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Microfacies and sedimentary sequences in the Lower Aptian (Bedoulian) of the Urgonian platform (Chartreuse massif, SE-France)

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ABSTRACT

The "Côte de Berland" section in the Chartreuse massif (SE-France) contains carbonate rocks with marly intercalations of Early Aptian (Bedoulian) age.

One hundred and thirty samples were analyzed and subsequently classified into nine microfacies types and two subtypes.

Shallow-marine (inner-platform), open-lagoonal carbonates dominate the studied section. Marly intercalations represent restricted-lagoonal conditions.

The vertical succession of microfacies types implies a sea-level fall during the Early Aptian: an obvious shallowing-upward succession (late highstand deposits) is truncated by a pronounced exposure surface (sequence boundary). The exposure surface is overlain by marls rich in charophytes (lowstand deposits and/or early transgressive deposits).

Palaeontological data (occurrence of *Heteraster oblongus* BRONGNIART, indicating the *Consobrinus* zone and Early *Matheroni* zone) make it very probable that this emersion surface corresponds to the 112 Ma sequence boundary of Haq et al. (1987, 1988).

RESUME

La coupe de la «Côte de Berland» dans le Massif de la Chartreuse (SE-France) représente des roches carbonatées avec intercalations marneuses de l'Aptien inférieur (Bédoulien).

Les 130 échantillons analysés ont été classé en 9 types de microfaciès et 2 sous-types de microfaciès.

La coupe étudiée est dominée par des carbonates représentant des dépôts marins peu profonds (plate-forme interne) de lagons ouverts. Les conditions de lagon restreint (lagon fermé) sont exclusivement démontrées par les différentes intercalations marneuses.

Une chute du niveau marin à la base de l'Aptien est indiquée par une succession verticale de microfaciès montrant une tendance nette de la diminution de profondeur (dépôts terminaux de haut niveau marin). Elle est tronquée par une surface d'émersion prononcée (limite de séquence). Cette dernière est recouverte par des marnes riches en charophytes (dépôts de bas niveau marin et/ou dépôts de transgression initiale).

Les données paléontologiques (*Heteraster oblongus* BRONGNIART, indicateur des zones à *Consobrinus* et *Matheroni* inférieur) donnent à penser que la surface d'émersion décrite correspondrait à la limite de séquence de 112 Ma d'Haq et al. (1987, 1988).

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ZUSAMMENFASSUNG

Untersucht wurde die sedimentologische und sequenzielle Entwicklung einer Kalkstein-Mergel Wechselfolge des Aptian (Bedoulian) im Chartreuse Massiv (Côte de Berland, SE-Frankreich).

Die 130 analysierten Proben konnten in 9 Mikrofaziestypen mit 2 Untertypen gegliedert werden.

Das Profil wird dominiert von Mikrofaziestypen, welche flachmarine, offenlagunäre Ablagerungen (innere Karbonatplattform) widerspiegeln. Ablagerungen des eingeschränkten marinen Milieus ("cut-off lagoons") werden ausschließlich durch die eingeschalteten Mergelbänke repräsentiert.

Auf eine Absenkung des Meeresspiegels während des frühen Aptian deutet eine Abfolge von Mikrofaziestypen mit eindeutiger "shallowing upward" Tendenz hin ("late highstand deposits"). Diese Abfolge wird von einer ausgeprägten Emersionsfläche begrenzt ("sequence boundary"), welche wiederum von einer charophytenreichen Mergellage überlagert wird ("lowstand deposits" und/oder "early transgressive deposits"). Paläontologische Daten (*Heteraster oblongus* BRONGNIART, Leitfossil für die *Consobrinus* und untere *Matheroni* Zone) lassen den Schluß zu, daß die angesprochene Emersionsfläche der Sequenzgrenze 112 Ma von Haq et al. (1987, 1988) entspricht.

Introduction

The study area is located in the western part of the Chartreuse massif, which is situated between the towns of Chambery, Grenoble and Voiron, in southeastern France (Fig. 1). Two sections of Upper Barremian to Lower Aptian (Bedoulian) strata were studied in detail by Orsat (1991). The Chartreuse massif is part of the northern Subalpine chains. In a strict sense, the "Côte de Berland" section described in this article, still belongs to the easternmost part of the Jura chains which are separated from the Subalpine massif by the Voreppe fault (Lory 1852, Santos Narvaez 1980). A succession of bedded carbonate rocks with intercalated marls (about 63 m), which represents the upper part of the Urgonian Limestone, is well exposed along the road between the small villages of Saint-Christophe-sur-Guiers and Berland (Fig. 1). The thickness of the limestone beds ranges from 0.1 m to a maximum of 3 m (rare). With one exception (5 m), the 22 intercalated marls have a very uniform thickness of about 0.1 m.

The section is divided in three parts; A, B and C in ascending order. A major, tectonically induced discontinuity occurs between parts A and B (Fig. 7, Pl. 1). A minor gap separates parts B and C (Fig. 2). An erosive contact separates the studied Early Aptian sediments from overlaying Vindobonian Molasse deposits (Gibon & Barféty 1969).

Methods

One hundred and thirty samples were subdivided into nine microfacies types (MFT-1 to MFT-9) with two subtypes (MFT-1 A and MFT-1 B) using thin sections (carbonate rocks) and isolated fossils (marls). In addition, the carbonate content of the carbonate rocks and marls was determined with the "Karbonat-Bombe" (Müller & Gastner 1971), and the mineralogical composition (calcite/dolomite/quartz) determined by X-ray diffraction. The quartz content, never more than 20% of the total rock, was determined semi-quantitatively by comparing the intensity of the X-ray peaks (no peak: absent, "short" peak: present, "medium high" peak: rare, "high" peak: frequent, "very high" peak: abundant).

