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Depositional trends in the Valdorbia Section (Central Italy) during the Early Jurassic, as revealed by micropaleontology, sedimentology and geochemistry

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Key words: Depositional trends, micropaleontology, sedimentology, geochemistry, Early Jurassic, Umbria-Marche basin, Central Italy

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ABSTRACT

In the Umbria-Marche basin open marine Jurassic sediments are well exposed in the Valdorbia section (ENE of Gubbio, Central Italy). The time interval considered here is from the Carixian to the Early Aalenian. The depositional units, already dated by means of ammonites and calcareous nannofossils, are: limestones and cherty limestones, Pliensbachian in age ("Corniola" = COR); marls of Early – Middle Toarcian age ("Marne del Monte Serrone" = MS), including black shales in the Tenuicostatum Zone; reddish nodular calcareous marls and limestones, Middle Toarcian to Early Aalenian in age, which constitute the "Rosso Ammonitico Umbro-Marchigiano" (= RAUM); and bivalve-bearing cherty limestones, Aalenian in age ("Calcari a Posidonia" = CP). Micropaleontological, sedimentological, trace fossil and geochemical-mineralogical analyses have been carried out. The microfossil study has revealed changes in the microforaminiferal assemblages, corresponding to changes in both oxygen conditions and depth of the sea floor: Miliolina, Textulariina and Lagenina are common in the Carixian; Textulariina and Lagenina in the Domerian and Lagenina, Spirillinina in the Toarcian/Aalenian. Opportunistic small species bloom in the most anoxic levels of the black shales.

The sedimentological study reveals two peaks in the detrital sedimentation. The first – probably connected with local tectonics (without excluding sea-level changes) – is found in the interval from the Carixian to the lower part of the Lower Toarcian. Metre-scale cycles of fine-grained calcareous turbidites, due to low-density flows, evolve gradually into coarse-grained, metre-thick turbidites often amalgamated and containing reworked skeletal grains of a carbonate platform environment, and gravity flow deposits. The second peak occurs in the Middle-Upper Toarcian. Fine-grained turbidites are overlain by hummocky cross-stratified (HCS) deposits and winnowed beds (WB), with large and pervasive bioturbation. The vertical transition from turbidites to sharp-based HCS deposits and WB is probably indicative of a general regressive trend and of a depositional environment above major storm wave base. This trend has also been indicated from the microfossil study.

Geochemical analysis of the Lower Toarcian (Tenuicostatum Zone) has revealed strong positive anomalies in Ba, V, Cr, Ni, Co, Cu, Zn, As, Sb and Pb, elements which are characteristic of black shale episodes. Weaker positive anomalies occur in similar sediments of the lower part of MS Formation, while such positive anomalies are absent in the largely bioturbated sediments deposited below (COR) and above (RAUM) the MS.

Depositional trends related to tectonic-eustatic variations in the depositional environment are suggested on the basis of information provided by the study of the Valdorbia Section and of other Umbria-Marche sections.

RIASSUNTO

Sedimenti pelagici del Giurassico sono ben esposti lungo la sezione della Valdorbia (ENE di Gubbio, Appennino Centrale). Tale sezione è ben nota in quanto è indicativa della sedimentazione giurassica di mare aperto che ha sostituito, nel Lias inferiore dell'area Umbro-Marchigiana, la sedimentazione tipica di una piattaforma carbonatica (Calcare Massiccio). Le seguenti unità litostratigrafiche, già datate in base alle ammoniti e ai nannofossili calcarei, sono state qui studiate mediante analisi micropaleontologica, sedimentologica, delle tracce fossili e geochimico-mineralogica: l'unità calcareo-silicea della «Corniola» (COR, Pleinsbachiano); la Formazione marnosa delle «Marne del Monte Serrone» (MS, Toarciano inferiore-medio) con episodi anossici («black shales») del Toarciano inferiore; l'unità calcareo-nodulare del «Rosso Ammonitico Umbro-Marchigiano» (RAUM,Toarciano medio – Aaleniano inferiore); e infine l'unità calcarea dei «Calcari a Posidonia» (CP, Aaleniano s. l.).

L'esame dei microfossili ha rilevato variazioni nelle associazioni a microforaminiferi, corrispondenti a cambiamenti nel grado di ossigenazione e profondità del fondo marino. Essi sono rappresentati da Miliolina, Textulariina e Lagenina nel Carixiano, da Textulariina e Lagenina nel Domeriano e da Lagenina e Spirillinina nel Toarciano ed Aaleniano. Nei livelli a black shales le associazioni a foraminiferi sono caratterizzate da forme opportunistiche. I resti di macroinvertebrati sono sempre comuni, ad eccezione nel Toarciano inferiore.

Lo studio sedimentologico ha evidenziato essenzialmente due acmi di sedimentazione detritica: il primo, tra il Carixiano ed il Toarciano inferiore, legato prevalentemente a tettonica locale senza escludere variazioni eustatiche; il secondo, legato probabilmente a regressione tettonico/eustatica, tra il Toarciano inferiore/medio e la base dell'Aaleniano. Nel primo acme si hanno calcisiltiti torbiditiche a laminazioni piano-parallele, riferibili a flussi a bassa densità, a cui seguono nel Toarciano inferiore calcareniti/ruditi torbiditiche amalgamate, legate a flussi di alta densità, e depositi gravitativi. Il secondo acme è rappresentato per lo più da calcareniti ad stratificazione incrociata «hummocky» (HCS) nel Toarciano medio-superiore, ed infine a livelli selezionati «granulo sostenuti» (WB) nel Toarciano superiore. Questo secondo trend indica probabilmente una diminuzione di profondità del bacino, da sotto la base d'onda di tempesta (torbiditi) a intorno o poco sopra essa (HCS e WB), con aumento anche del grado di ossigenazione del fondo, dimostrato dalla bioturbazione pervasiva.

L'analisi mineralogica delle argille ha messo in evidenza una certa uniformità negli apporti argillosi del Toarciano, mentre quella geochimica ha permesso di riconoscere nelle MS del Toarciano inferiore (Zona a Tenuicostatum) forti anomalie positive in Ba, V, Cr, Ni, Co, Cu, Zn, As, Sb e Pb in corrispondenza dei black shales e di simili anomalie più deboli nei sedimenti argillosi immediatamente sottostanti. Queste anomalie sono assenti nei sedimenti della COR e del RAUM che si presentano anche decisamente bioturbati (tracce fossili grandi e penetrative), testimoniando un buon grado di ossigenazione sul fondo marino.

L'approccio interdisciplinare ha permesso di individuare una tendenza all'approfondimento del fondo marino in corrispondenza del Toarciano inferiore (Zona a Tenuicostatum) ed una tendenza alla diminuzione di profondità in corrispondenza della facies calcareo-nodulare del RAUM nel Toarciano medio-superiore. Vengono perciò suggerite variazioni tettonico-eustatiche nel bacino di sedimentazione, tenendo in considerazione anche informazioni derivate dallo studio di altre aree del bacino Umbro-Marchigiano.

1. Introduction

The Valdorbia Section (Fig. 1) is well known in the literature on the Early Jurassic of the Umbria-Marche Basin because it is easily accessible and offers good exposure of the Early Jurassic formations. Moreover the abundance of ammonites allows good stratigraphic resolution. Pelagic sedimentation was continuous after the drowning of the Calcare Massiccio carbonate platform, as shown by the Lower Jurassic stratigraphic units which are without obvious significant hiatuses in the composite Valdorbia succession (Fig. 2). The section has been studied both by paleontologists and by sedimentologists (Donovan 1958; Gallitelli Wendt 1969; Colacicchi et al.1970; Colacicchi et al. 1988; Passeri 1971; Centamore et al. 1969, 1971; Elmi 1981a, b; Venturi 1981; Cresta et al. 1988; Cresta et al. 1989; Monaco 1992). Other studies have involved magnetostratigraphy (Channell et al. 1984) and the Toarcian Anoxic event (Jenkyns & Clayton 1986; Jenkyns 1988). The black shales, which occur in the Lower Toarcian, have recently been examined by Baudin et al. (1990) and by Bartolini et al. (1992). Some clay mineral assemblages and geochemical characteristics have been investigated by Ortega-Huertas et al. (1993). Besides the ammonite biostratigraphy, calcareous nannofossils have been analysed by Reale (1988, 1989) and by Reale et al. (1991).

