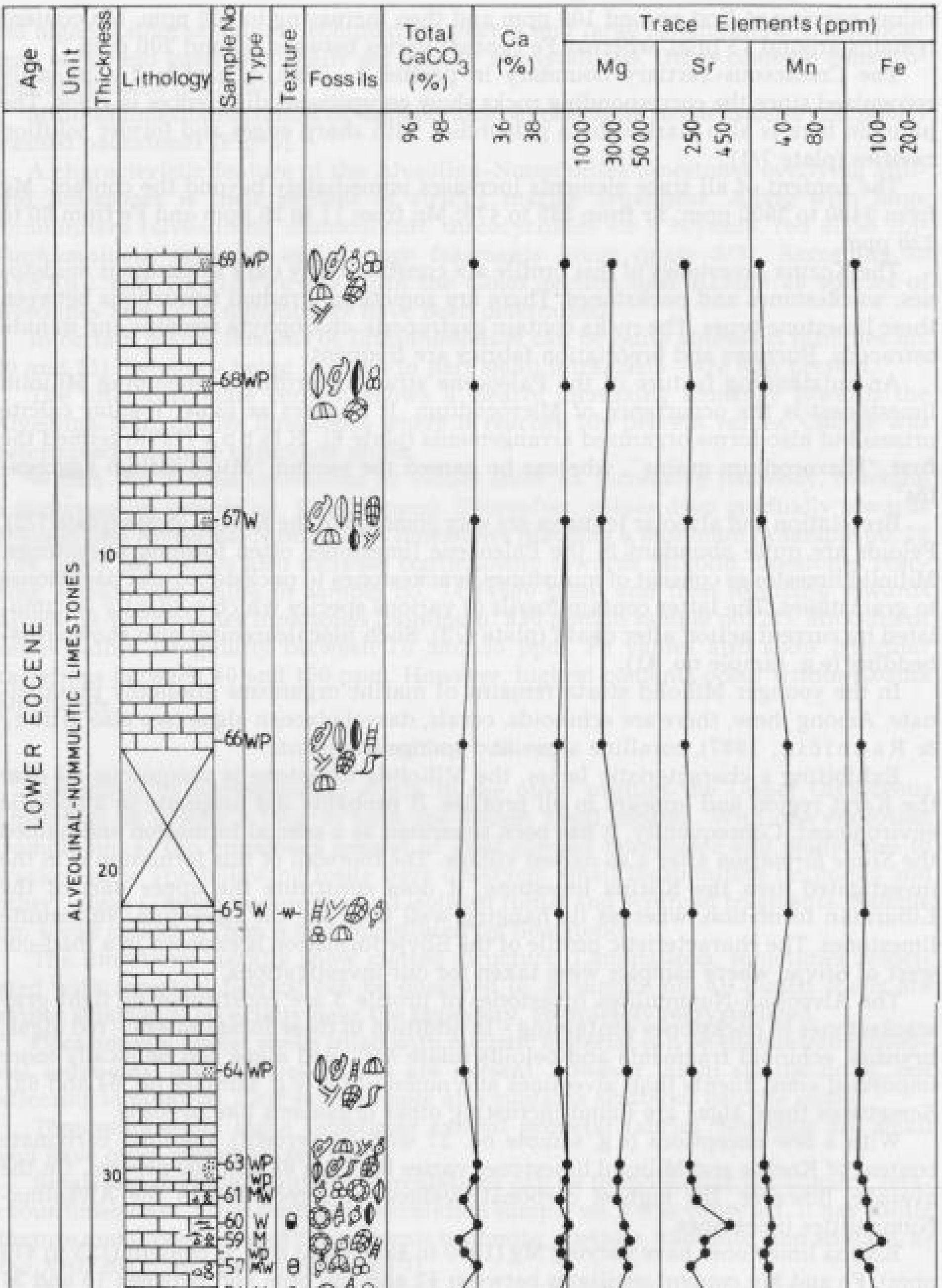
Exhibiting a characteristic facies, the Miliolida limestone is ubiquitous all over the Karst region and appears in all profiles. It probably did originate in a specific environment. Consequently, it has been separated as a special formation and named the *Slivje formation* after a so named village. The footwall of this formation is in the investigated area the Kozina limestone; it does constitute the upper part of the Liburnian formation, whereas its hanging wall beds are the Alveolina-Nummulite limestones. The characteristic profile of the Slivje formation is exposed in a road-cut west of Slivje, where samples were taken for our investigations.

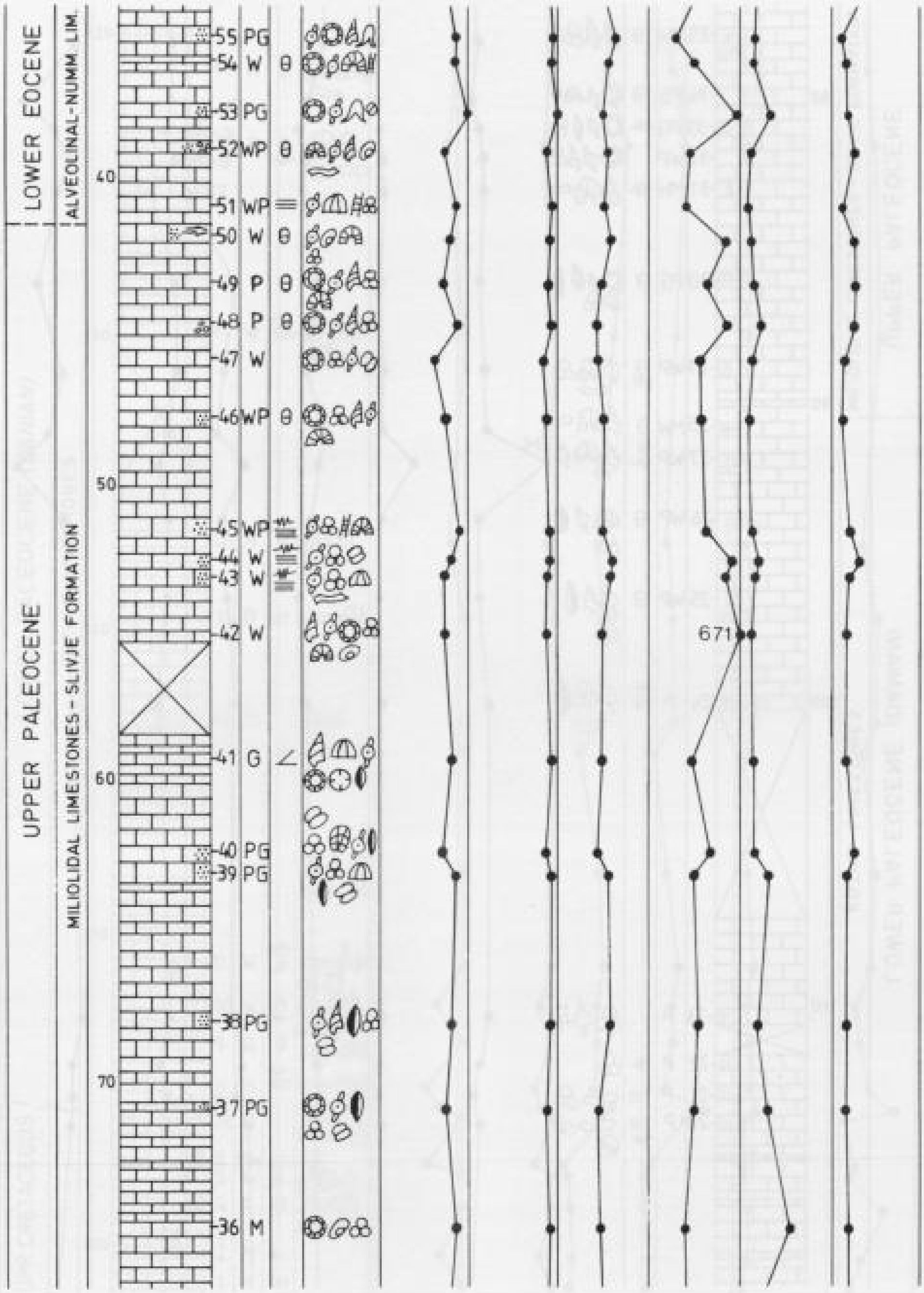
The Alveolina-Nummulites limestones of profile 3 are constituted by light gray wackestones to packstones containing – in addition to these foraminifera – red algae, bryozoa, echinoid fragments and peloids (plate 6/4). Red algae can be locally more important constituents than alveolines and nummulites (e.g. samples no. 64 and 65). Sometimes these algae are found incrusting other organisms like bryozoa.