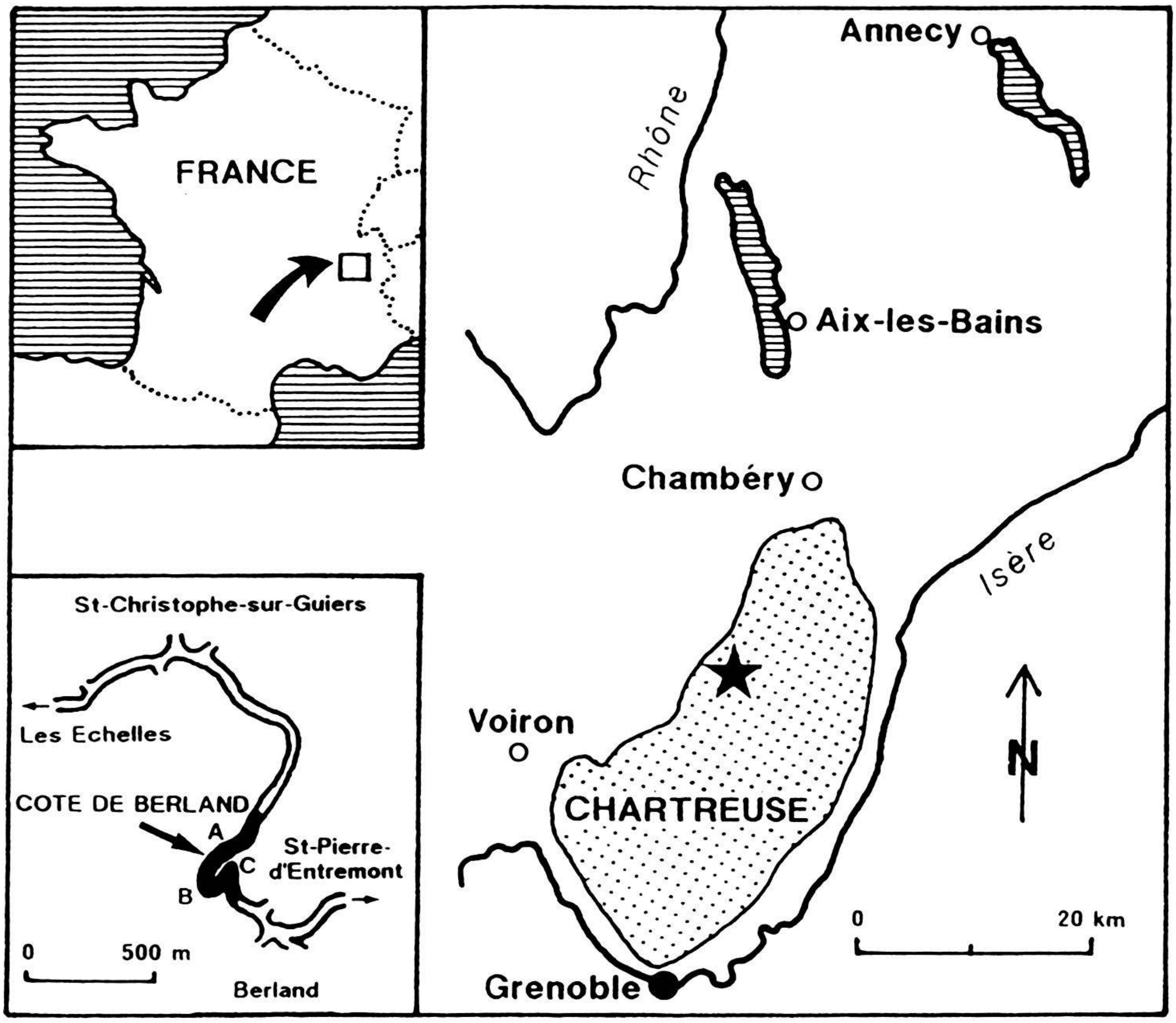


Fig. 1. Location of the studied section.

Palynofacies analysis of two representative marl intercalations (samples OV23 and OV25) was done by G. Gorin & E. Monteil (pers. comm. 1990) in order to reconstruct the paleoenvironment (Gorin & Steffen 1991). The results are summarized on plate 1.

Stratigraphy

The rich orbitolinid fauna, and the echinoid *Heteraster oblongus* BRONGNIART, made it possible to assign the studied succession to the Early Aptian (Bedoulian) (Arnaud-Vanneau et al. 1972, 1976, Charollais et al. 1986, Masse 1979). This age corresponds to that of the Lower Orbitolina beds, which represent the upper part of the Urgonian Limestone (Arnaud-Vanneau 1980, Arnaud 1981, Arnaud-Vanneau & Arnaud 1990). *Orbitolinopsis buccifer* ARNAUD-VANNEAU, an index fossil of the latest Barremian and Bedoulian, first appears about 12 meter, above the base of the studied section (Fig. 2). *Orbitolinopsis kiliani* SILVESTRI, which also appears in the latest Barremian (R. Schroeder, pers. comm. 1989), occurs only above the first 23 m of the studied section. The echinoid *Heteraster*

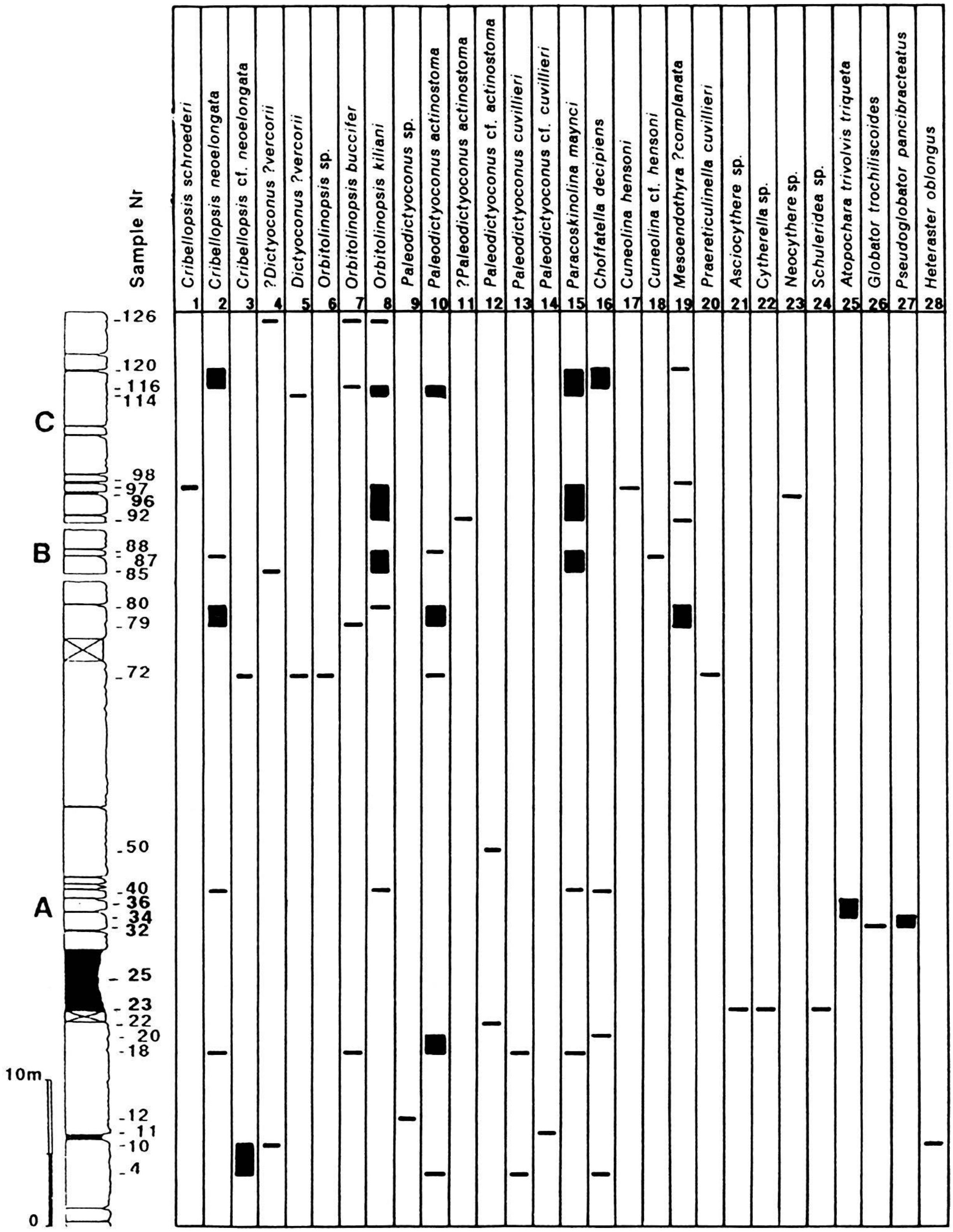


Fig. 2. Distribution of orbitolinids (1–15), benthic foraminifera (16–20), ostracods (21–24), charophytes (25–27) and echinoid (28).

oblongus BRONGNIART found by Clavel (pers. comm. 1993) at the base of the marl intercalation about 6 m above the base of the section, and was also found together with ammonites in various outcrops throughout southeast France, is considered to be an index fossil of the *Consobrinus* zone and the Early *Matheroni* zone by Clavel (1992). The studied section is therefore well defined as being of Bedoulian age.