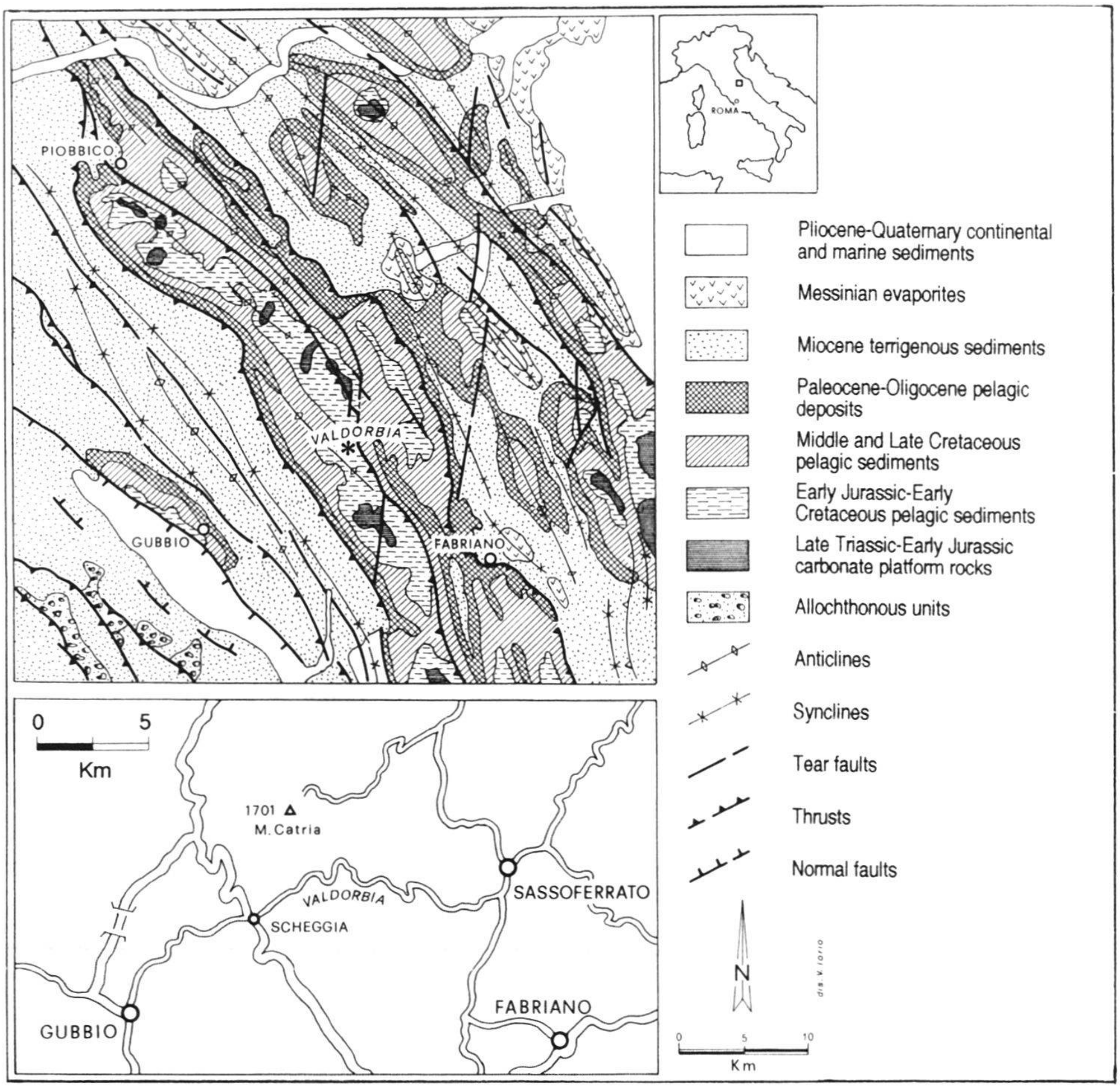


Fig. 1. Schematic geological map and location of the Valdorbia Section.

The object of the present work is to study further the sedimentology, the microfacies and loose microfossils with particular consideration to benthic foraminifers. In such a way it is possible to integrate the ammonite biostratigraphy with benthic microfossil information in order to better understand the depositional environment and its evolution during the Carixian to Lower Aalenian. Other aspects taken into consideration are trace fossils and clay mineral assemblages together with their geochemical characteristics.

The observations and their inferences fit into a wider context based on the results obtained from the study of several other sections of the Umbria-Marche Basin (Monaco 1992; Nocchi & Bartolini in press; Nocchi 1992; Nocchi et al. 1991). Finally, the succession of the stratigraphic units with their main paleontological and sedimentological features has been compared to the proposed eustatic curve of Hallam (1988) in order to differentiate the influence of the eustatic sea-level fluctuations and tectonics.

2. Geological setting

The examined area belongs to the Umbria-Marche Apennine fold and thrust belt and, particularly, to its inner Ridge ("Ruga interna", Scarsella 1951). It consists of a right lateral "en echelon" set of three main anticlines designated, from west to east, as internal, intermediate and external (Fig. 1). The outer limb of each anticline is partially overturned and thrusted (Barchi et al. 1989). Mesozoic and Paleogene pelagic formations, consisting mainly of marls and limestones, are involved in this late Tertiary compressive phase which followed transtensive Jurassic activity responsible for the thinning of the Apulian continental margin.

The Valdorbia section (lat. N 43°25', long. E12°42') is located along the State Road N. 360 which runs between Scheggia and Sassoferrato (Fig. 2), on the left bank of the Sentino Creek, near the Molino delle Ogne (mineral water spring). The outcropping Jurassic stratigraphic units constitute the core of the internal asymmetrical anticline (M. Petria-M. Cucco), which is cut by the Sentino Creek and characterized by a well extended and slightly deformed axial zone. The western limb of the anticline dips westward while its eastern flank is vertical and partially overturned.

3. Stratigraphy

In the last 20 years many studies concerning the Umbria-Marche Basin (UMB) have revealed the existence of three main kinds of succession of Jurassic open marine or pelagic sediments deposited above the "Calcare Massiccio" carbonate platform: a) "condensed" successions, which are represented by thin, mainly calcareous, sedimentary sequences deposited on submarine elevated areas with slow or no subsidence (morphostructural highs), b) "extended" successions constituted of thick calcareous-clayey sediments, rich in detrital material, deposited in depressed and subsiding areas, c) "intermediate" successions that are very common in the UMB and are formed by sediments of medium thickness (compared to a – b above) without detrital material.

Recently Cresta et al. (1988) and Colacicchi et al. (1988) have distinguished five types and two subtypes of succession on the basis of the occurrence and the vertical extent of the Jurassic formations. These successions show heterogenous sedimentation in the Early and Middle Jurassic which reflects a diverse paleogeography, inherited from the Liassic break-up of the "Calcare Massiccio". The Valdorbia succession belongs to the "extended" successions (type 1, subtype b) and is characterized by abundant clay (Ortega-Huertas et al., 1993) and calcareous detrital sedimentation during the Toarcian.

The study of the section starts along the road at km 57 below an abandoned quarry, and only the stratigraphic interval from Carixian to the Lower Aalenian has been considered (Fig. 2). The lithostratigraphic units, well known from the literature (Cresta et al. 1988; Farinacci et al. 1978; Farinacci & Elmi (Eds.) 1981), are here briefly described.

a The "Corniola" unit (COR). The lower part of the section is represented by about 50 m of well-bedded hard limestones (Bathurst 1987), of white-grey colour and 10 – 30 cm thickness. The lower limit of the COR is not exposed. Abundant stylolites (Bathurst 1975) and small amounts of dark chert in lenses and nodules are present. In the middle part of the section fissile pink and nutty brown nodular marly limestones, of 20 – 50 cm in thickness, separated by thin reddish marly-shaley bands, occur. Undulose dissolution seams fit around grains or nodules instead of cutting through them (Bathurst 1987). In the upper part