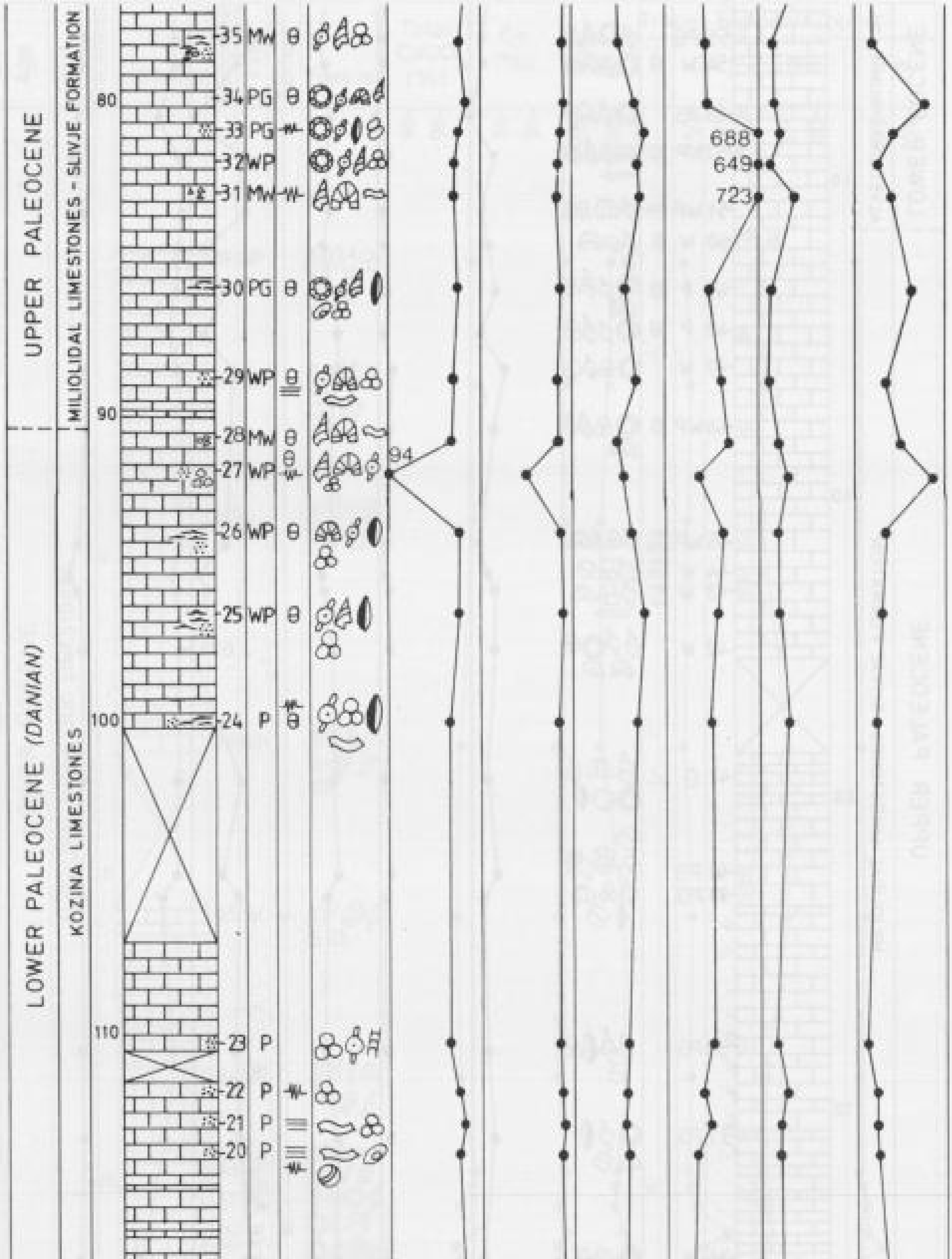
With a few exceptions (e.g. sample no. 27 with 94 percent), the total carbonate content of Kozina and Miliolid limestones varies between 98 and 100 percent. On the average, however, the highest carbonate values were recorded in the Alveolina-Nummulites limestones.

Kozina limestones have varying Mg (1800 to 4850 ppm) and Sr content (125 to 470 ppm). Fe and Mn content oscillates between 42 and 230 ppm and between 10 and 37 ppm, respectively.

The highest content of trace elements was measured right at the basis of the Tertiary sequence.


Age
Unit
Thickness
Lithology
Sample No
Type
Texture
Fossils
Total CaCO$_3$ (%)
Ca (%)
Trace Elements (ppm)
Mg
Sr
Mn
Fe
96
98
36
38
1000
3000
5000
250
450
40
80
100
200
LOWER EOCENE
ALVEOLINAL-NUMMULITIC LIMESTONES
10
20
30
-69 WP
-68 WP
-67 W
-66 WP
-65 W
-64 WP
-63 WP
WP
-61 MW
-60 W
-59 M
WP
-57 MW
-56 M


LOWER EOCENE
ALVEOLINAL-NUMM. LIM.
UPPER PALEOCENE
MILIOLIDAL LIMESTONES - SLIVJE FORMATION
40
50
60
70
55 PG
54 W
53 PG
52 WP
51 WP
50 W
49 P
48 P
47 W
46 WP
45 WP
44 W
43 W
42 W
41 G
40 PG
39 PG
38 PG
37 PG
36 M
671


UPPER PALEOCENE
LOWER PALEOCENE (DANIAN)
MILIOLIDAL LIMESTONES - SLIVJE FORMATION
KOZINA LIMESTONES
80
90
100
110
35 MW
34 PG
33 PG
32 WP
31 MW
30 PG
29 WP
28 MW
27 WP
26 WP
25 WP
24 P
23 P
22 P
21 P
20 P
94
688
649
723