A complete list of the index fossils found in the samples follows (Fig. 2). The fossil determinations were done by R. Schroeder (Frankfurt): orbitolinids and diverse benthic foraminifera, B. Clavel (Geneva): echinoids, H. J. Oertli (Pau): ostracods and P. O. Mojon (Geneva): charophytes.

Microfacies Analysis

Recent studies of Urgonian facies of the northern Subalpine chains and the Jura mountains in relation to variations in sea level have been done by Arnaud & Arnaud-Vanneau (1989), Arnaud-Vanneau & Arnaud (1990), Jacquin (1989) and Jacquin et al. (1991).

In the study area it was possible to define nine microfacies types (MFT-1 to MFT-9) and two subtypes (MFT-1 A, MFT-1 B) (Pl. 1). The sample description is based on the classifications proposed by Dunham (1962) with supplements by Embry & Klovan (1972), and Folk (1959, 1962) with supplements by Strohmenger & Wirsing (1991).

The microfacies types (MFT) were compared with the standard microfacies types (SMF) of Wilson (1975) and Flügel (1972), as well as with the facies zones (FZ) of Flügel (1982).

The bioclastic (orbitolinid-rich) and oo-bioclastic limestones as well as the intercalated fossil-rich marls correspond to the typical Urgonian facies *sensu lato* (Masse 1966, Arnaud-Vanneau 1980, Viéban 1983, Cotillon coord. 1984, Clavel et al. 1986).

Most of the studied carbonate rocks have a $CaCO_3$ content of over 90% (average of 102 samples: 96%). Only 10 samples yielded lower values between 82 and 90% (average of 10 samples: 88%). X-ray analysis showed that most of the insoluble residue is composed of quartz.

Microfacies type 1 (MFT-1): Charophyte marl/Bioclastic marls.

Microfacies type 1A (MFT-1 A): Charophyte marl.

Charophytes were the only bioclasts that could be found after the separation of the microfossils from the marly sediments.

The carbonate content of the charophyte marl (1 sample) is 20%. Quartz is abundant.

The exclusive occurrence of charophytes as well as the position of the marl over a pronounced emersion horizon clearly indicates a lacustrine (pond) deposit.

Microfacies type 1 B (MFT-1 B): Bioclastic marl (FZ 8).

The separation of bioclasts from the marly sediment yielded a rich assemblage, dominated by orbitolinids. Other fossils include diverse benthic foraminifera, echinoid spines and ostracods.

Based on the classification scheme proposed by Füchtbauer (1959) and Füchtbauer & Müller (1977), the measured carbonate content of the nineteen investigated marls leads to a separation into three groups:

- calcareous clays (4 samples: 10–25% $CaCO_3$, with an average of 20%). Quartz is always abundant.
- marls (3 samples: 25–75% $CaCO_3$, with an average of 66%). Quartz is always abundant.
- argillaceous carbonates (12 samples: 75–90% $CaCO_3$, with an average of 82%). Quartz content varies between present to abundant.

Only three marls merit their name in a strict sense. The fossil distribution within the different marls is independent of the varying carbonate content. The quartz content on the contrary shows a good negative correlation with the carbonate content: a high quartz fraction is found within the samples with low carbonate content.

The absence of planktonic foraminifera renders a deep water origin of the described marls unlikely. The presence of ostracods (*Asciocythere* sp., *Cytherella* gr. *ovata*, *Cytherella* gr. *parallela*, *Neocythere* sp., *Schuleridea* sp.) on the other hand favors the interpretation of restricted shallow-water deposits in a schizohaline environment. This argues for a deposition of the marls in cut-off lagoons and/or coastal ponds with highly restricted water circulation.

Microfacies type 2 (MFT-2) (Fig. 3.1): Charophyte-peloid wackestone; Biopelmicrite (FZ 8).

Pelmicritic limestone with charophytes, ostracods and gastropods.

Dominant sedimentary structures are birds-eyes, rootmarks, bioturbation, burrows and wispy microstylolites (horsetailing).

The carbonate content (3 samples) ranges from 95 to 96%, averaging 95.5%. Quartz is always present.

The low fossil diversity as well as the charophytes themselves indicate a restricted environment. The charophyte-peloid wackestones are interpreted as brackish to lacustrine shallow-water sediments, which had been emerged (rootmarks) after deposition.

Microfacies type 3 (MFT-3) (Fig. 3.2): Bioclastic wackestone; Biomicrite (SMF 9, FZ 7/8).

Micritic limestones with a highly diverse fossil assemblage: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), gastropods, pelecypods, serpulids, ostracods, bryozoans, brachiopods, echinoderms and very rare charophytes.

The limestones commonly are bioturbated.

The carbonate content (6 samples) ranges from 91 to 95%, averaging 94%. Quartz is always present.

The rare occurrence of charophytes, which are thought to be washed into the marine environment, could indicate a near-shore (coastal) deposition of the limestones. The bioclastic wackestones are interpreted as quiet-water deposits in bays or protected shelf lagoons under somewhat restricted conditions.

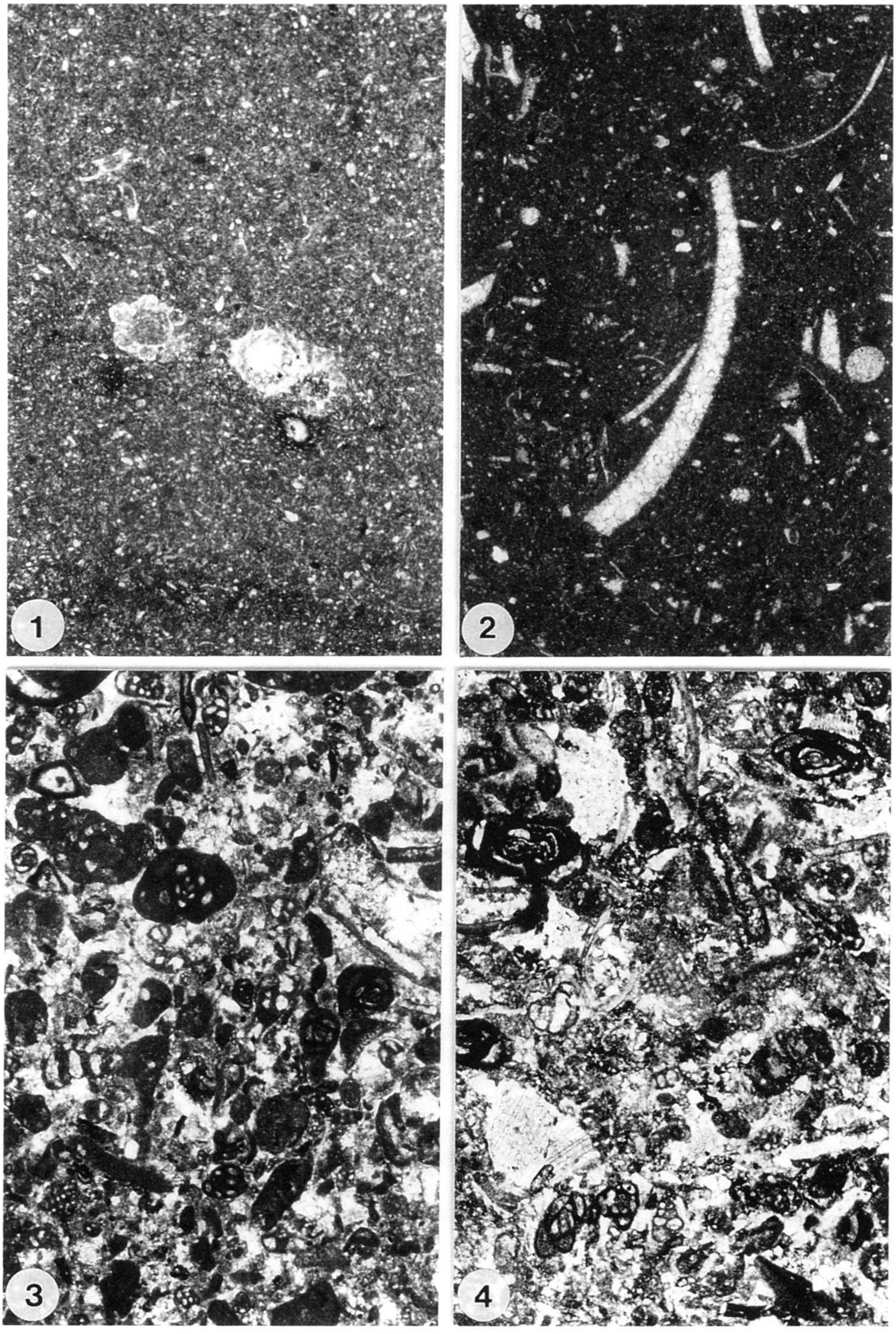
Microfacies type 4 (MFT-4) (Fig. 3.3): Intraclastic-bioclastic-peloid packstone/wackestone; Poorly washed intra-biopelsparite/intra-biopelmicrite (SMF 9, FZ 7).