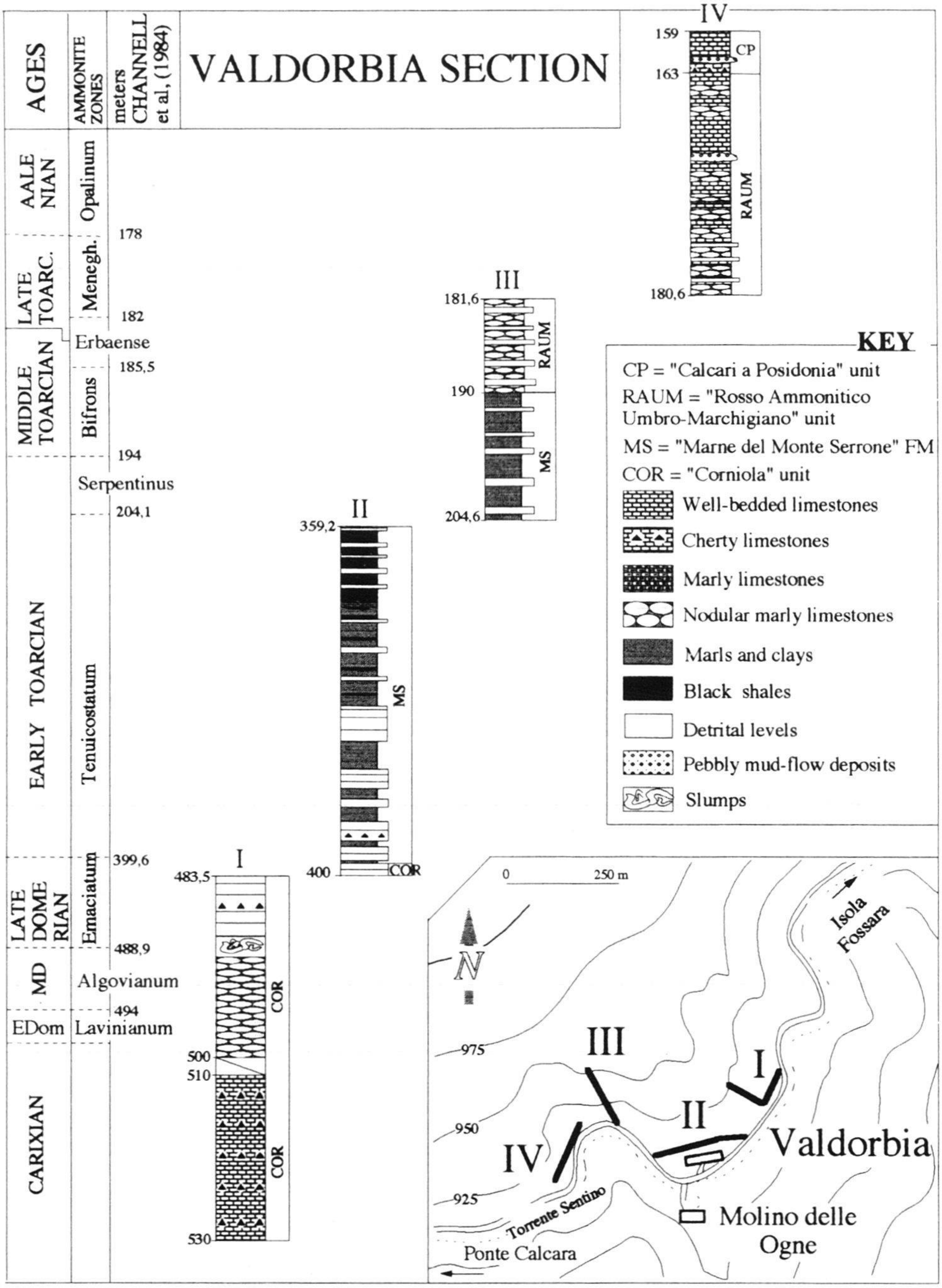


Fig. 2. Topographic location in the Sentino valley of four schematic partial sections (I, II, III and IV) that constitute the Valdorbia Section.

of the COR amalgamated calcisiltitic turbidites and associated gravity-flow deposits appear suddenly and the thickness of the beds almost doubles. There are two slumps, one at 495 m and the other at 489 m.

b The "Marne del Monte Serrone" Formation (MS) (Pialli 1969a) (= "Unità Calcareo-Marnosa del Sentino" of Centamore et al. 1969, 1971). The thickness of the MS reaches 49 m and its contact with the underlying Corniola unit can be observed immediately before the mineral water factory. The MS consists of dark shales and grey marls with intercalated calcarenitic/calcisiltitic turbidites that reach thicknesses of up to 1.5 m, especially in the lower part of the unit. Towards the top of this part, behind the mineral water building, there are three horizons rich in organic carbon, related by several authors (Jenkyns & Clayton 1986; Jenkyns 1988; Baudin et al. 1990; Bartolini et al. 1992) to a widespread Early Toarcian anoxic event. These horizons contain fine-grained (calcisiltites) turbidites in the form of rounded nodules probably due to synsedimentary loading processes (Fig. 3b). The upper part of the "Marne del M. Serrone" Fm. was sampled beginning at the base of a cliff, corresponding to 205 m on the log of Channell et al. (1984). The contact between this Formation and the overlying "Rosso Ammonitico Umbro-Marchigiano" unit falls at 190 m (Channell et al. 1984) where there is the first nodular band on the cliff face and where the colour of the shales becomes reddish (Fig. 3a).

c The "Rosso Ammonitico Umbro-Marchigiano" unit (RAUM). The MS Formation is overlain by about 27 m of reddish nodular marly limestones, calcareous nodular marls and reddish shales of the RAUM Unit, with ammonite-rich horizons which are mainly Middle/Upper Toarcian in age (Cresta et al. 1988; Cecca et al. 1990). Sharp-base calcarenites of 25–40 cm in thickness, showing low-angle cross-stratification, are interbedded with nodular marls. At 185.7 m (Channell et al., 1984) a well-bedded calcilutite level, of 5 cm thickness, showing a characteristic yellow colour is present (Elmi 1981b). The contact between the RAUM and the overlying "Calcari a Posidonia" unit has been set where the predominantly calcareous sedimentation resumes and cherts occur again, while the nodular calcareous bands become less important.

d The "Calcari a Posidonia" (CP) unit. The CP unit was sampled along the road for a few metres. This unit is represented by white limestone beds, roughly 10 cm thick, with rare nodular cherty horizons in the lower part. In some beds the faunal content (mainly bivalves and/or radiolarians) is very high. In the topmost part of the section pebbly mud-flow deposits are present, interbedded with hard limestones containing nodular chert.

The four stratigraphic units described above are exposed along four partial sections (Fig. 2) which constitute the composite Valdorbia Section, already measured for paleomagnetic purposes by Channell et al. (1984). The paleomagnetic numbering used by these authors has been maintained here. Channell et al. (1984) began their numbering from 530 m for the oldest rocks and used descending numbers in stratigraphic sequence. They left intervals in the sampling between each of the partial sections to allow for discovery of sediments of intermediate age. Thus the numbering for the four partial sections is as follows: Section I – 530 m to 483.5 m, formed only by COR sediments (Fig. 4); Section II – 400 m to 359.2 m, covering the MS deposition from the COR/MS boundary and including the black shale lithofacies (Fig. 3b and 5); Section III – 204.6 m to 181.6 m, represented by both MS and RAUM strata which dip into the hillside on the left of the Valley (Fig. 3a and 6); Section IV – 180.6 m to 160, including RAUM and CP outcropping along the road (Fig. 6). Beside each lithologic column, information concerning sedimentology, mineralogy, geochemistry and paleontology are exposed.

Biostratigraphic studies (Reale, 1989) suggest that the gaps between the sections are non-existent or insignificant. Therefore, in figure 19 and 21 the sections have been combined in a schematic manner into one continuous section, using the conventional ascending numbering system beginning from one for the oldest rock. In this way the approximate thickness of the stratigraphic units, the sedimentological trends, the microfacies and the foraminiferal assemblage changes can be seen more easily all together with the mineralogical and geochemical data. Concerning the magnetostratigraphy the authors refer the reader back to the Valdorbia section published in Reale (1989).