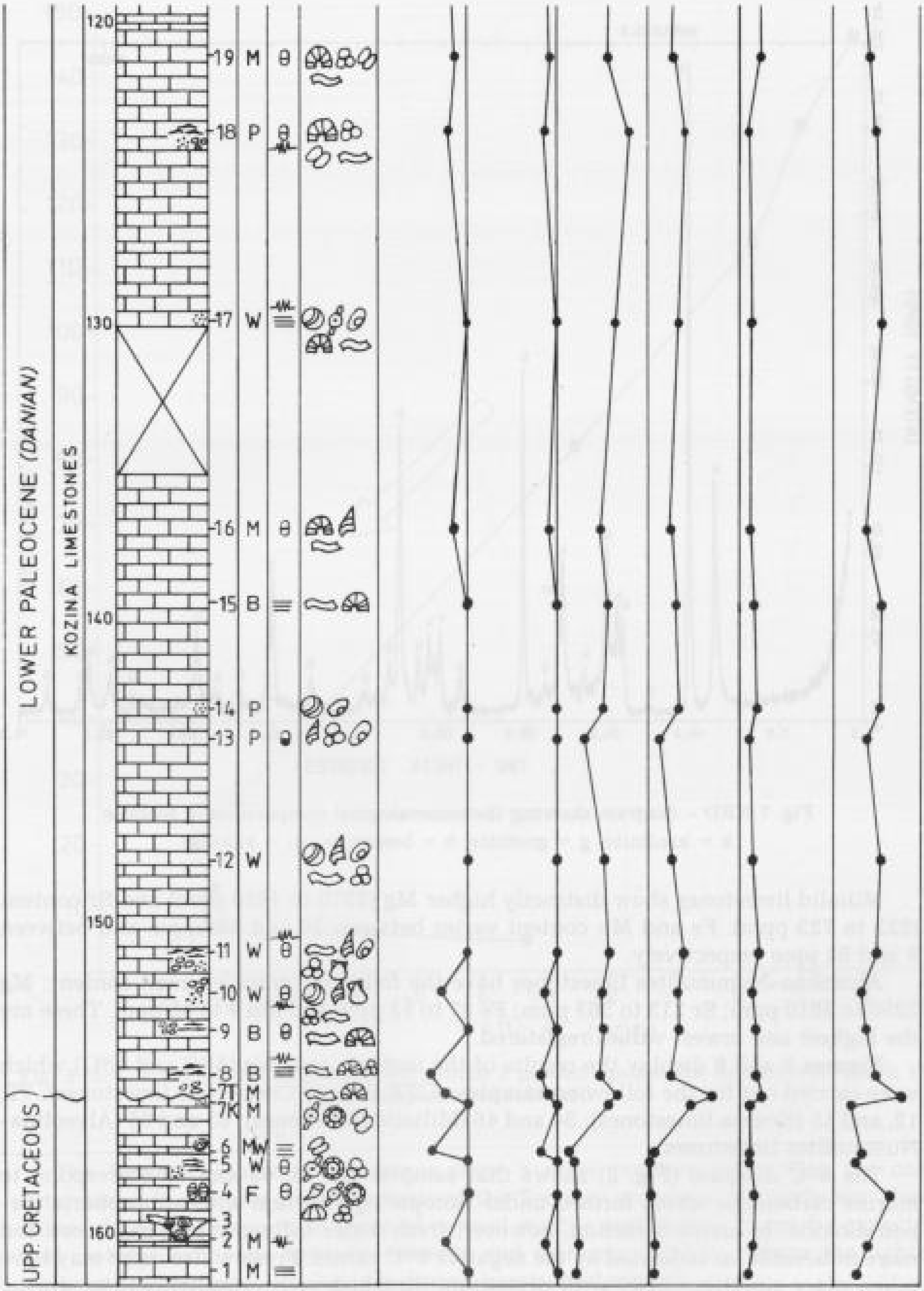


Fig. 6. Profile 3

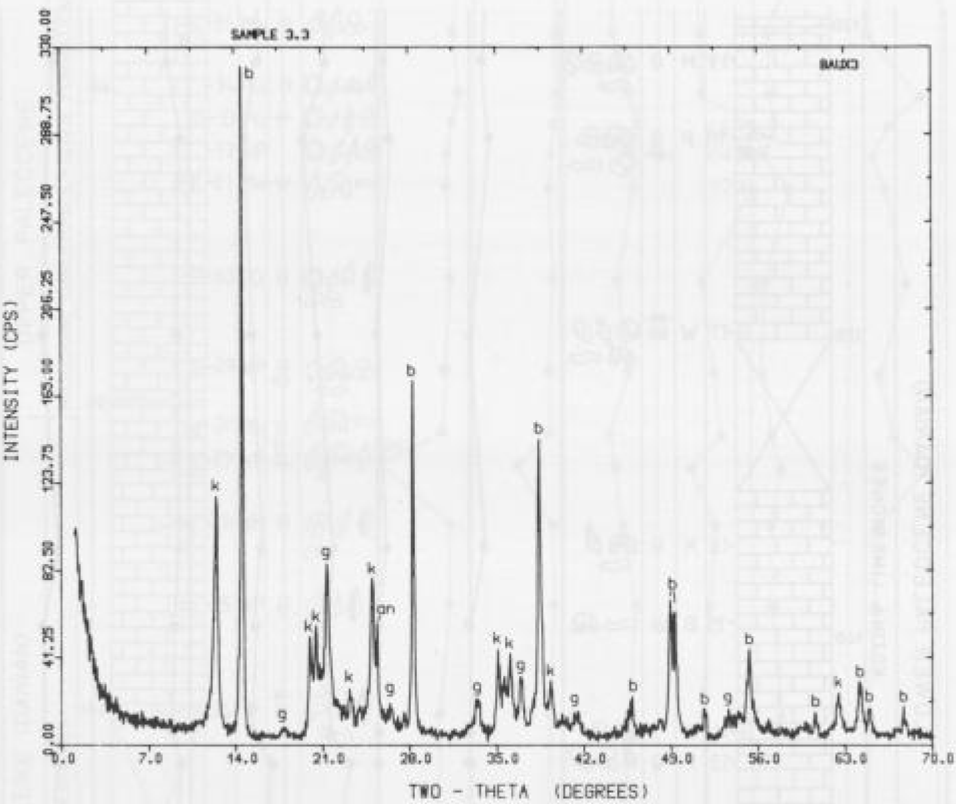


Fig. 7 XRD – diagram showing the mineralogical composition of bauxite
k = kaolinite; g = goethite; b = boehmite; an = anatase

Miliolid limestones show distinctly higher Mg (2570 to 4850 ppm) and Sr content (223 to 723 ppm). Fe and Mn content varies between 36 and 266 ppm and between 9 and 64 ppm respectively.

Alveolina-Nummulites limestones have the following trace element content: Mg 2250 to 3910 ppm; Sr 213 to 263 ppm; Fe 37 to 53 ppm and Mn 9 to 45 ppm. These are the highest and lowest values registered.

Figures 8 and 9 display the results of the isotopic analysis ($\delta^{13}C$ and $\delta^{18}O$) which were carried out for the following samples: 6, 7K (Upper Cretaceous limestones); 7T, 12, and 15 (Kozina limestones); 34 and 46 (Miliolid limestones); 63 and 66 (Alveolina-Nummulites limestones).

The $\delta^{13}C$ diagram (Fig. 8) shows that samples no. 46, 63 and 66 correspond to marine carbonates which formed under isotopic equilibrium with atmospheric carbon dioxide. In arrow direction, however, fresh water influence becomes more and more noticeable, as indicated by the negative $\delta^{13}C$ values. Fresh water input may have taken place simultaneously with deposition (brackish environments) and/or during subaerial exposure, where soil forming and subaerial diagenetic processes were active.

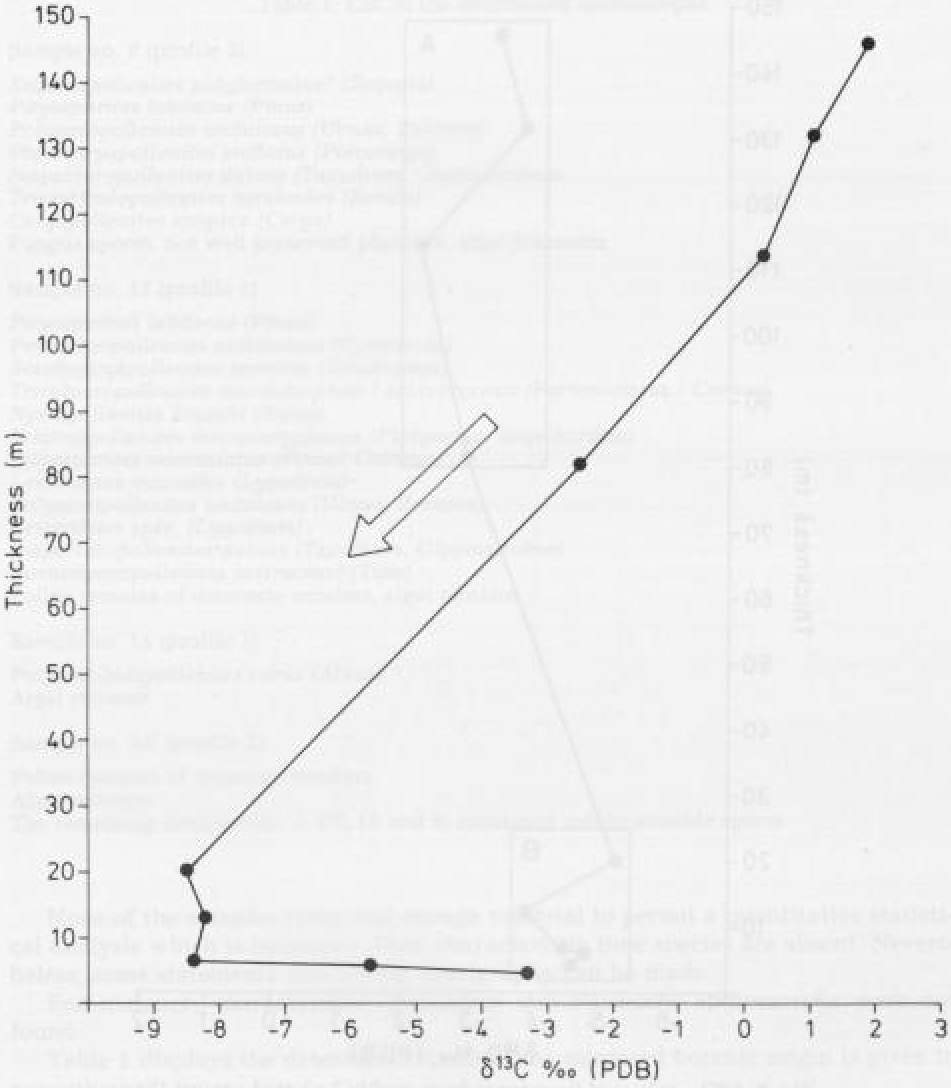


Fig. 8. $\delta^{13}C$ – values of limestones from profile 3 plotted against the thickness at which the samples were collected

The Upper Cretaceous limestones show a more positive value than the ones determined in samples from the basis of the Tertiary sequence. Nevertheless, these values do not correspond to those of normal marine carbonates. It can be expected that isotopic exchange between cements and meteoric waters – where the lighter isotopes predominate – took place during karst development.

The $\delta^{18}O$ diagram (figure 9) shows two areas. The values within area A are less negative than those in area B. Although they do not actually correspond to carbona-

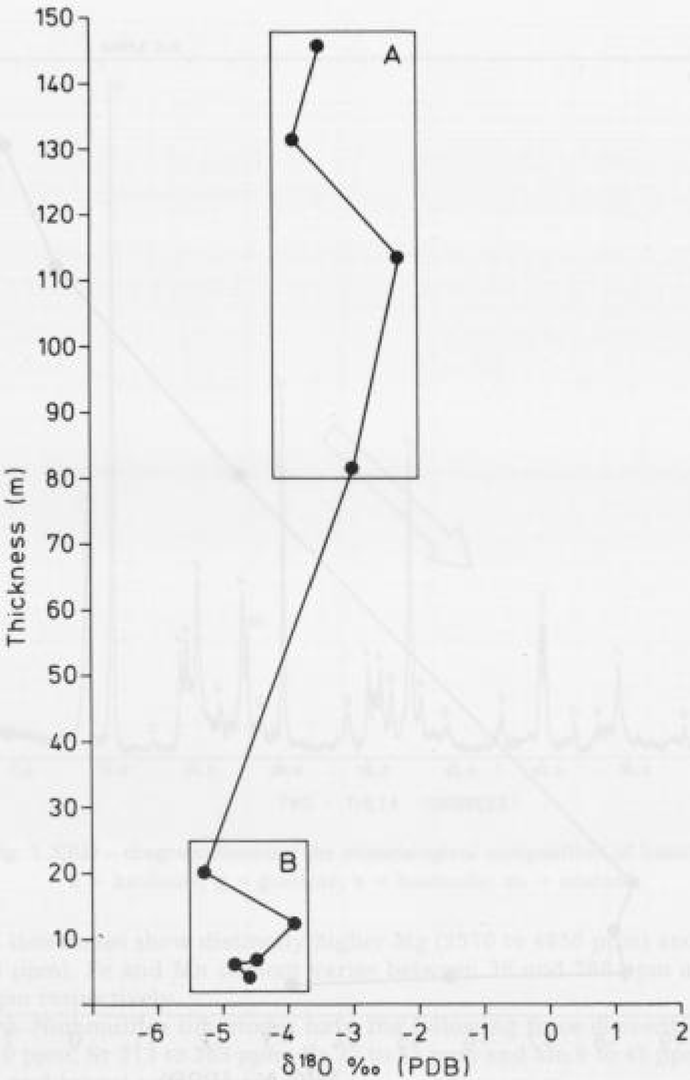


Fig. 9. $\delta^{18}O$ – values of limestones from profile 3 plotted against the thickness at which the samples were collected

tes formed under normal marine conditions, they do document a tendency towards characteristic values of marine carbonates. In contrast, area B shows values that distinctly indicate fresh water influence.

Palynological analysis

The following samples were selected for palynological analysis: 13, 14, 15 (profile 1); 6K, 6T, 9 (profile 2); 7, 8 (profile 3). Only two of these samples, no. 13 and no. 8, yielded well preserved sporomorph species that allowed sure determination.