Commonly bioturbated and partly planar cross-stratified intraclastic-peloidal limestone with abundant fossils: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), dasycladacean algae, rare hydrozoans, rare corals, gastropods, undifferentiated pelecypods, oysters, serpulids, ostracods, bryozoans, brachiopods and echinoderms.

The carbonate content (61 samples) ranges from 87 to 100%, averaging 95%. Quartz ranges from absent to abundant.

The limestones are interpreted as middle carbonate shelf deposits, which were formed in shallow bays and/or open to somewhat protected but not restricted lagoons, with good water circulation under moderate to elevated water-energy conditions above fair weather wave base.

Fig. 3.1: Microfacies type 2: Charophyte-peloid wackestone. OV36. 25x. 2: Microfacies type 3: Bioclastic wackestone. OV29. 25x. 3: Microfacies type 4: Intraclastic-bioclastic-peloid packstone/wackestone. OV53. 25x 4: Microfacies type 5: Echinoderm-peloid packstone. OV47. 25x.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Microfacies type 5 (MFT-5) (Fig. 3.4): Echinoderm-peloid packstone; Poorly washed biopelsparite (SMF 10, FZ 7/5).

This microfacies type is characterized by the abundance of echinoderms which, together with other bioclasts and peloids form a grain-supported fabric. Fossil content: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), dasycladacean algae, gastropods, pelecypods, serpulids, bryozoans, brachiopods and abundant echinoderms.

The carbonate content (5 samples) ranges from 82 to 98%, averaging 94%. Quartz content ranges from absent to abundant.

The fossil assemblage as well as the occurrence of planar cross-stratification point to good water circulation and stenohaline conditions. The described limestones represent typical open-lagoonal (inner to outer platform) deposits.

Microfacies type 6 (MFT-6) (Fig. 4.1): Intraclastic-charophyte-peloid packstone/grainstone; Poorly washed intra-biopelsparite/intra-biopelsparite (SMF 18, FZ 8/7).

Grain-supported intraclastic peloidal limestone with abundant foraminifera (miliolids), dasycladacean algae, pelecypods, brachiopods, echinoderms and charophytes.

The carbonate content (3 samples) ranges from 95 to 98%, averaging 97%. Quartz is always present.

Marine bioclasts (e.g. dasycladacean algae) and fresh water indicators such as charophytes suggest textural inversion (Wilson 1975). Intraclasts containing charophytes clearly demonstrate the reworked character of these algae. The charophytes are thought to be washed into a lagoonal environment under elevated water-energy conditions. The commonly cross-stratified, limestones are interpreted as coastal deposits (tidal channels ?).

Microfacies type 7 (MFT-7) (Fig. 4.2): Intraclastic-bioclastic-peloid grainstone/packstone; Intra-biopelsparite/ poorly washed intra-biopelsparite (SMF 16, FZ 7/8).

Grain-supported limestone with intraclasts, peloids and bioclasts: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), dasycladacean algae, gastropods, pelecypods, serpulids, ostracods, brachiopods and echinoderms.

The carbonate content (14 samples) ranges from 95 to 100%, averaging of 98%. Quartz ranges from absent to rare.

The intraclasts typically have fairly large miliolids present in a micritic matrix. In contrast miliolids occurring in the host rock are of much smaller size, possibly indicating restricted conditions. The grain-supported fabric of the sediment suggests elevated water-energy.

This microfacies type may correspond to channel deposits of a mostly restricted shelf lagoon.

Microfacies type 8 (MFT-8) (Fig. 4.3): Ooid-bioclastic grainstone; Oo-biosparite (SMF 15; FZ 6).

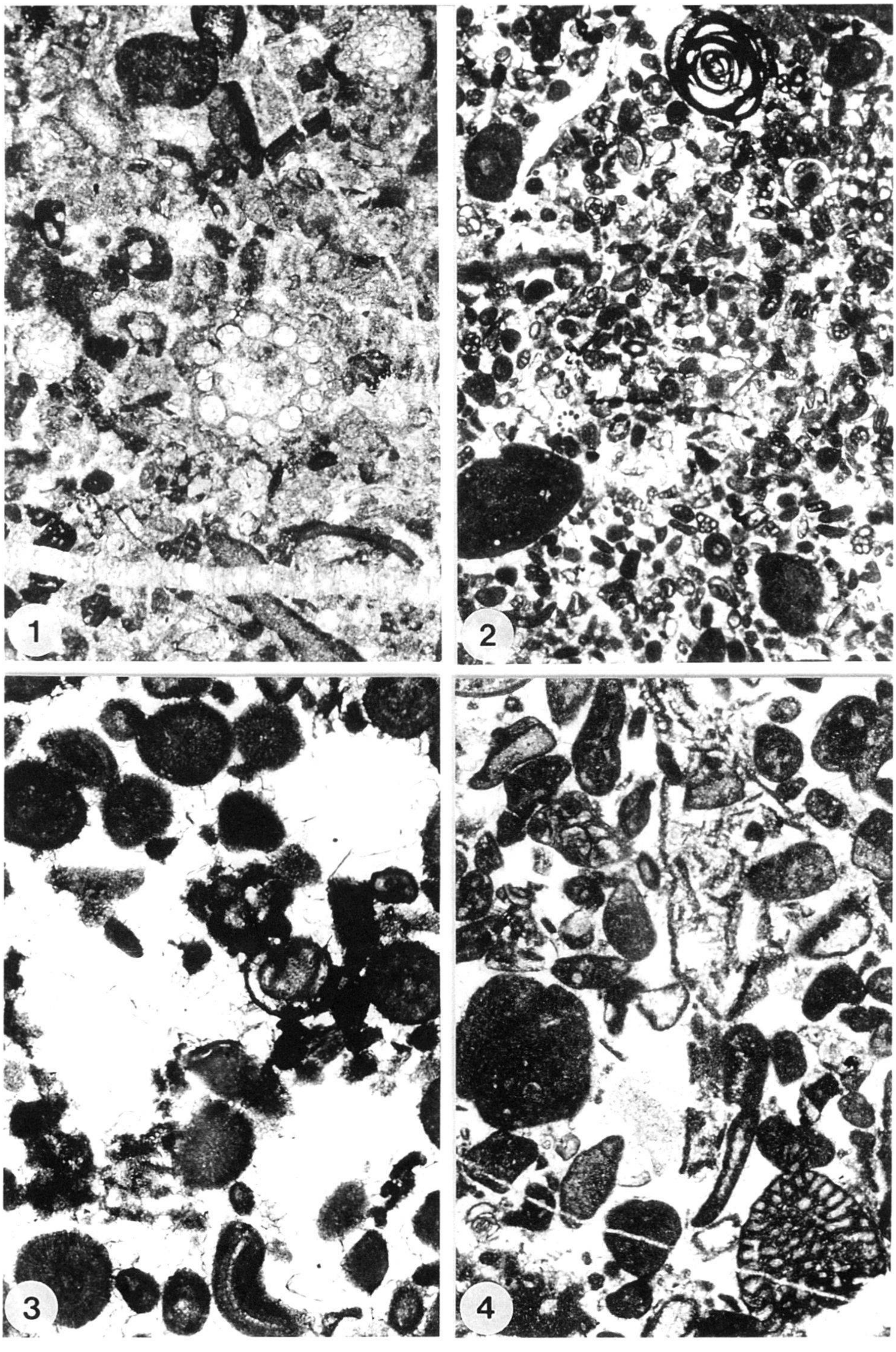
Grain-supported microfacies dominated by sorted ooids and bioclasts: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), rare corals, gastropods, pelecypods, serpulids, brachiopods and echinoderms.