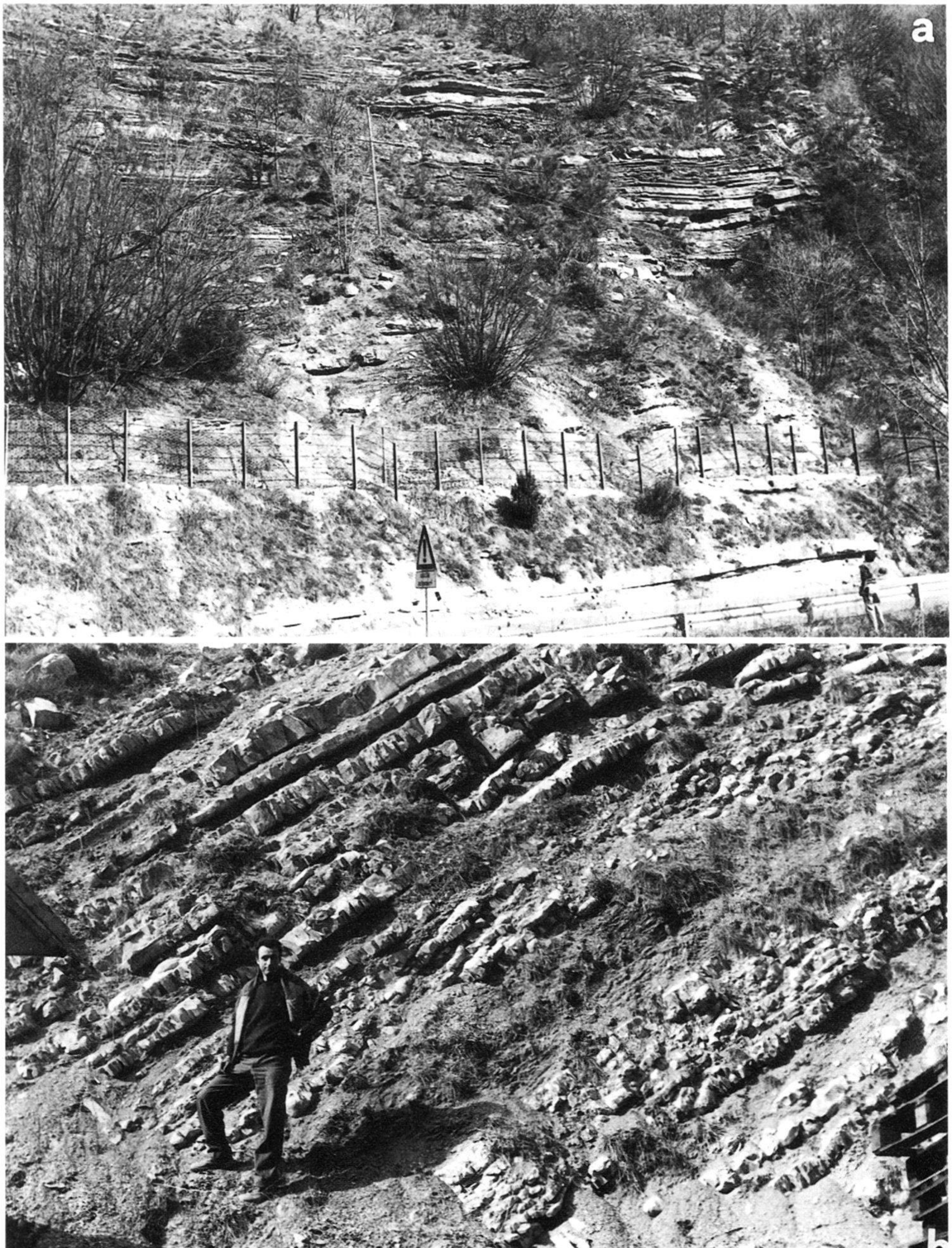


Fig. 3. **a** The MS-RAUM transition (Middle-Upper Toarcian). The MS Formation consists of soft grey marls intercalated with calcarenitic-calcisiltitic turbidites. The RAUM Unit is represented by reddish nodular marly limestones and reddish nodular marls. Sharp-based hummocky cross-stratified calcarenites (HCS) occur in this part of the VD Section. **b** Black shale deposits with low-density calcisiltitic turbidites containing radiolarians (Lower Toarcian, middle-upper part of Tenuicostatum Zone).

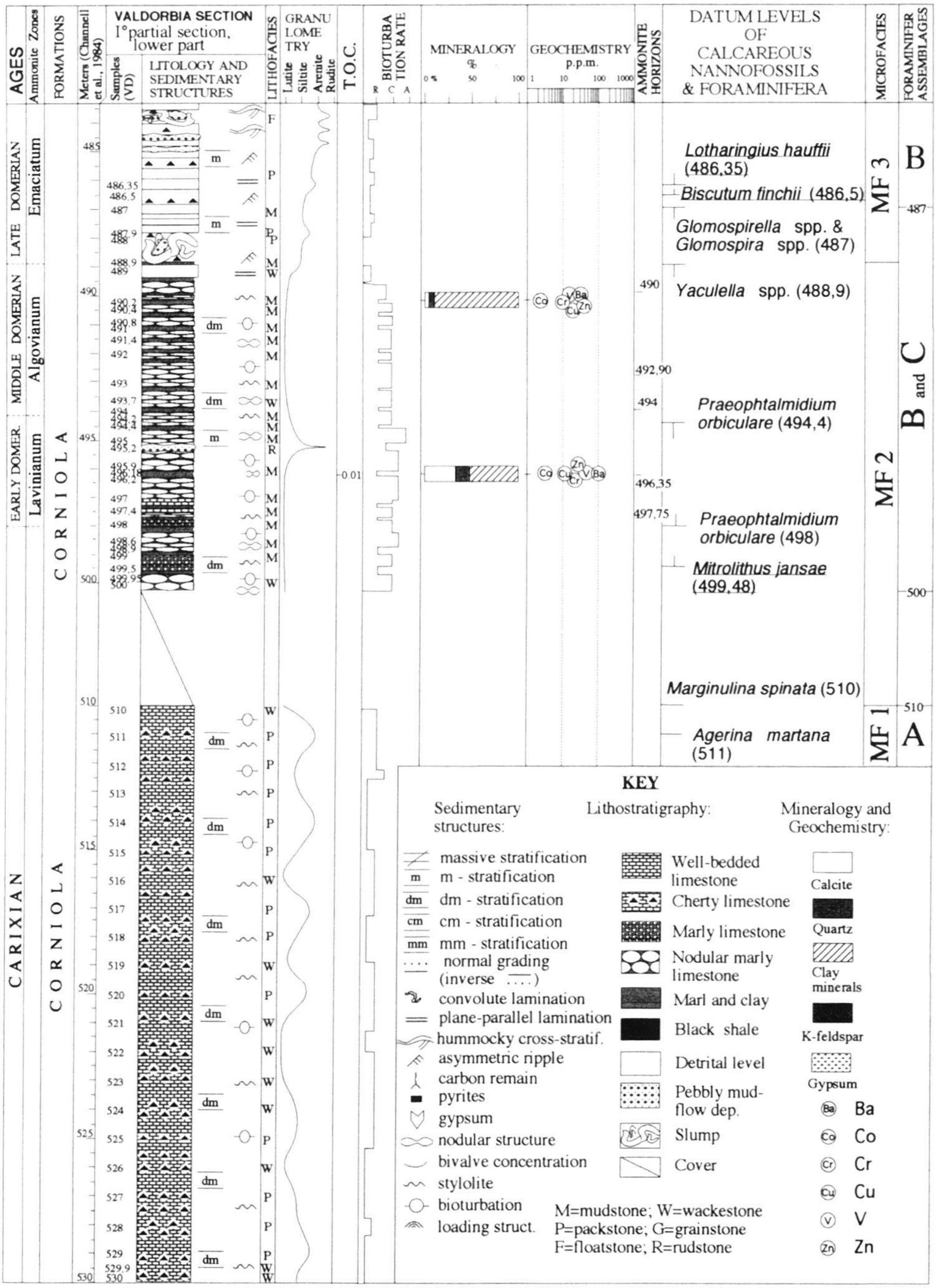


Fig. 4. Partial Section I, lower part of the Valdorbia Section.