Table 1. List of the determined sporomorphs

Sample no. *8* (profile 3)

Sequoiapollenites polyformosus? (Sequoia)
Pityosporites labdacus (Pinus)
Polyporopollenites undulosus (Ulmus, Zelkova)
Pterocaryapollenites stellatus (Pterocarya)
Inaperturopollenites dubius (Taxodium, Glyptostrobus)
Trivestibulopollenites betuloides (Betula)
Caryapollenites simplex (Carya)
Fungus spores, not well preserved plancton, algal filaments

Sample no. *13* (profile 1)

Pityosporites labdacus (Pinus)
Porocolpopollenites vestibulum (Symplocos)
Sciadopityspollenites serratus (Sciadopitys)
Tricolporopollenites marcodurensis / satzveryensis (Partenocissus / Cornus)
Nyssapollenites kruschi (Nyssa)
Triatriopollenites microcoryphaeus (Platycarya, Engelhardtia)
Pityosporites microalatus (Pinus? Cathaya)
Leiotriletes maxoides (Lygodium)
Polyporopollenites undulosus (Ulmus, Zelkova)
Leiotriletes spec. (Lygodium)
Inaperturopollenites dubius (Taxodium, Glyptostrobus)
Intratriporopollenites instructus? (Tilia)
Pollen remains of disaccate conifers, algal remains

Sample no. 14 (profile 1)

Polyvestibulopollenites verus (Alnus)
Algal remains

Sample no. *6K* (profile 2)

Pollen remains of disaccate conifers
Algal remains
The remaining samples (no. 7, 6T, 15 and 9) contained indeterminable spores

None of the samples contained enough material to permit a quantitative statistical analysis which is necessary when characteristic time species are absent. Nevertheless, some statements concerning stratigraphy can be made.

For instance, characteristic Cretaceous and Paleocene sporomorphs were not found.

Table 1 displays the determined species. The supposed botanic origin is given in parentheses.

Beside some forms that reach into the Mesozoic (disaccate conifers, pinus forms), most sporomorphs are rather typical for the Eocene and the Miocene. Almost all detected forms appear sooner or later during the Eocene and last until the Upper Miocene, and partly the Pliocene.

Sample no. 8, for example, contained the unmistakable pollen of *Pterocarya* which appeared in the Middle Eocene and attained its maximal distribution between the Upper Oligocene and the Upper Miocene, partly the Pliocene and locally until the Lower Pleistocene.

Polyporopollenites undulosus (Ulmus, Zelkova) also reach from the Eocene to the Pleistocene, having its maximal distribution since the Oligocene.

The uncertain *Intratriporopollenites instructus (Tilia)* does not seem to appear before the Upper Oligocene.

To summarize, the following remarks are pertinent:

- An accurate stratigraphic statement is not possible because characteristic time sporomorphs are lacking. Moreover, a quantitative statistical analysis could not be carried out.
- The detected sporomorphs do point, however, to a time period somewhere between the Eocene and the Pliocene.

It should be pointed out that the corresponding flora may have appeared earlier in the Mediterranean region than it is generally believed.

The lack of dinoflagellate cysts excludes the possibility of deposition under marine conditions. Furthermore, plant remains were often observed.

Facies interpretation

Upper Cretaceous rocks

The Upper Cretaceous floatstones from profile 1 probably correspond to accumulated debris from former rudist mounds. Rudist and echinoid fragments contained in these limestones are angular indicating short transport or none at all. Moreover, the limestones exhibit clotted structure which is generally indicative of low energy environments. However, at least temporal energy increases are suggested by the presence of an intrabiosparite interlocking the floatstone (sample no. 7, plate 1/1). Intraclasts are constituted by grapestones which form, according to Flügel (1978, 109), within the subtidal to intertidal zones of a shallow water environment with little water circulation.

The Upper Cretaceous limestones of profiles 2 and 3 show a higher volumetric micrite content than corresponding rocks of profile 1. Rudist and echinoid fragments are more rare. The dominating organisms here are miliolids, the alga *Thaumatoporella* and planktonic foraminifera. Although the latter are rather numerous, they are most probably allochthonous. Local laminations likely associated with both peloids and blue-green algae are present (e.g. sample no. 6 from profile 3).

Low energy conditions are indicated – in addition to micrite dominance – by the locally found clotted structure. Furthermore, the observed miliolids are very small and thin-shelled.

Microfacies data of the Upper Cretaceous limestones suggest a warm-water shallow open shelf with relatively small rudist mounds.

Bauxite ooids are accessory constituents of the Upper Cretaceous limestones. Since this bauxitic material is obviously penecontemporaneous to sediment deposition, it can be concluded that the bauxitization took already place in Upper Cretaceuos time. Furthermore, bauxitic material in these limestones indicates land proximity.

The observed bauxite pocket shows a conglomeratic fabric which is indicative of redeposition. The rock fragments contained in it belong to limestones showing glaebules and incipient crumbly fracturing (plate 1/5). These features have been observed in caliche hardpans, thus pointing to its occurrence in hinterland. This seems plausible since "the soil cover of karst may also evolve in the direction of carbonate rich soils of the caliche type, particularly in mature and late stages of karst evolution" (Esteban & Klappa, 1983, 14).

After a long cessation of sedimentation which extended until the end of Upper Cretaceous time the Kozina limestones started to form at the beginning of the Tertiary age.

Kozina limestones

Facies interpretation of these sediments is difficult because of their polygenetic character. According to Pavlovec and Pleničar (1979), these bads show "quick exchanges of lagoonal, brackish, lacustrine and partly marine facies" (p. 28). Grubić (1980, 41) referred to the Kozina limestones as limnic and estuarine sediments. The encountered facies diversity is attributed to tectonic movements which took place at sedimentation time.

The criteria pointing to a lacustrine origin of the Kozina limestones are essentially paleontological. Frequent remains of charophyta, blue-green algae, gastropods, minute ostracods and thin lamellibranch shells constitute the rather poor flora and fauna remains of these beds.

Limitation of species could be, theoretically, caused by frequent climatic changes to which lakes are sensitive (Collinson, 1978, 67). However, low organism diversity is in the first place the result of stress conditions which can be found in other environments (see Picard & High, 1972, 117).

Flügel (1978, 67) pointed out that charophyta are useful fresh water indicators. Nevertheless, some species seem to tolerate salinity variations up to 18 and 26 parts per thousand (Heckel, 1972, 277), and other can be even found in hypersaline milieus (Flügel, 1978, 265). Charophyta can thus be found in various habitats (compare Johnson, 1961, 36).

The Kozina limestones show high carbonate contents, varying mostly beetween 95 and 100 percent. The lack of any significant clastic component indicates that the depositional setting was, at least in the studied area, not fed by any river. Moreover, no fluvial series are known from the region. This is an important argument against the suggested estuarine origin of the Kozina limestones, all the more so as estuarine sediments show particular characteristics that cannot be compared with the ones observed (see Elliot, 1978, 171 ff.).

According to Picard and High (1972) the association of supposed lacustrine beds with fluvial sediments can be (also) important to distinguish between lacustrine and lagoonal environments. The same authors add: "If the unknown unit is in close proximity with marine rocks, and no intervening fluvial rocks are present, a lagoonal setting that opens to the sea is indicated" (p. 117).

This is of particular importance since we know that the transition to the next unit (Miliolid limestones) is gradual, and that the predominance of marine organisms is more and more conspicuous the younger the sequence gets.

Kozina limestones are predominantly micritic, a fact that is generally indicative of low energy environments. The rocks are typically dark and bituminous pointing to deposition under euxinic conditions. These were probably caused by restricted water circulation. Such restricted environments can develop as brackish water, anoxic swamps or as hypersaline shelf basins (see Enos, 1983, 281).

In several samples dissaminated aggregates of Microcodium were detected. According to Klappa (1978, 510), Microcodium is the result of calcification of mycorrhizae, a symbiosis between fungi and the cortical cells of higher plant roots. Since soil is the natural environment in which plants grow, Microcodium is ultimately indicative of pedogenetic processes. Furthermore, Esteban (personal communication) stated that rather typical environments for the formation of Microcodium are hydromorphic soils, meaning water-saturated sediments subjected to incipient soil processes. Such environments may be found in palustrine areas (swamps, marsh). Indeed, Microcodium has been reported from palustrine milieus (Freytet, 1971, 1973).

Another important feature of the Kozina limestones is the occurrence of calcite pseudomorphs after gypsum. Sellwood (1978) referred to gypsum formation in marshes (supratidal zone) from subtropical carbonate shelves. Moreover, he adds, interstitial gypsum crystals can also be found in mostly undisturbed algal mats from the upper intertidal zone "where muddy sediment brought in by storms is trapped" (p. 265). The textural characteristics of sample 19 from profile 1 strongly resemble this situation (plate 1/1). Freytet (1973, 43) also reported calcite pseudomorphs after gypsum from palustrine environments.

The observed bioturbation textures were probably not only caused by burrowing organisms within the sediment but also by physical, chemical and biological disturbance of the soil material during subaerial exposure ("pedoturbation"). A close examination of the brecciation textures reveals that they may have originated in various ways. As the result of reworking of lime mud material under subaqueous conditions, the clasts may be angular to subrounded, coated or not, depending on the lithification degree of the parent material. Some of the observed breccia, however, may have been caused by pedoturbation (e. g. root penetration) or by diagenetic processes (calichification).

The calculated carbon and oxygen isotopic ratios support the idea that the Kozina limestones formed in a coastal palustrine area submitted to sea level and salinity changes. During rather long periods of subaerial exposure, calichification followed soil-forming processes as the accumulation of $CaCO_3$ increased in detriment of porosity and permeability of the soil profile. Climatic factors also played an important role, particularly in controlling rainfall and evaporation.