The ooids are about 0.5 mm in diameter and show tangential and radial concentric microstructures. Locally, keystone vugs are present (Fig. 4.3).

The carbonate content ranges from 97 to 100%, averaging 98%. Quartz content varies between absent to present.

The ooid-bioclastic grainstones represent a high-energy environment such as periodically emerged ooid shoals or beaches.

Fig. 4.1 Microfacies type 6: Intraclastic-charophyte-peloid packstone/grainstone. OV33. 25 x. 2: Microfacies type 7: Intraclastic-bioclastic-peloid grainstone/packstone. OV65. 25x. 3: Microfacies type 8: Ooid-bioclastic grainstone displaying keystone vugs. OV68. 60x. 4: Microfacies type 9: Intraclastic-bioclastic grainstone/rudstone. OV91. 25x.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Microfacies type 9 (MFT-9) (Fig. 4.4): Intraclastic-bioclastic grainstone/rudstone; Intra-biosparite/intra-biosparrudite (SMF 18, FZ 6/7).

Grain-supported limestone with relatively coarse-grained fossils: benthic foraminifera (orbitolinids, miliolids, textulariids and undifferentiated foraminifera), dasycladacean algae, rare hydrozoans, gastropods, pelecypods, serpulids, rare bryozoans, brachiopods and echinoderms.

Planar cross-stratification and graded bedding are common.

The carbonate content ranges from 94 to 100%, averaging 98%. Quartz content ranges from absent to rare.

This microfacies type represents a high-energy environment and is interpreted as tidal dominated inlets between the lagoon and the open-marine carbonate platform.

Discussion

1) Microfacies types

Sample density, typically about 1 sample per 0.5 m (130 samples, thickness of section: about 65 m) allows comparison of the relative abundances of the different microfacies types.

The graph displaying the percentage of the subdivided microfacies types (Fig. 5 A) clearly shows three maxima. The section is dominated (46.6%, max. I) by intraclastic-bioclastic-peloid packstones/wackestones (MFT-4) which represent open-lagoonal deposits. Restricted-lagoonal deposits (max. II), which are represented by the different marls (MFT-1 B: bioclastic marls), are also quite common (16.0%). A third, less pronounced maximum (max. III), is formed by microfacies types reflecting elevated water-energy: intraclastic-bioclastic-peloid grainstones/packstones (MFT-7, 10.7%), intraclastic-bioclastic grainstones/rudstones (MFT-9, 8.4%) and ooid-bioclastic grainstones (MFT-8, 4.6%). Other microfacies types only occur in minor quantities: bioclastic wackestones (MFT-3, 4.6%), echinoderm-peloid packstones (MFT-5, 3.8%), intraclastic-charophyte-peloid packstones/grainstones (MFT-6, 2.3%), charophyte-peloid wackestones (MFT-2, 2.3%) and charophyte marl (MFT-1 A, 0.8%).

The microfacies analysis shows that open-marine conditions prevailed in the studied part of the Urgonian platform (MFT-4: intraclastic-bioclastic-peloid packstones/wackestones, MFT-5: echinoderm-peloid packstones). Good water circulation is also indicated by the intraclastic-bioclastic-peloid grainstones/packstones (MFT-7) and the relatively high percentage of samples suggesting inlet deposits (MFT-9: intraclastic-bioclastic grainstones/rudstones). The small quantity of ooid grainstones (MFT-8: ooid-bioclastic grainstones) makes it unlikely that they formed extensive barrier complexes.

The only microfacies types representing restricted conditions are bioclastic marls (MFT-1 B) and bioclastic wackestones (MFT-3). They reflect extreme depositional conditions that are only expected in embayments almost completely isolated from the open-marine shelf. Some of the marls with high carbonate content may also represent tidal-pool deposits.

An emersion of the Urgonian platform during the Early Aptian is indicated by an erosive surface which allows subdivision of the section into a lower and an upper part. Microfacies types displaying an increasing terrestrial influx are present only just below and above the emersion surface (Fig. 5 B): charophyte-peloid wackestones (MFT-2), intraclastic-charophyte-peloid packstones/grainstones (MFT-6), bioclastic wackestones with reworked charophytes (MFT-3) and charophyte marl (MFT-1 A). These microfa-