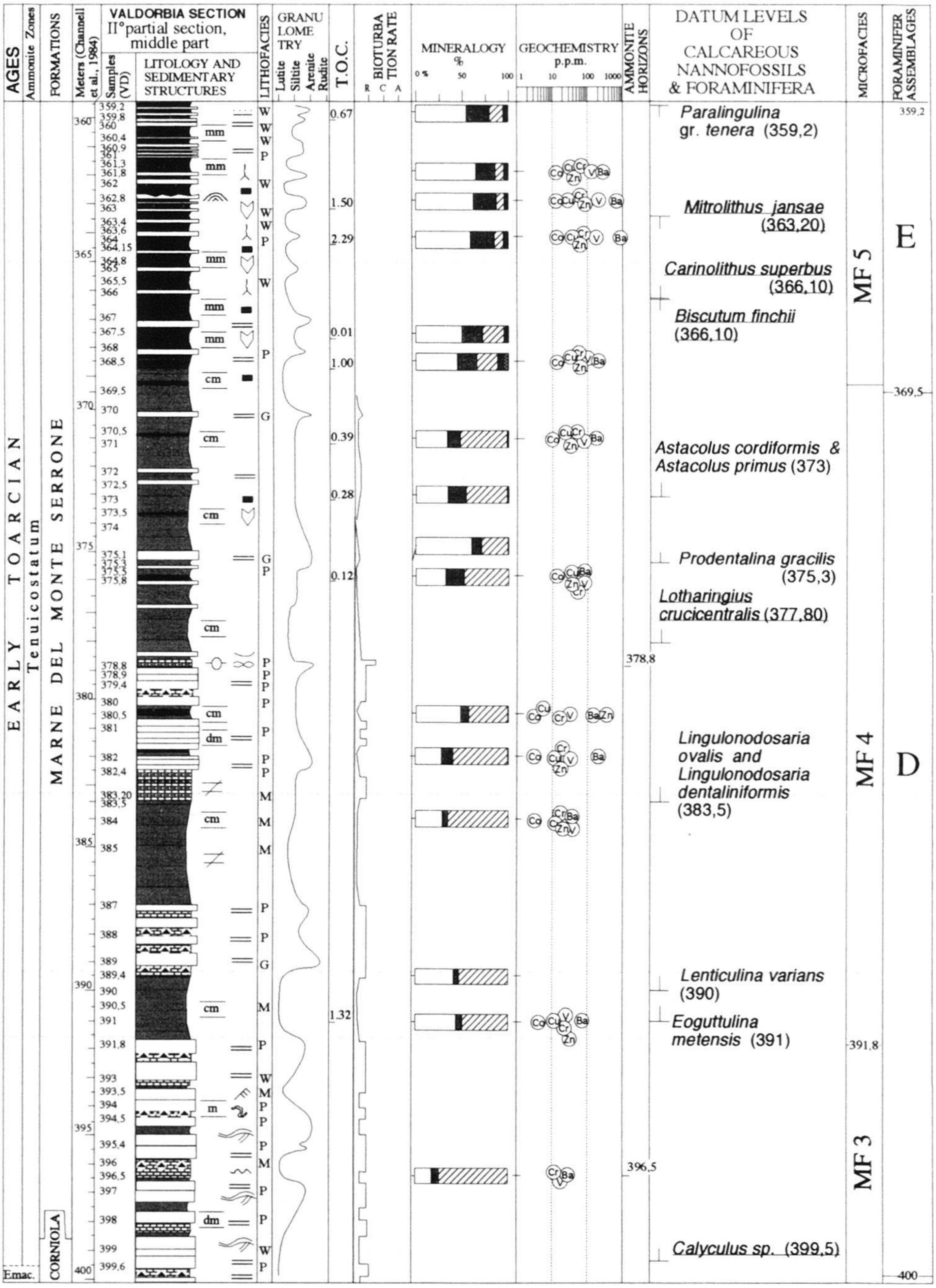


Fig. 5. Partial Section II, middle part of the Valdorbia Section.

4. Ages

The biostratigraphy is based on ammonite horizons within the Tenuicostatum and Serpentinus Zones (Venturi, in press) and on provisional horizons within the other zones studied by Venturi and not yet published (personal communication). The ammonite horizons are summarized in Table 1 and ammonite zones have been indicated, for graphic convenience, with age initials followed by a number. Each horizon is reported in metres in Figure 4, 5 and 6, following the Channell et al. (1984) sampling. Recently published data of the Valdorbia Section have been used as well (Cresta et al. 1989, Fig. 37 and 38). Calcareous nannofossil events, reported by Reale (1989), are located on the right side of the four partial sections. The lower part of the Valdorbia section (530 m to 510 m) has been attributed to the Carixian on the base of the first occurrence of Mitrolithus jansae at 499.8 m (Fig. 4) which falls in the upper part of the Davoei Zone (Carixian) according to Reale et al. (1991).

5. Micropaleontology

An important micropaleontological study of the Valdorbia Jurassic microfacies has been carried out by Centamore et al. (1971) in which the Valdorbia section was indicated as "Sezione del Sentino Ovest". A preliminary study of the microfossils occurring in the Valdorbia section both in thin section and in the sample washed residues was illustrated by Cresta et al. (1988), by means of a schematic distribution chart. No distinction between microfacies (observed in thin section) and microfossils (separated from the sediments) was indicated and a further study has allowed a better understanding of the microfaunal distribution and of the microfossil reworking.

In this work the micropaleontological observations concern both the microfaunal content of the microfacies analysed in thin section and the assemblages of the separated microfossils from the washed residues. 160 samples have been collected in stratigraphic order at 1 m interval roughly spanning the period of time from the Carixian to the Early Aalenian. 92 samples, mainly limestones have been processed for microfacies study from the COR, while 68 samples, mainly argillaceous and marly sediments, about 400 gr. each, have been collected mainly from the MS and RAUM units.

5.1 Data presentation

5.1.1 Microfacies

The fossil content is summarised in Figure 20 where the microfacies are arranged in groups with different characteristics.

- Microfacies 1 (Carixian). The most characteristic fossils are stout calcareous sponge spicules and recrystallized echinoid remains (Pl. 1, Fig. 1, 2 and 3) while other organisms are scattered discontinuously. Radiolarians are associated with gastropods and other microfossils. This microfacies contains Miliolina (Pl. 1, Fig. 8), simple agglutinated foraminifers (Pl. 1, Fig. 5), plurilocular agglutinated foraminifers and Lagenina, both sculptured and smooth (Pl. 1 Fig. 7, Fig. 1, 2, 12, 13 and 14) of which Lenticulina is the dominant taxon.
  Besides Ophthalmidium (Pl. 1, Fig. 11) and Agerina martana (Pl. 1, Fig. 10), there are some tubular, porcellaneous, biloculine forms interpreted here as Planiinvoluta (Pl. 1, Fig. 6 and 9) with a porcellaneous test, according to Koehn Zaninetti (1969). The latter are characteristic but of controversial interpretation be-

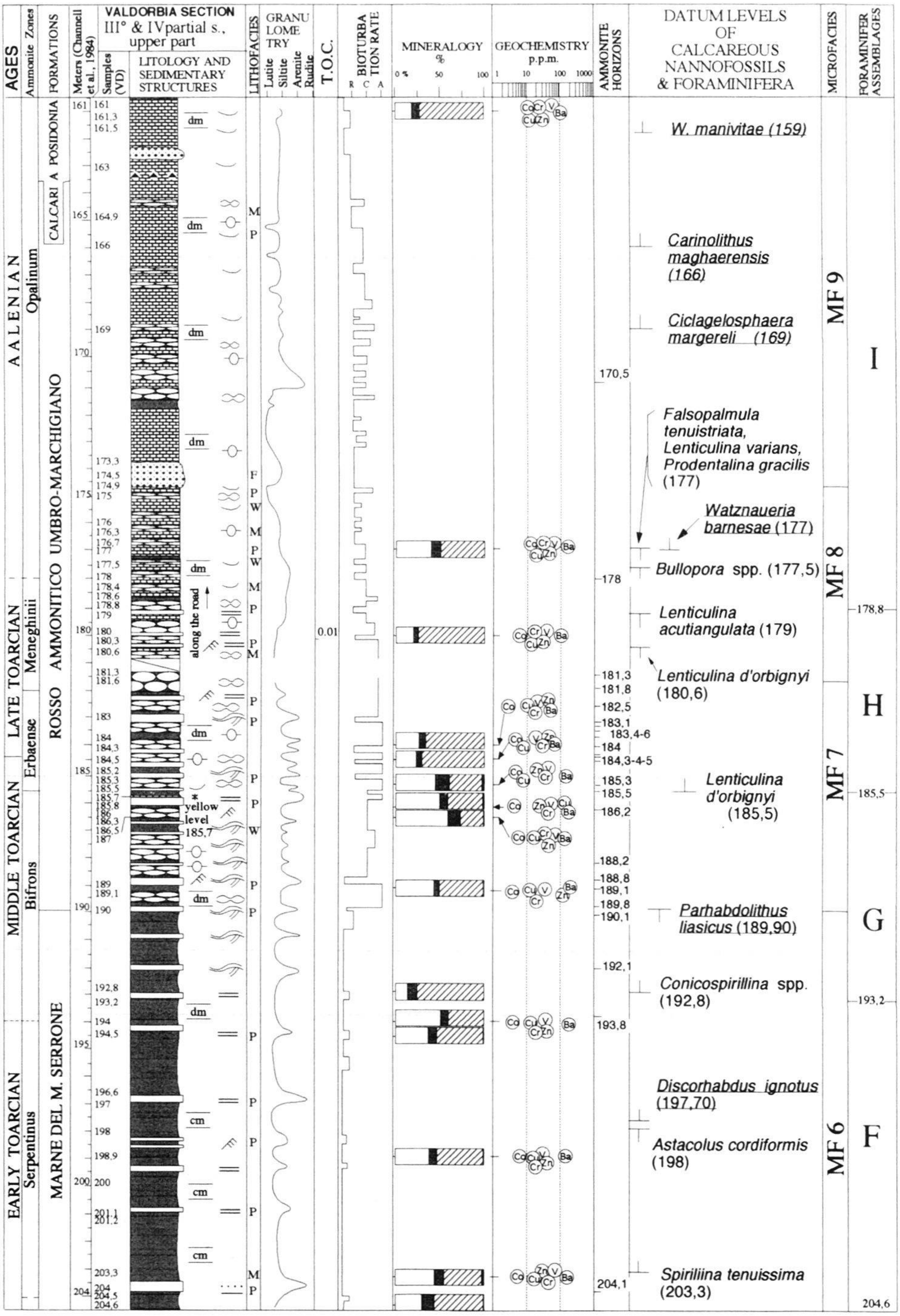


Fig. 6. Partial Sections III and IV, upper parts of the Valdorbia Section.