Not until the younger beds, a relative diversity of benthonic foraminifera can be observed. These beds represent the gradual transition to the Miliolid limestones and are constituted by poorly washed foraminiferal biosparites, indicating some water circulation within the deposition site. This slight increase in water energy allowed some oxygenation creating better conditions for life to develop.

This should also be regarded as expression of the continuous trangressive development, since the limestone types observed in the Miliolid strata correspond to those Wilson (1975) described as having formed within facies zone 8. Moreover, the younger beds show a marked dominance of marine organisms which indicates that the fresh water input gradually grew weaker. This assumption is supported by the isotopic data.

Miliolid limestones – Slivje formation

Primary Miliolid limestone types are comparable to several standard microfacies described by Wilson (1975), which indicate restricted conditions: peloidal packstones to grainstones containing foraminifera (SMF 16); grapestone-peloid-intraclast grainstones (SMF 17); foraminiferal or dasyclad algal packstones to grainstones with peloids (SMF 18); laminated to bioturbated pellet mudstones to wackestones, locally with fenestral fabric (SMF 19).

Miliolid limestones also show horizons containing in situ formed Microcodium. An alternative to the idea of periodic discontinuities which must have lasted long enough to allow pedogenetic processes to take place is the conception of islands (similar to modern mangrove islands) within the intertidal zone, which were colonized by higher plants. In the proximity of these islands channels occurred where sediments formed exhibiting diverse depositional textures. Texture diversity is probably due to the fact that current velocity within channels may vary greatly, thus causing the lithologic spectrum to range from mudstones to grainstones (compare Sellwood, 1978, 266). Moreover, analogous to some modern environments, bars may occur within the channel system showing cross-bedded sediments. Such a sediment could be recognized in sample no. 41 from profile 3 (grainstone). It contains gastropods, dasycladacean algae, miliolids, corals and echinoid remains, peloids and grapestones.

Organism diversity in the Miliolid limestones indicates favorable living conditions. Surely, some of the observed organisms were not buried in the place they lived on. Particularly in the case of the biocalcarenites, probably most organisms accumulated by current action. Nevertheless, especially in the younger beds of the Miliolid limestones, biota abundance indicates a gradual disappearence of stress conditions which were perhaps determined by strong variations in salinity and/or poor water circulation.

A gradual transition also exists between Miliolid and Alveolina-Nummulites limestones simultaneously indicating a gradual change of facies.

Alveolina-Nummulites limestones

The encountered limestones obviously formed in the subtidal zone of a well oxygenated, strictly marine area of the carbonate platform. The presence of frequent organisms such as coralline algae and bryozoa point to the proximity of reefs. Furthermore, their rather high carbonate content and light color indicate off-shore deposition lacking significant clastic and organic residues.

The depositional setting of the Alveolina-Nummulites limestones can be probably compared with the one assumed for similar fossil strata from the Mediterranean region. An extended open carbonate platform with a more or less horizontal sedimentation basis has been suggested (see Cita, 1965, 39; Wilson & Jordan, 1983, 316–317).

Isotopic and paleontological data point to marine conditions.

Depositional history and concluding remarks

During the Mesozoic a typical shallow water carbonate sedimentation took place on the Dinaric carbonate platform (Buser, 1989).

As suggested by the occurrence of bauxitic ooids in the Upper Cretaceous limestones, the sea began to retreat from the platform in Upper Cretaceous time already.

The regressive development was caused by the tectonic uplift of the Dinaric plate which is generally associated with the Alpine orogenesis.

Subaerial exposure was firstly characterized by karst development and bauxitization. Carbonate loss by dissolution was then followed by carbonate accumulation during calichification.

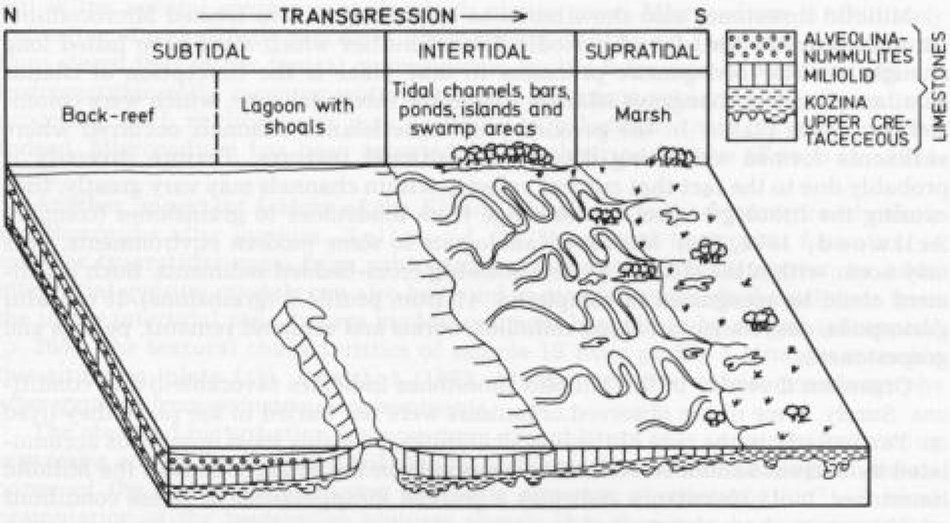


Fig. 10. Block diagram showing facial relationships between the studied units

Facies interpretation of the Paleocene strata (Kozina and partly Miliolid limestones) is difficult because we are dealing with polygenetic sediments. We suggest that these sediments originated within a coastal zone submitted to sea level and climatic changes. In this sense, the vertical sequence shows superimposed palustrine and brackish lagoonal horizons that were altered by soil-forming processes and caliche development.

It should be examined whether possibly overlooked fluvial series are associated with the Kozina limestones, in which case a partly lacustrine origin could be postulated.

The primary limestone types of the Miliolid limestones clearly formed within the intertidal and subtidal zones, thus documenting the transgressive character of the sequence. As we found Microcodium aggregates within the Miliolid limestones, this may point either to prolonged emergence periods, or to the existence of emerged areas (islands) that were colonized by higher plants.

Alveolina-Nummulites limestones clearly formed under subtidal conditions. The sediments were deposited in a strictly marine, well oxygenated environment. This indicates an important facies change, since restricted conditions gradually weakened. At the same time, Alveolina-Nummulites limestones give evidence of the next step in a transgressive development which finally culminated in the formation of deep water sediments (flysch).

The low Sr and Mg contents of the Upper Cretaceous limestones correspond to those commonly found in carbonate rocks affected by meteoric diagenesis. This is also supported by the isotopic data (negative values).

Whereas Kozina and Alveolina-Nummulites limestones have comparable Sr and Mg contents (average: 250 and 2600 ppm respectively), the content of these trace elements is distictly higher in the Miliolid limestones (average: 420 and 4100). It cannot be positively concluded whether these differences in content are related to the former mineralogical composition of the carbonates (high magnesian calcite, aragonite) and/or to diagenetic recrystallization. Mn and Fe values are rather low for all units.

The block diagram (Fig. 10) integrates the three stratigraphic units which were treated in this paper stressing their facies significance.

Finally, and in spite of its facies complexity, the analyzed sequence can be regarded as a good example for the validity of Walther's Law which stated that the vertical succession of facies in the rock record reflects lateral sequence in the depositional setting (Walther, 1894).

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Plate 1

1 Sample 7
Poorly washed intrabiosparite (floatstone to rudstone)

An utterly recrystallized rudist shell showing internal sediment and micritized shell structures. Rounded components are intraclastes ("grapestones") that probably formed within the subtidal to the intertidal zones of shallow water environment with little water circulation. The A cement has been completely obliterated during meteoric diagenesis

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 8
Biomicrosparite (floatstone)

Foraminifera are accessory components of the Cretaceous floatstones. They commonly exhibit, as the one shown here, micritized tests. Note areas of clotted micrite that subsisted recrystallization

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 2
Biomicrosparite (floatstone)

In spite of extensive recrystallization, blue-green algal laminae can be recognized. The observed clotted structure may be in some way associated with these algae. On the left side, a cross section of an echinoid spine showing incipient micritization and relicts of syntaxial rim cement

Thin section, plane polarized light. Scale bar = 1 mm

4 Sample 11
Biomicrosparite (packstone)

Allochems consist mostly of echinoid fragments showing rim cement. The dark spheroidal objects are bauxite ooids which were incorporated to the biogenic debris at deposition time thus indicating ongoing bauxitization

Thin section, plane polarized light. Scale bar = 1 mm

5 Samle 10
Conglomeratic bauxite

Limestone fragments show features commonly found in caliche. The clast on the left is laminated and exhibits circumgranular cracking. On the lower right, non-laminated glaebules are cemented with microspar. A bauxit ooid (arrow) is also shown