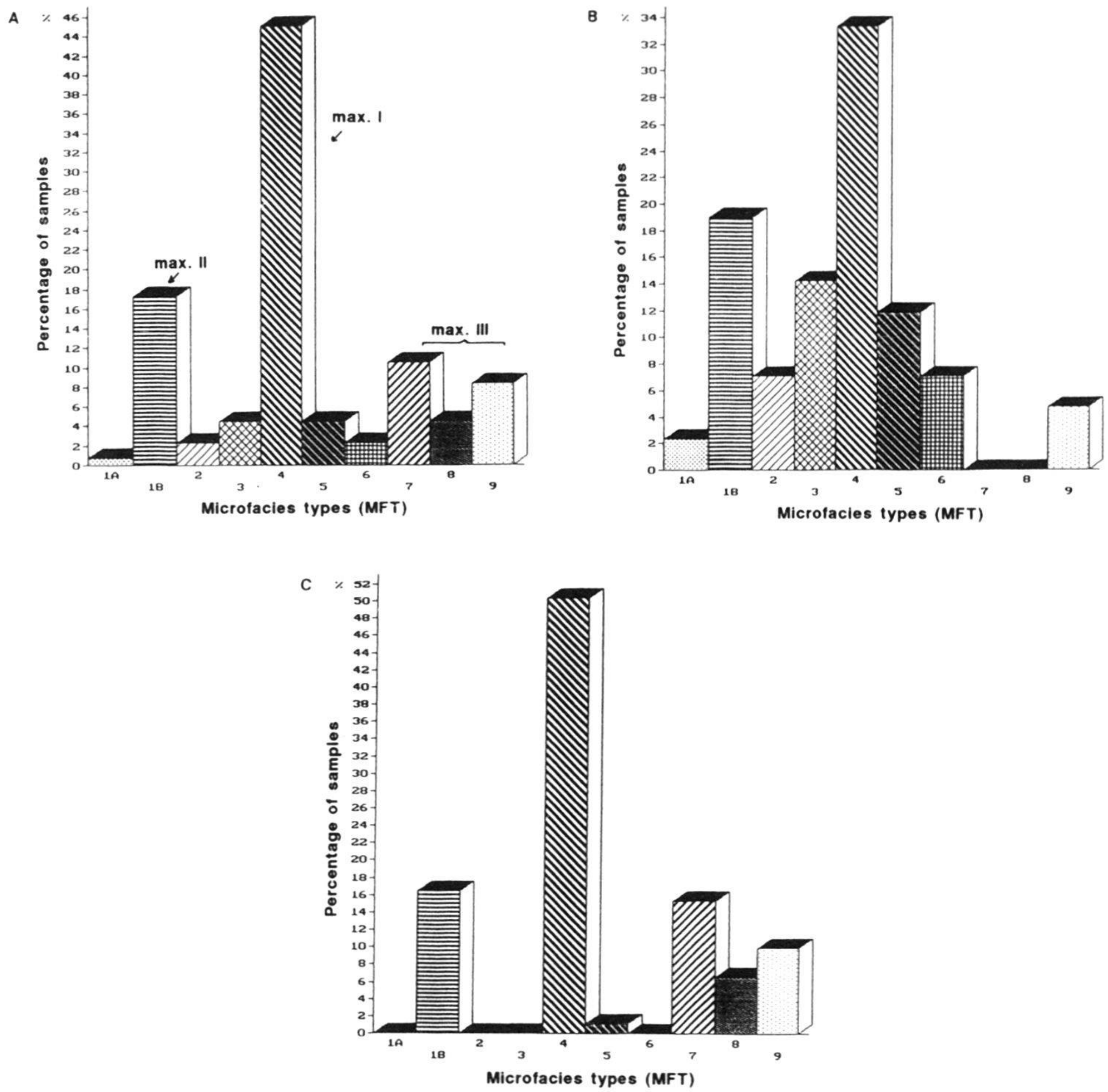

Fig. 5. Percentage of microfacies types. A) Whole section. B) Lower part of the section (below and directly above sequence boundary, samples OV222 to OV39). C) Upper part of the section (samples OV40 to OV126).

cies types reflect a marine regression which led to exposure of the carbonate platform. Intraclastic-bioclastic-peloid grainstones/packstones (MFT-7), ooid-bioclastic grainstones (MFT-8) and intraclastic-bioclastic grainstones/rudstones (MFT-9) representing high-energy deposits are present only above the emersion surface (Fig. 5C). Subsequently, open-marine conditions (MFT-4: intraclastic-bioclastic-peloid packstones/wackestones) dominated the studied section. Minor regressions are, however, indicated by the change from intraclastic-bioclastic-peloid packstones/wackestones (MFT-4) to bioclastic marls (MFT-1 B).

2) Distribution of the microfacies types

According to Walther's law (Walther 1893/94), only such microfacies types can be found superimposed in a vertical, undisturbed succession which had once been laterally juxtaposed in their depositional environment. In a shallow-marine environment with complex lateral facies migrations such as the one described here, this law is only partly applicable (Miall 1985). With well-defined microfacies types and an estimation of their relative abundance, however, the general facies succession can be reconstructed.

The number of vertical transitions between the different microfacies types were calculated by means of an embedded Markov-chain analysis (Krumbein & Dacey 1969, Hoque & Nwajide 1985). The program was arranged in such a manner that different parts of the section could be tied together, in order to prevent that transitions between samples separated by tectonic surfaces or unexposed zones be counted (Strohmenger 1988). The resulting matrix is presented in Fig. 6.

The studied section shows many shifts from MFT-4 to MFT-1 B (11 transitions) and from MFT-1 B to MFT-4 (9 transitions). The high frequency of transitions between these two microfacies types indicates cyclic changes in the environmental conditions. The transitions from MFT-4 to MFT-1 B are interpreted as the migration of coastal deposits over clearly marine sediments, indicating a falling relative sea level (regressive sequences). On the opposite, changes from MFT-1 B to MFT-4 indicate the reestablishment of open-marine conditions induced by a rising relative sea level (transgressive sequences). Also common are transitions from MFT-4 to MFT-7 (7 transitions) and from MFT-7 to MFT-4 (6 transitions). This confirms the interpretation of MFT-7 as channel deposit, which partly reworked MFT-4. The relatively frequent transitions from MFT-5 to

Overlying microfacies types

Underlying microfacies types	1A	1B	2	3	4	5	6	7	8	9
1A				1						
1B			1	1	9	2	1	2		3
2	1									
3		2			1					
4		11		1		1		7	1	3
5					4					
6		1								
7		1			6				2	2
8		2			3					
9		1			2	1		2	2	

Fig. 6. Matrix of vertical transitions of microfacies types (explanations in the text).

MFT-4 (4 transitions) seem to indicate the installation of more protected (but not restricted) conditions (MFT-4) over more open-marine ones (MFT-5). The two observed transitions from ooid-bioclastic grainstones (MFT-8) into restricted-lagoonal deposits (MFT-1 B) suggest rapid falls of sea level. In both cases, the grainstones exhibit keystone vugs (Fig. 4.3), which are indicative for intertidal sediments. They were then covered by basinward migrating coastal sediments (MFT-1 B). This relation makes it probable that the ooid grainstones represent rather beach than barrier deposits.

3) Sequential development

The studied carbonate rocks show a pronounced emersion surface in the lower part of the section (Fig. 7, Pl. 1). A fall of relative sea level is already indicated by the thick marl intercalation (about 5 m) in which the investigated palynofacies show a marked tendency to more terrestrial influence (proximal conditions) towards the top (G. Gorin, pers. comm. 1990, Gorin & Steffen 1991; Fig. 7). The emersion surface, identified by rootmarks and birds-eyes in the underlying sediments, is covered by a thin veneer of marls (0.05 m) extremely rich in charophytes (MFT-1 A). Charophytes are already present in the carbonate rocks directly underlying the discontinuity surface. The paleontological data, in particular the occurrence of the echinoid *Heteraster oblongus* BRONGNIART (B. Clavel, pers. comm. 1993) makes it possible to correlate this surface with the 112 Ma sequence boundary of Haq et al. (1987, 1988).

From bottom to top, the section can be interpreted as follows (Fig. 7, Pl. 1):

- transgressive deposits (TD: beginning of the section)
- maximum flooding (mf: in the middle of the relatively thick limestone bed where orbitolinids are abundant and quartz is missing)
- early highstand deposits (eHSD: starting on top of the maximum flooding until the onset of the marl intercalation
- late highstand deposits (lHSD: onset of the marls, MFT-1 B, which show an obvious trend to more terrestrial palynofacies overlain by shallow water carbonates containing charophytes, MFT-3)
- sequence boundary (SB: on top of the charophyte-bearing limestones)
- lowstand deposit and/or early transgressive deposits (LSD/eTD: charophyte marl, MFT-1 A directly overlying the sequence boundary)
- transgressive deposits (TD: shallow-water carbonates frequently interrupted by marly intercalations representing very restricted conditions, MFT-1 B)
- a rapidly rising relative sea level (mf: marine flooding or maximum flooding) is indicated by the lack of quartz and the relatively thick-bedded carbonates (HSD) about 9 m above the previously mentioned sequence boundary.

In the upper, presumably displaced part of the section, quartz becomes more abundant (Pl. 1).

Conclusions

The obtained paleontological data point to an Early Aptian (Bedoulian) age of the studied carbonate-marl succession.