AGE		Ammonite Zones		Ammonite horizons	VD sections
AAL.	EARLY	AA1	Opalinum	m 170,5 - *Ericites* gr. *fallifax, Tmetoceras scissum* m 178 - *Leioceras* sp.	sections III and IV
TOARCIAN	LATE	TO5	Mene ghinii	m 181,3 horizon 14 - *Pleydellia* gr. *ovata* m 181,8 hor. 13 - *Dumortieria meneghinii, Dumortieria sp.," Erycites" elaphus*	sections III and IV
TOARCIAN	LATE	TO4	Erbaense	m 182,5 hor. 12b - *Merlaites alticarinatus* m 183,1 hor. 12a - *Merlaites alticarinatus, Polyplectus apenninicus* m 183,4 hor. 11c - *Peronoceras aculeatum* m 183,6 hor. 11b - *Paroniceras sternale* m 184 hor. 11a - *"Phymatoceras" speciosum, Phymatoceras erbaense, Chartronia venustula, Praerycites civitellensis*	sections III and IV
TOARCIAN	MIDDLE	TO4	Erbaense	m 184,3 hor. 10b - *"Phymatoceras" speciosum.* m 184,4 hor. 10 - *Merlaites clausus* m 184,5 hor. 9 - *Merlaites clausus, Merlaites* gr. *gradata* m 185,3 hor. 8 - *Collina meneghinii* m 185,5 hor. 7 - *Collina gemma, Collina meneghinii, Pseudomercaticeras* gr. *frantzii, Hildoceras* gr. *bifrons.*	sections III and IV
TOARCIAN	MIDDLE	TO3	Bifrons	m 186,2 hor. 6b - *Hildoceras angustisiphonatum* m 188,2 hor. 6 - *Hildoceras* gr. *semipolitum, Collina* gr. *gemma, Mercaticeras* gr. *mercati, Mercaticeras dilatum* m 188,8 hor. 5 - *Hildoceras angustisiphonatum, Hildoceras* gr. *semipolitum, Mercaticeras thyrrenicum, Mercaticeras* gr. *mercati, Pseudomercaticeras n. sp. (aff. venzoi), Phymatoceras* gr. *erbaense, Chartronia* gr. *fabale.* m 189,1 hor. 4 - *Hildoceras* gr. *lusitanicum, H.* gr. *semipolitum, Pseudomercaticeras sp.* m 189,8 hor. 3b - *Hildoceras* gr. *lusitanicum* m 190,1 hor. 3a - *Hildoceras lusitanicum, H. tethysi, Mercaticeras thyrrenicum, Frechiella subcarinata, Rarenodia planulata, Mesodactylites broilii.* m 192,1 hor. 2b - *Hildoceras sublevisoni* m 193,8 hor. 2a - *Hildoceras raricostatum*	sections III and IV
TOARCIAN	EARLY	TO2	Serpe ntinus	m 204,1 hor. 1c - *Hildaites* gr. *undicosta, Parahildaites meisteri, Praepolyplectus sp., Maconiceras ? sp.*	sections III and IV
TOARCIAN	EARLY	TO1	Tenuico statum	m 378,8 hor. 1b - *Dactylioceras sp., Praemercaticeras ? sp., Meneghiniceras eximium* m 396,5 hor. 1a - *Dactylioceras (Eodactylites) mirabile, Neolioceratoides sp., "Coeloceras" sp.*	sect. II
DOMERIAN	L.	DO3	Emac.		section I
DOMERIAN	MIDDLE	DO2	Algovia num	m 490 - *Arieticeras algovianum, Arieticeras retrorsicosta* m 492,90 - *Arieticeras algovianum* m 494 - *Arieticeras* sp.	section I
DOMERIAN	EARLY	DO1	Lavinia num	m 496,35 - *Protogrammoceras* gr. *cerebratum* m 497,75 - *Fuciniceras lavinianum*	section I

Tab. 1. Symbols of the ammonite zones.

cause they have been considered, in general, as shallow water agglutinated foraminifers such as Glomospira and/or Glomospirella. In the Valdorbia Section Glomospira and Glomospirella show, instead, a siliceous test and the microanalysis of the separated specimens exhibits a greater amount of silica cement than agglutinated grains. It is possible, however, that in the Carixian these Ammodiscidae possess a finely agglutinated wall with a calcareous crypto-crystalline cement (Pl. 1, Fig. 5).

In this microfacies Planiinvoluta occurs scattered in the matrix, not included in intraclasts.

- Microfacies 2 (Lower Domerian - Middle Domerian). This microfacies is distinguished from microfacies 1 on account of the decrease in organic content and the almost total disappearance of plurilocular Textulariina and Miliolina. Gastropods, thick ostracod valves, Lagenina, some Ammodiscus and Repmanina with siliceous tests, occur together with ammonite nuclei, echinoid fragments, radiolarians and calcispherids (Pl. 1, Fig. 4, 15, 16, 17, 18, 19 and 20). Within microfacies 2, the microfauna does not show clear indications of reworking, with the exception of those at levels 495.2 m and 489 m which are rich in stout calcareous sponge spicules. At 488.95 m – 488 m, corresponding to a slump, the biofacies does not change but is richer in organisms, which suggests that the slumped sediments have a local source in the basin and the sliding process has concentrated the skeletal remains.
- Microfacies 3 (Upper Domerian-LowerToarcian). Microfossils are rare or absent. (Pl. 2, Fig. 1 and 2).
- Microfacies 4 (Lower Toarcian, Tenuicostatum Zone). Strong input of fine detrital materials and pyrite occur at this time. The laminated calcarenite/rudite beds contain reworked oolites, green algae, algal coated grains, large lituolids (Pl. 2, Fig. 3–7 and 9), and Earlandia all derived from a carbonate platform. Miliolina (Pl. 2, Fig. 11–13), almost absent in the marly, autochthonous lithotypes, occur again and are considered as reworked from sediments deposited in an open marine environment immediately after the beginning of the carbonate platform drowning, because they are absent in the "Calcare Massiccio" microfacies. Other rare types of microfacies are mudstones with flat and thin bivalves, absent in the sample washed residue, and some calcified radiolarians (Pl. 2, Fig. 8). Of all the microfacies, number 4 shows the most reworking, as microfauna of different environments and ages are involved. It has to be remarked that in the microfossil distribution chart in Cresta et al. (1988) the vertical distribution of Ophthalmididae and Glomospira and Glomospirella (here interpreted as Planiinvoluta) within the Mirabile Zone has been made on the basis of their occurrence in fine detrital calcisiltite.
- Microfacies 5 (upper part of Tenuicostatum Zone). Calcified radiolarians (Pl. 2, Fig. 10 and 14) are dominant.
- Microfacies 6 and 7 (Serpentinus to Erbaense Zone). These microfacies still indicate an input of fine detrital material into the area but with a minor degree of reworking compared to microfacies 4. However, the occurrence of Planiinvoluta and Earlandia (Pl. 3, Fig. 2, 3 and 4) testify a persistent influence of allochems, such as small porcellaneous foraminifers and pellets. Ophthalmidium and Agerina martana no longer occur above level 190 m. Lagenina are present as well, probably removed from the same environment of deposition. From sample 189 (middle part of Bifrons Zone) upwards the microfacies starts to become enriched with flat bivalve tests (Pl. 3, Fig. 1).
- Microfacies 8 (Meneghinii – Opalinum Zones). This microfacies contains microfossils characteristic of the typical calcareous nodular RAUM such as that of the Pozzale (M. Martani) Section (an "intermediate" section without detrital input, studied by Venturi, in press). The organic content consists of ammonite nuclei and bivalves with shelter porosity, small low-trochospiral gastropods, globochaetes, very tiny heart-shaped brachiopods, biconvex Lenticulina's and a few radiolarians (Pl. 3, Fig. 5–9). These microfossils are also characteristic of the "Dogger" microfacies which is found on the morphostructural highs.
- Microfacies 9 (Aalenian) (Pl. 3, Fig. 10 and 11). In the pebbly mudstone at 174.5 m the intraclasts commonly exhibit the same microfacies as microfacies 8.