Thin section, plane polarized light. Scale bar = 1 mm

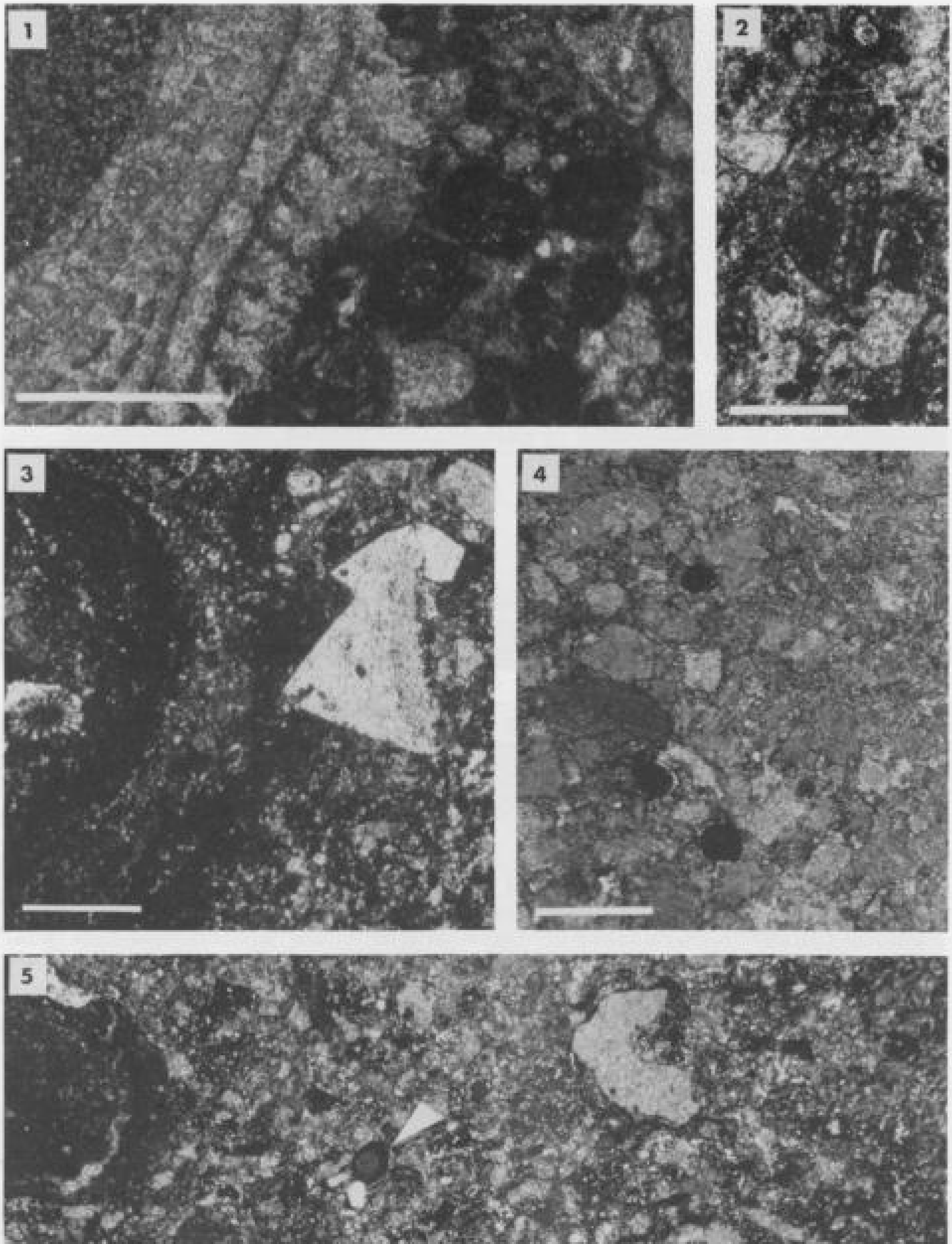
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Plate 2

1 Sample 19
Intrapelmicrite (wackestone to packstone)

Detritic tiny tooth-like crystals are calcite pseudomorphs after gypsum. They are arranged along straight lines indicating growth on an even surface, probably algal mats. Algal laminations can be observed on the left. Abundant components are peloids. Intraclasts are rounded and mostly darker than the matrix

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 21
Algal biolithite (bindstone)

Irregular fenestral fabrics are characteristic of this laminated limestone. Binded material consist of micrite and abundant peloids

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 24
Biopelmicrite (wackestone)

Charophyta remains are not very well preserved. The occurrence of these green algae in the Kozina limestones has been one of the criteria indicating lacustrine conditions. However, these algae have been found in other environments (see section 7.2)

Thin section, plane polarized light. Scale bar = 1 mm

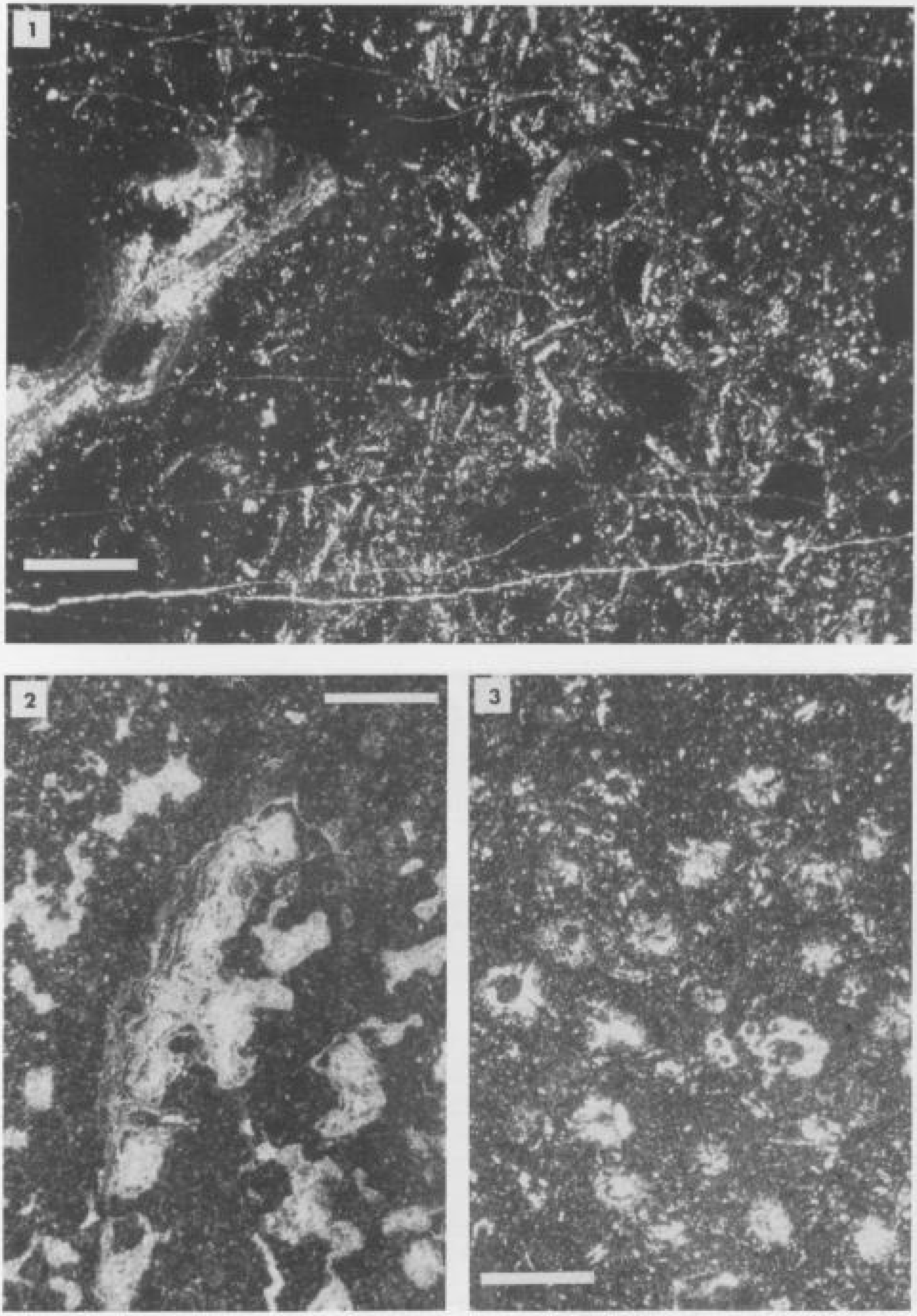
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Plate 3

1 Sample 49
Caliche crust

"Flower spar" calcite cement. Elongate calcite crystals grow in a rosette-like fashion as a result of continued precipitation in a void. Such features are particularly indicative of calcareous crusts

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 60
Caliche crust (?)

Clotted micrite fabric resulted from the abundance of peloids which exhibit incipient crumbly fracturing

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 50
Caliche crust

View of a caliche pisoid displaying circumgranular and intragranular cracking. Note detritic Microcodium grains in the nucleus. Glaebules of various sizes can be observed. Cement consists of microspar