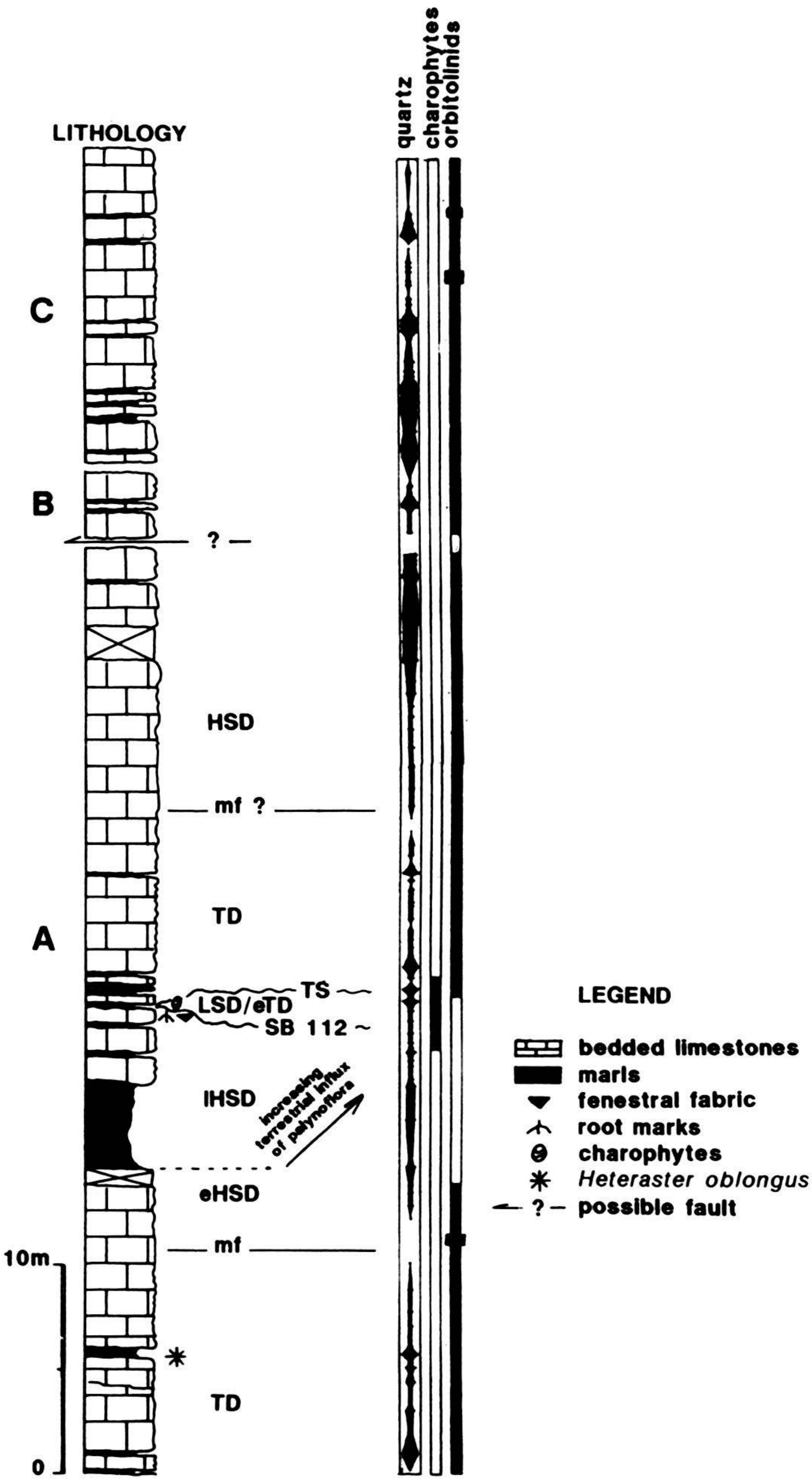

Fig. 7. Relative sequential development of the section (TD: transgressive deposits, eTD: early transgressive deposits, HSD: highstand deposits, eHSD: early highstand deposits, lHSD: late higstand deposits, LSD: lowstand deposits, SB: sequence boundary, TS: transgressive surface, mf: maximum flooding).

The dominant microfacies type (MFT 4) represents normal marine (good water circulation) sediments, deposited under open-lagoonal conditions, above the fair weather wave base. An elevated water-energy is further indicated by the occurrence of cross-stratification throughout the whole section. Restricted-marine conditions are indicated by bioclastic marls (MFT 1 B) rich in quartz.

The interrelationship between the different microfacies types is ascertained by Markov-chain analysis. It allows to demonstrate the migration of the different microfacies types in relation to varying relative sea level. The frequent changes from restricted-marine conditions to open-marine conditions correspond to small-scale transgressive-regressive cycles.

A pronounced emersion surface, dated by the index fossil of the *Consobrinus* zone and Early *Matheroni* zone (*Heteraster oblongus* BRONGNIART) indicates a sea-level fall during the Early Aptian (Bedoulian). This probably corresponds to the 112 Ma sequence boundary (Haq et al., 1987, 1988). Just below this discontinuity, the marls as well as the bedded carbonate rocks show an obvious trend to more terrestrial conditions.

Marls:
- increasing quartz content
- decreasing carbonate content
- increasing abundance of terrestrial-influenced palynofacies

Carbonates:
- appearance of charophytes
- influence of vadose conditions (fenestral structures, rootmarks)

Above the sequence boundary, the section is dominated by open-lagoonal sediments deposited under somewhat elevated to high water-energy.

Terrestrial influence is indicated by locally abundant detrital quartz in the upper part of the carbonate succession (parts B and C), which might represent fault-displaced Early Aptian (?) limestones.