5.1.2 Microfossils

The term "microfossils" is used to describe the fossil content which occurs in the washed residue fraction between 63 μm and 2 mm. Microfossils can be rare or absent if only sample fractions greater than 150 μm are used.

The coarse fraction (>2 mm) has been observed, but no qualitative or quantitative analyses have been carried out. Tests or skeletons are mainly calcareous and consist of benthic foraminifers, ostracods, fragments of macroinvertebrates or small whole macroinvertebrates (< 1 cm), represented by microbrachiopods, bivalves, microgastropods, echinoderms,

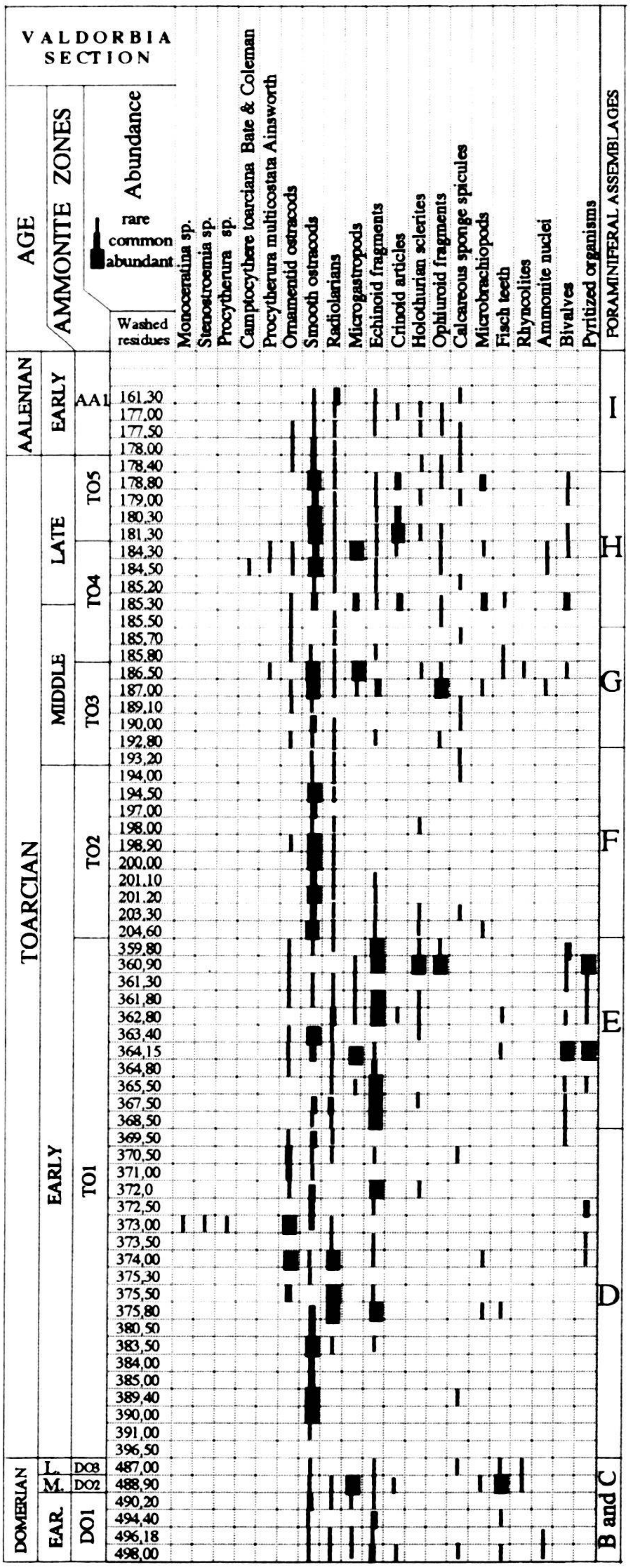


Fig. 7. Microfossil (excluding foraminifers) distribution chart.

ammonite protoconchs and rhyncholites. The non-calcareous microfossils are fish teeth (very rare) and radiolarians, which occur abundantly in some stratigraphic intervals.

As the benthic foraminifers are the object of this study, quantitative analyses have been carried out only on them and are described in detail below. The other microfossils were processed for semi-quantitative analysis which consists of spreading the washed residue uniformly three times on a standard extraction tray (6 x 10 cm) and establishing numerical classes using the symbols R (rare), defined as less than 10, C (common) between 10 and 50, and A (abundant) for more than 50. With this methodology the distribution chart of microfossils has been constructed (Fig. 7). Ostracods are as abundant or common as benthic foraminifers and these two groups of organisms are the ones most continuously distributed in the sediments. Some sculptured ostracods have been classified by C. Arias (personal communication) and are shown on Figure 7.

Benthic foraminifers are almost always present in the marly lithotypes in variable abundance, according to the different stratigraphic intervals. They are represented by a few Textulariina, Lagenina and Miliolina in the Carixian, by Lagenina and simple agglutinated forms in the Domerian, and mainly by Lagenina in the Toarcian with an increase of Spirillina in the Middle and Upper Toarcian. Faunal analyses were conducted on the benthic foraminifers after all the specimens, occurring in 6 gr. of the washed residue of the sample fraction > 63 µm, have been picked and counted (see Tab. 1 in Bartolini et al., 1992). They were diagnosed in detail and the species distribution and abundance (R < 10%, C = 10–30%, A > 30%) are reported in Figure 8 in order of first occurrence from the bottom to the top of the section. Some of the most indicative species are illustrated in Pl. 4 and 5. Although in the Lagenina etching or other chemical dissolution traces are rare or absent, the tests generally show poor preservation, due to recrystallization or mechanical processes. Thus several forms are left under open nomenclature. The genera are identified in accordance with the classification proposed by Loeblich & Tappan (1988).

Recently several authors (Bernard 1986; Chamney 1976; Morris 1982; Kaiho 1991) have recognized the influence of chemical, physical and trophic parameters of the sea-bottom environment on the general test morphology of benthic foraminifers. There is a general agreement that flat morphology and uncoiled forms of Lagenina are characteristic of a low energy, muddy environment, sometimes poorly ventilated, while strictly coiled and stout specimens occur in ventilated and high energy hydrodynamic environments. For this reason, in Figure 9, the genera have been arranged in morphogroups according the scheme proposed by Bernard (1986) and modified by Bartolini et al. (1992) and reported in this paper in Table 2.

Variations of the foraminiferal dimensions have been noted within the different stratigraphic intervals. Thus the foraminiferal size, as shown in Figure 10, has been subdivided into three classes: small < 200 µm in diameter or length according to the specimen test shape, medium > 200 µm < 500 µm and large > 500 µm.

Percentage values of indicative parameters, such as species diversity, ornate Lagenina, agglutinated foraminifers and Spirillina abundance, have been plotted in Figure 10 as well. The results of the distribution charts and graphics enable us to draw the conclusion that benthic foraminiferal assemblages change with time, thus providing further paleoenvironmental information.

Morphogroup A =	elongated and flat forms: *Lingulonodosaria, Paralingulina, Vaginulina, Citharina.*
Morphogroup B =	elongated and pointed forms: *Eoguttulina.*
Morphogroup C =	cylindrical and elongated forms: *Prodentalina, Pseudolangella, Pseudonodosaria, Nodosaria, Marginulina.*
Morphogroup D =	flattened, planispiral forms: *Astacolus, Falsopalmula, Vaginulinopsis, Lenticulina varians.*
Morphogroup E =	Biconvex, planispiral, strictly coiled forms: biumbelicate Lenticulina as *Lenticulina münsteri.*
Morphogroup F =	planoconvex or conical forms: *Conicospirillina, Turrispirillina, Rehinoldella.*

Tab. 2. Foraminiferal morphogroups.