Thin section, plane polarized light. Scale bar = 1 mm

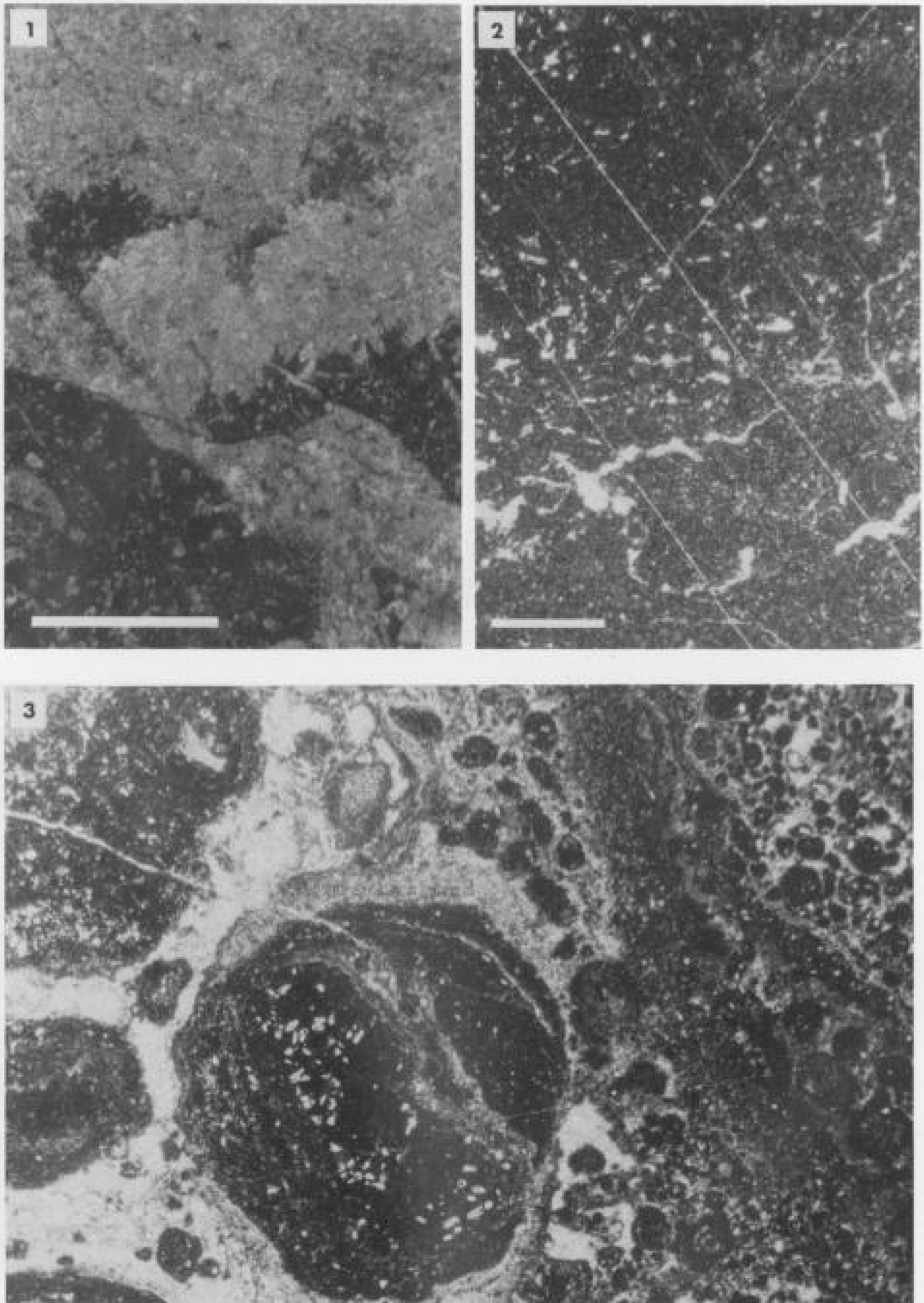
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Plate 4

1 Sample 5
Biomicrite (wackestone)

The algae *Thaumatoporella* as well as miliolids and other small foraminifera are common constituents of the Cretaceous rocks from profile 2. The micritic matrix is locally recrystallized and shows scattered silt – sized crystals and peloids

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 2
Biomicrite (wackestone)

Various sections of locally abundant planctonic foraminifera (*Pithonella* ?). Other small foraminifera with completely recrystallized test are also shown

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 2

Brecciation textures due to karst processes are common features of the Cretaceous limestones. Such textures can be also viewed in photomicrographs (microbreccia). Fissures are not always cemented with sparry calcite but, as shown in the photo, with micritic to silt – sized calcite. Note small foraminifera with utterly recrystallized tests on the right

Thin section, plane polarized light. Scale bar = 1 mm

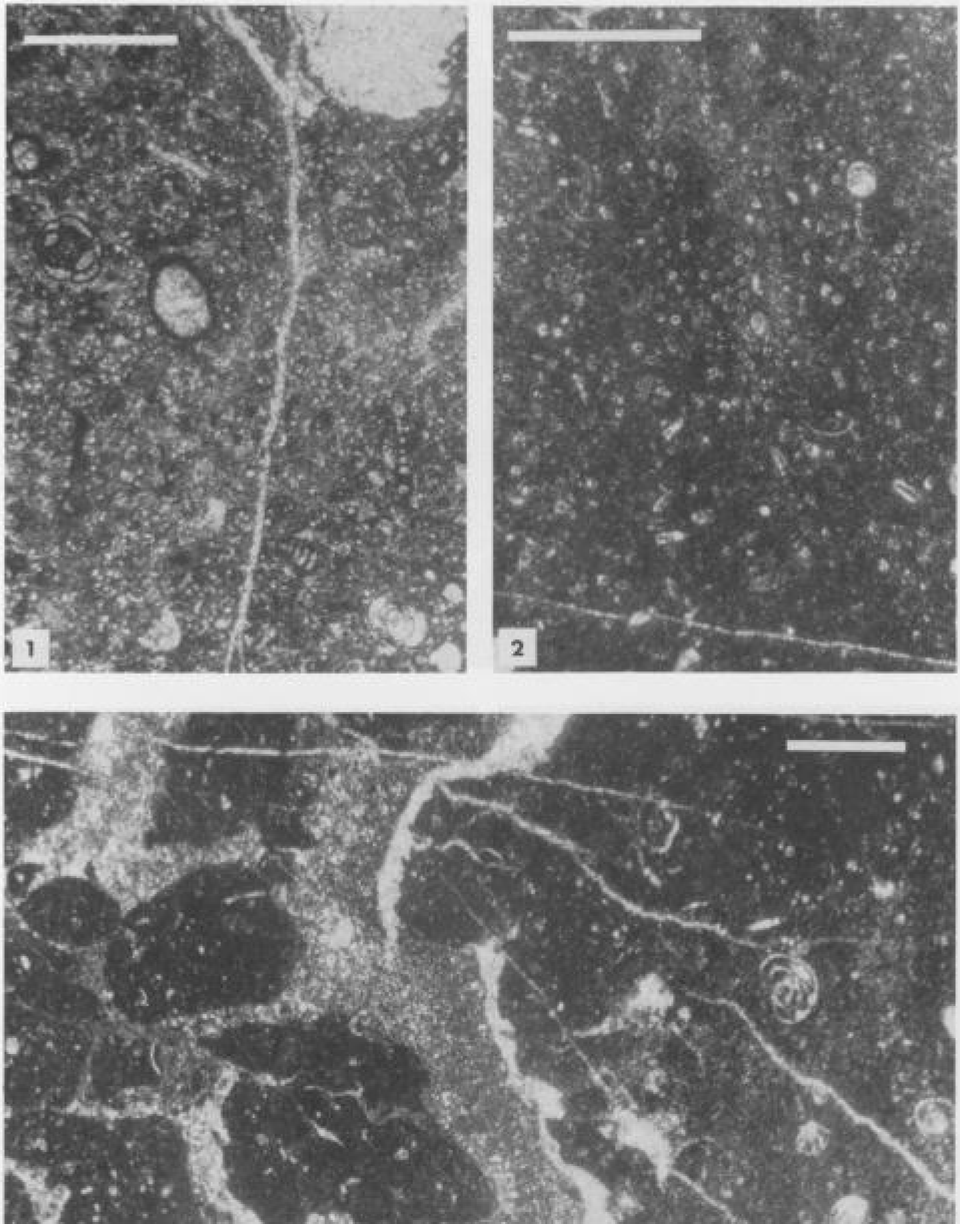
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Plate 5

1 Sample 9
Intrapelmicrite (wackestone to packstone)

Sample from the 'Kozina limestones showing clotted micrite and crumbly fracturing. Intraclasts probably consist of reworked soil material. Coatings can be readily distinguished from the original material by their darker color. The gastropod shell on the left is recrystallized but still recognizable due to the micritic envelope

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 18
Foraminiferal biomicrosparite (packstone)

Biogenic allochems consist of Miliolid and other benthonic foraminifera. Other constituents are peloids. The former micritic matrix recrystallized to microspar. Sample from the Miliolid limestones

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 20
Algal and foraminiferal biomicrite (wackestone)

View of a sample collected from the Alveolina-Nummulites limestones. Several foraminifera (nummulitids, lepidocyclina, rotalids) as well as coralline algae can be recognized