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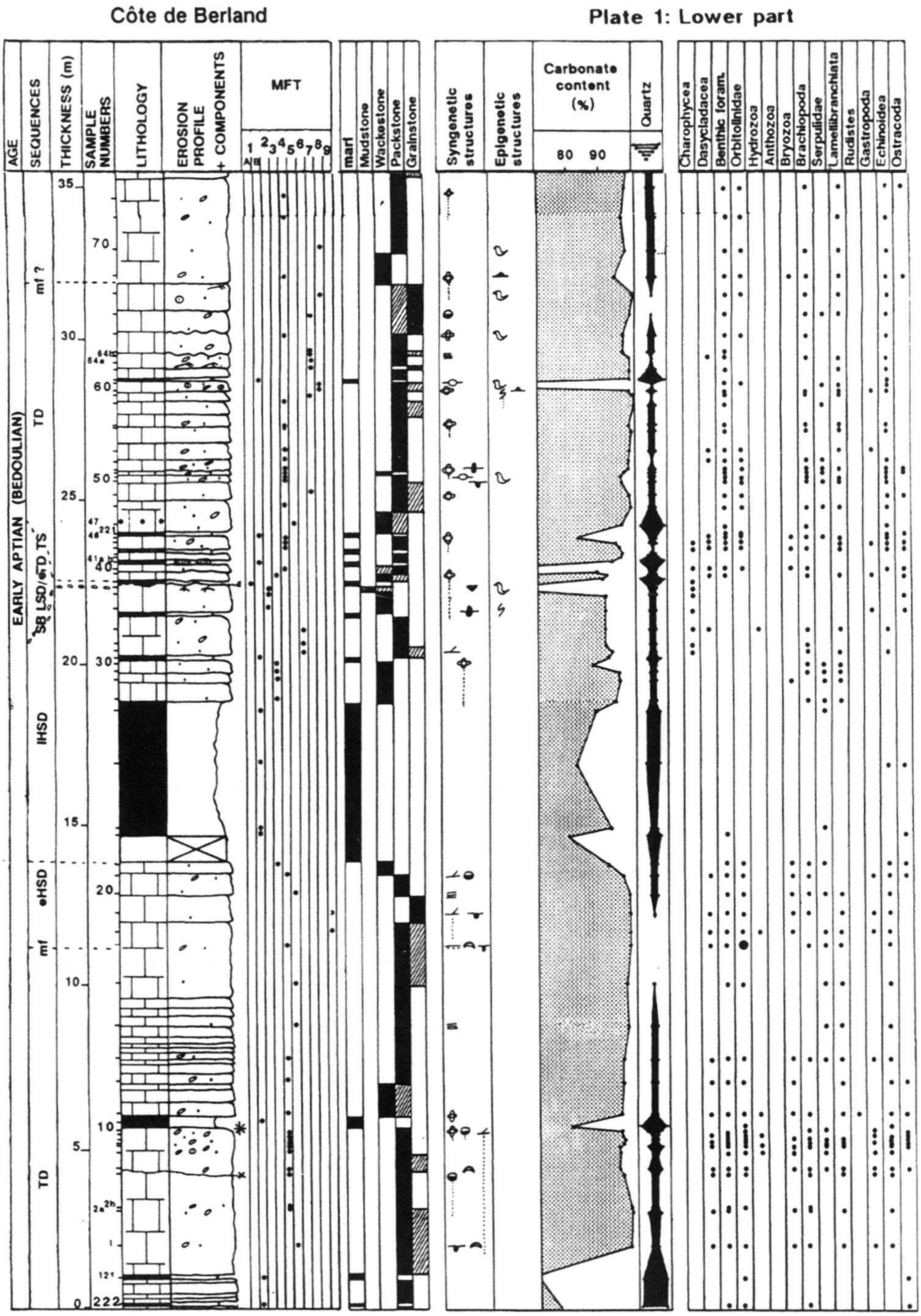
Côte de Berland
Plate 1: Lower part
AGE
SEQUENCES
THICKNESS (m)
SAMPLE NUMBERS
LITHOLOGY
EROSION PROFILE + COMPONENTS
MFT
marl
Mudstone
Wackestone
Packstone
Grainstone
Syngenetic structures
Epigenetic structures
Carbonate content (%)
80 90
Quartz
Charophycea
Dasycladacea
Benthic foram.
Orbitolinidae
Hydrozoa
Anthozoa
Bryozoa
Brachiopoda
Serpulidae
Lamellibranchiata
Rudistes
Gastropoda
Echinoidea
Ostracoda
EARLY APTIAN (BEDOULIAN)
mf ?
TD
SB LSD/eTD TS
IHSD
eHSD
mf
TD

Côte de Berland **Plate 1: Upper part**

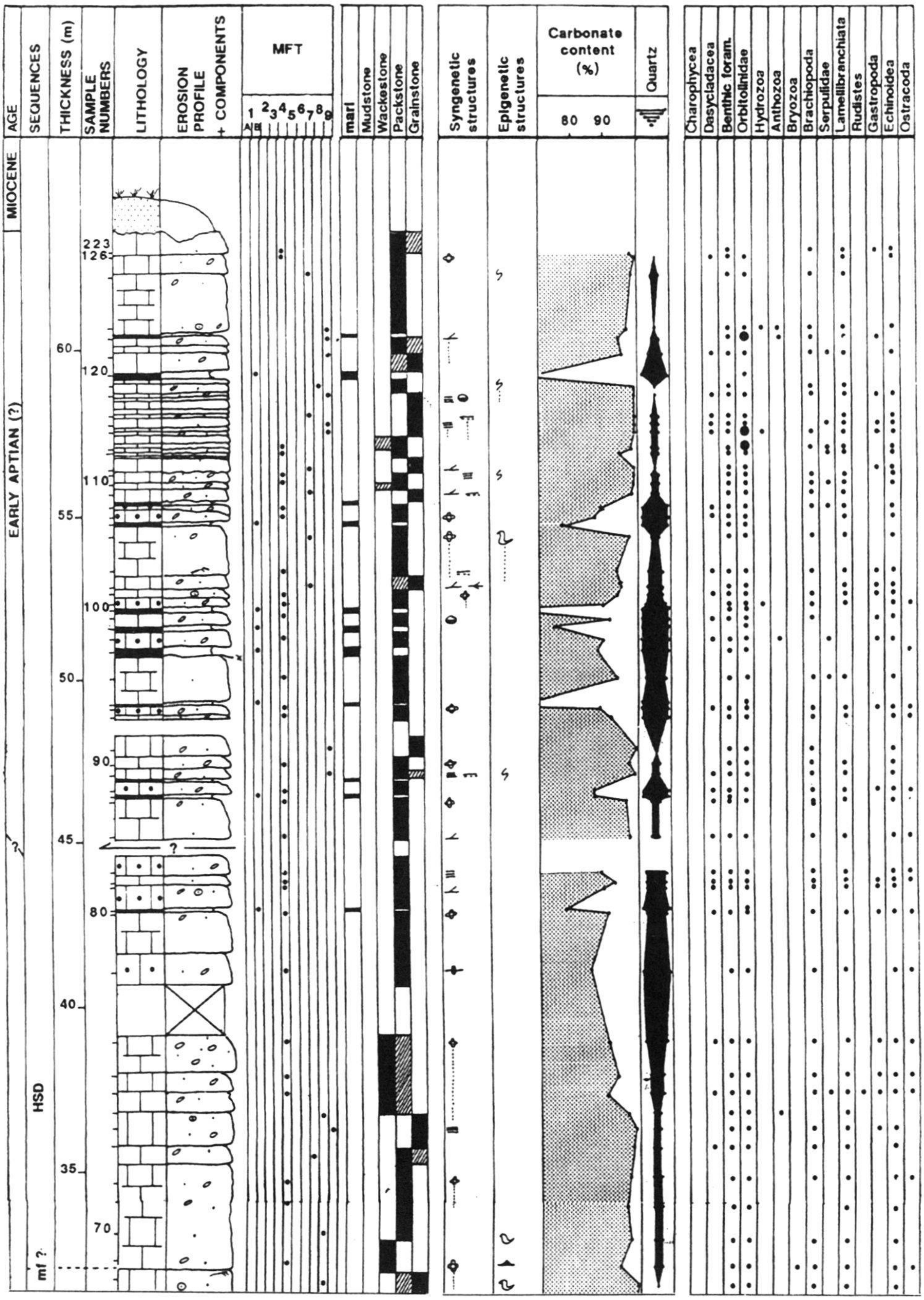

PLATE 1

LEGEND

Syngenetic structures

- parallel laminations
- planar cross-stratification
- trough cross-stratification
- sorting
- bioturbation
- keystone vugs
- birds-eyes
- geopetal fills
- shelter porosity
- root molds
- burrows
- bioerosion

Quartz content

- absent
- present
- rare
- frequent
- abundant

Epigenetic structures

- stylolites
- fissures
- dissolution seams

Components

- intraclasts
- ooids
- peloids
- chert nodules

Macroscopic structures

- ripple marks
- tectonic fractures
- E erosional surface

DUNHAM classification

- dominant
- subordinate

? — possible fault

Molasse sandstones

Heteraster oblongus

Sequences

HSD	highstand deposits
eHSD	early highstand deposits
LHSD	late highstand deposits
TD	transgressive deposits
eTD	early transgressive deposits
LSD	lowstand deposits
SB	sequence boundary
TS	transgressive surface
mf	maximum flooding