Thin section, plane polarized light. Scale bar = 1 mm

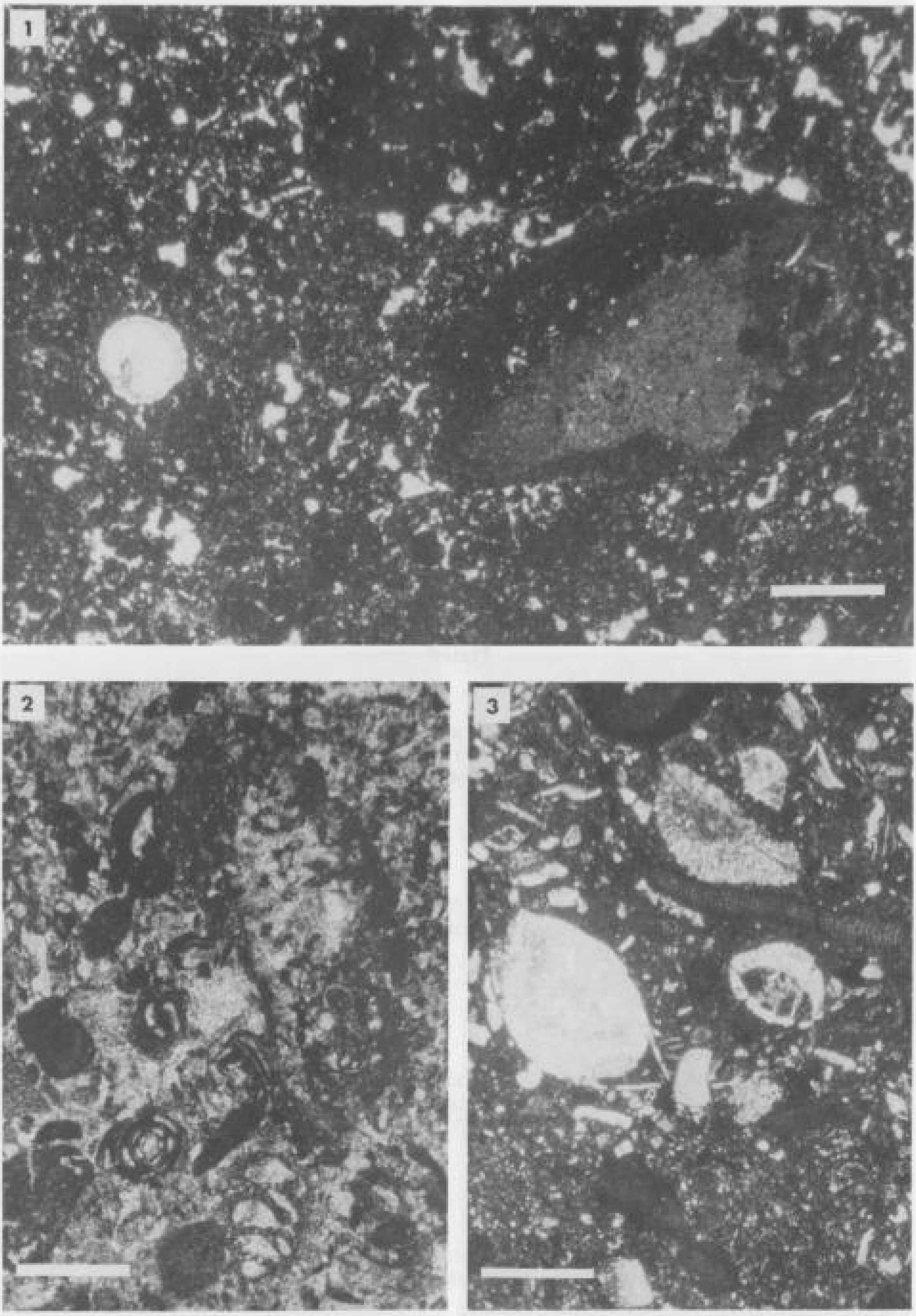
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Plate 6

1 Sample 26

The primary rock type may be regarded as a biopelmicrite (wackestone to packstone). The primary texture has been heavily altered by in situ formed Microcodium. Microcodium is ultimately indicative of pedogenetic processes which could only take place over rather long emergence periods

Thin section, plane polarized light. Scale bar = 1 mm

2 Sample 55

A petal-like Microcodium aggregate replaces a foraminifera with perforated test (*Europertia* ?). Microcodium aggregates are often found corroding primary limestone components and obliterating primary textures

Thin section, plane polarized light. Scale bar = 1 mm

3 Sample 41
Biosparite (grainstone)

Sample from the Miliolid limestones containing fossils of typical marine environments (fragments of corals and dasycladacean algae). The former aragonitic shells have been dissolved and only micritic envelopes are left

Thin section, plane polarized light. Scale bar = 1 mm

4 Sample 67
Foraminiferal biomicrite (wackestone)

Characteristic view of an Alveolina limestone. Accessory components are remains of echinoids and coralline algae. The micritic matrix is partially recrystallized.

Thin section, plane polarized light. Scale bar = 1 mm

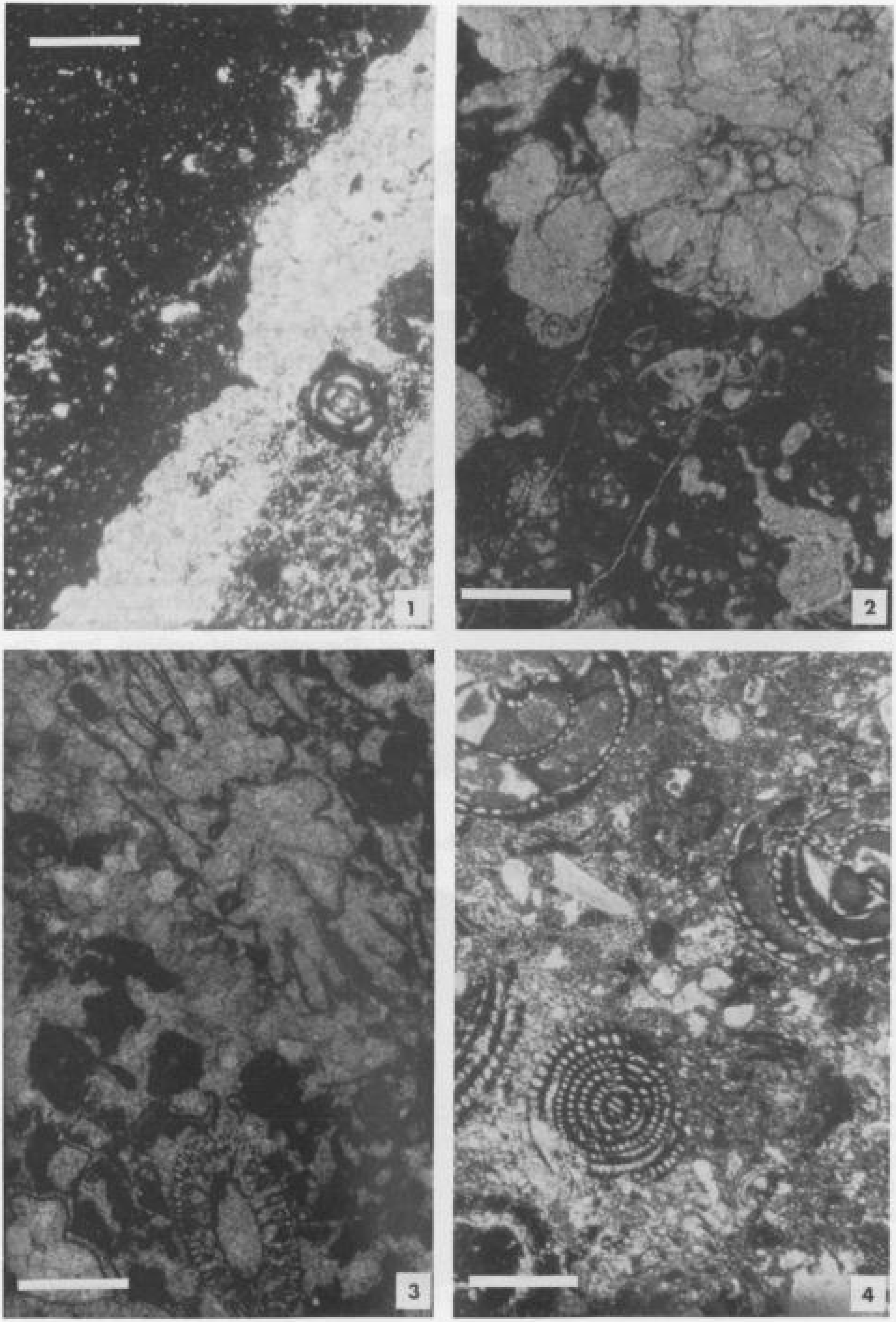
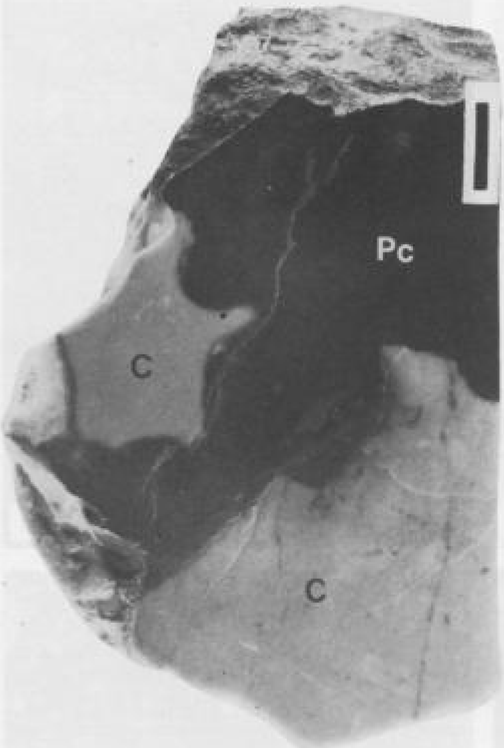
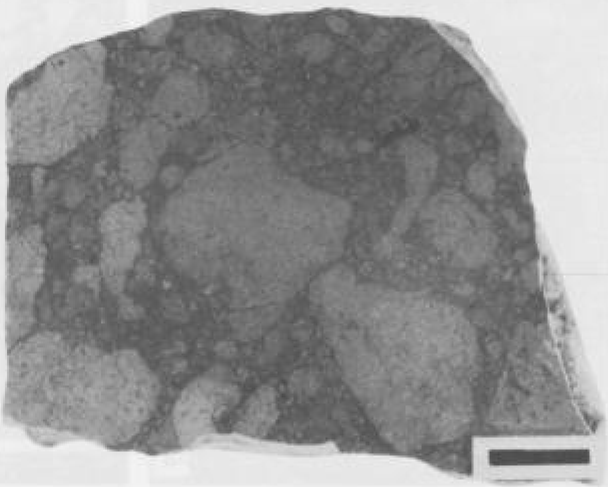


Plate 7



1 Sample collected right at the contact between Upper Cretaceous and Paleocene limestones. Note the sharpness of the contact and the contrasting limestone colors. The paleorelief resulted from dissolution processes during subaerial exposure (karst)

Scale bar = 1 cm



2 Brecciation textures are commonly observed in the Kozina limestones. Some of these breccia may have formed as a result of mechanical reworking of more or less consolidated lime mud. Others, however, resulted from bioturbation (or pedoturbation) or from diagenetic processes during calichification

Scale bar = 1 cm