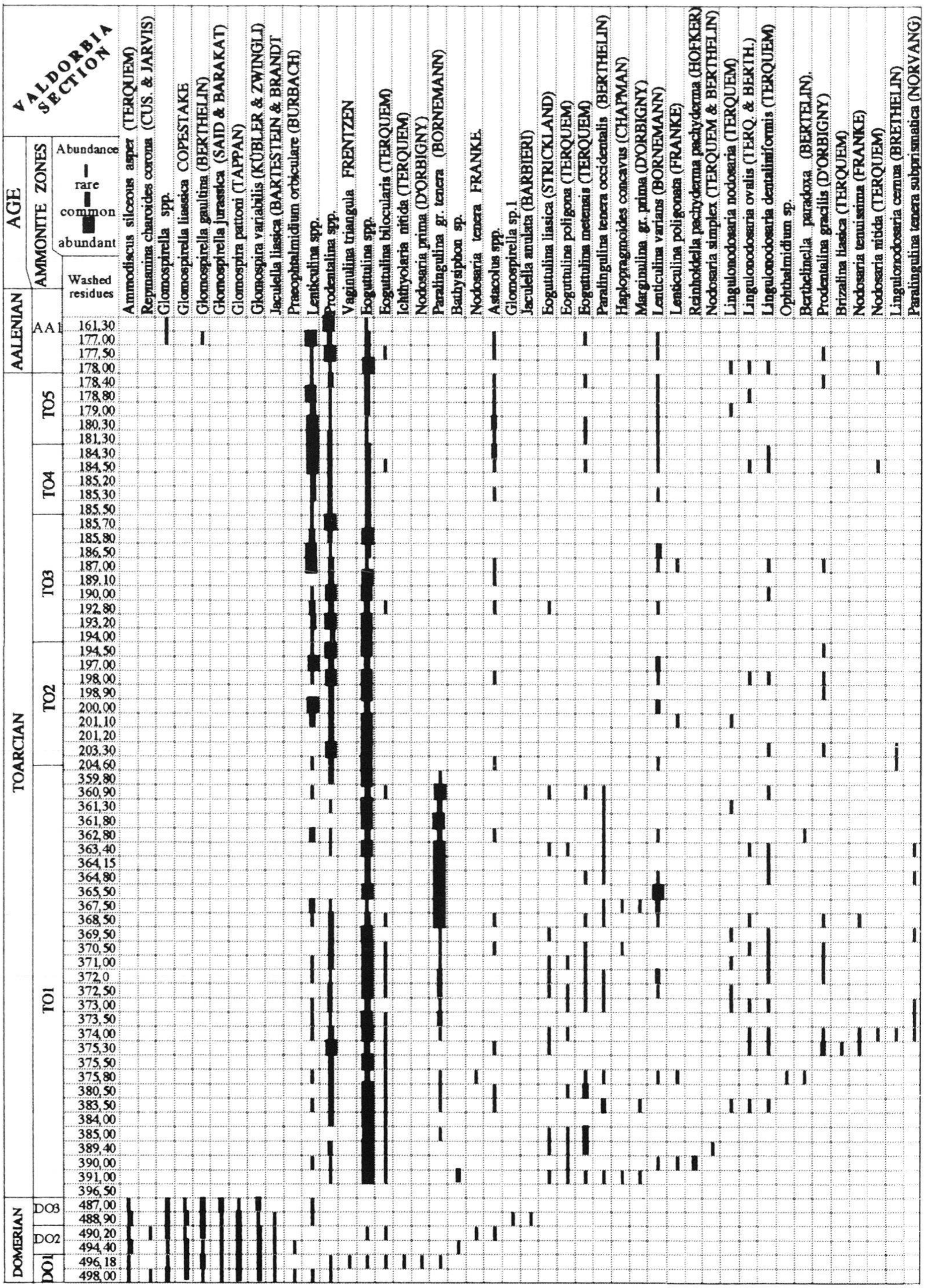
Although foraminiferal abundance in the sediments is low, the long interval of time makes changes in the microfossil assemblages easily recognisable. On the basis of micropaleontological examination of several sections of the UMB (Nocchi 1992), a stratigraphic succession of benthic foraminiferal assemblage units has been established. Each assemblage is distinguished from the others by a different ratio of foraminifer genera and morphogroups, by class sizes, species diversity and different accompanying fauna. They are indicated with capital letters in alphabetical order and arranged from the oldest to the youngest. These assemblages, with slight differences, have been recognized in the Valdorbia Section, and are summarized in the scheme of Figure 11. The foraminifer species included in each assemblage can be seen in Figure 8. This scheme is based also on the autochthonous microfacies. The grey-reddish marly stratigraphic interval found above the COR limestones by Nocchi & Bartolini (in press), has been replaced by pebbly mudstones and slumps in the Valdorbia Section. Thus, the cosmopolitan Pliensbachian foraminiferal assemblage BC, characteristic of this interval, is missing.

The following benthic foraminiferal trends can be identified:

a Decrease and disappearance of Miliolina and plurilocular Textulariina during the Domerian.

b Disappearance of siliceous biloculine tubular foraminifers in the uppermost Domerian sediments.

c The average size of foraminifers is between 200 μm and 500 μm (Fig. 10). However in the assemblage E, characteristic of the black shales of the Tenuicostatum Zone, the average foraminiferal size is below 200 μm. An increase in size can be clearly seen after the Serpentinus Zone, in particular at the boundary between the Bifrons and Erbaense Zones (Fig. 10).


VALDORBIA SECTION
AGE
AMMONITE ZONES
Abundance
rare
common
abundant
Washed residues
AALENIAN
TOARCIAN
DOMERIAN
AA1
TO5
TO4
TO3
TO2
TO1
DO3
DO2
DO1
161,30
177,00
177,50
178,00
178,40
178,80
179,00
180,30
181,30
184,30
184,50
185,20
185,30
185,50
185,70
185,80
186,50
187,00
189,10
190,00
192,80
193,20
194,00
194,50
197,00
198,00
198,90
200,00
201,10
201,20
203,30
204,60
359,80
360,90
361,30
361,80
362,80
363,40
364,15
364,80
365,50
367,50
368,50
369,50
370,50
371,00
372,0
372,50
373,00
373,50
374,00
375,30
375,50
375,80
380,50
383,50
384,00
385,00
389,40
390,00
391,00
396,50
487,00
488,90
490,20
494,40
496,18
498,00
Ammodiscus siliceous asper (TERQUEM)
Reymanina charoides corona (CUS. & JARVIS)
Glomospirella spp.
Glomospirella liassica COPESTAKE
Glomospirella gaultina (BERTHELIN)
Glomospirella jurassica (SAID & BARAKAT)
Glomospira pattoni (TAPPAN)
Glomospira variabilis (KÜBLER & ZWINGLI)
Jaculella liasica (BARTESTEIN & BRANDT
Praeophtalmidium orbiculare (BURBACH)
Lenticulina spp.
Prodentalina spp.
Vaginulina triangula FRENTZEN
Eoguttulina spp.
Eoguttulina bilocularis (TERQUEM)
Ichthyolaria nitida (TERQUEM)
Nodosaria prima (D'ORBIGNY)
Paralingulina gr. tenera (BORNEMANN)
Bathysiphon sp.
Nodosaria tenera FRANKE
Astacolus spp.
Glomospirella sp.1
Jaculella anulata (BARBIERI)
Eoguttulina liasica (STRICKLAND)
Eoguttulina poligona (TERQUEM)
Eoguttulina metensis (TERQUEM)
Paralingulina tenera occidentalis (BERTHELIN)
Haplopragmoides concavus (CHAPMAN)
Marginulina gr. prima (D'ORBIGNY)
Lenticulina varians (BORNEMANN)
Lenticulina poligonata (FRANKE)
Reinholdella pachyderma pachyderma (HOFKER)
Nodosaria simplex (TERQUEM & BERTHELIN)
Lingulonodosaria nodosaria (TERQUEM)
Lingulonodosaria ovalis (TERQ. & BERTH.)
Lingulonodosaria dentaliniformis (TERQUEM)
Ophthalmidium sp.
Berthelinella paradoxa (BERTELIN)
Prodentalina gracilis (D'ORBIGNY)
Brizalina liasica (TERQUEM)
Nodosaria tenuissima (FRANKE)
Nodosaria nitida (TERQUEM)
Lingulonodosaria cernua (BRETHELIN)
Paralingulina tenera subprismatica (NORVANG)

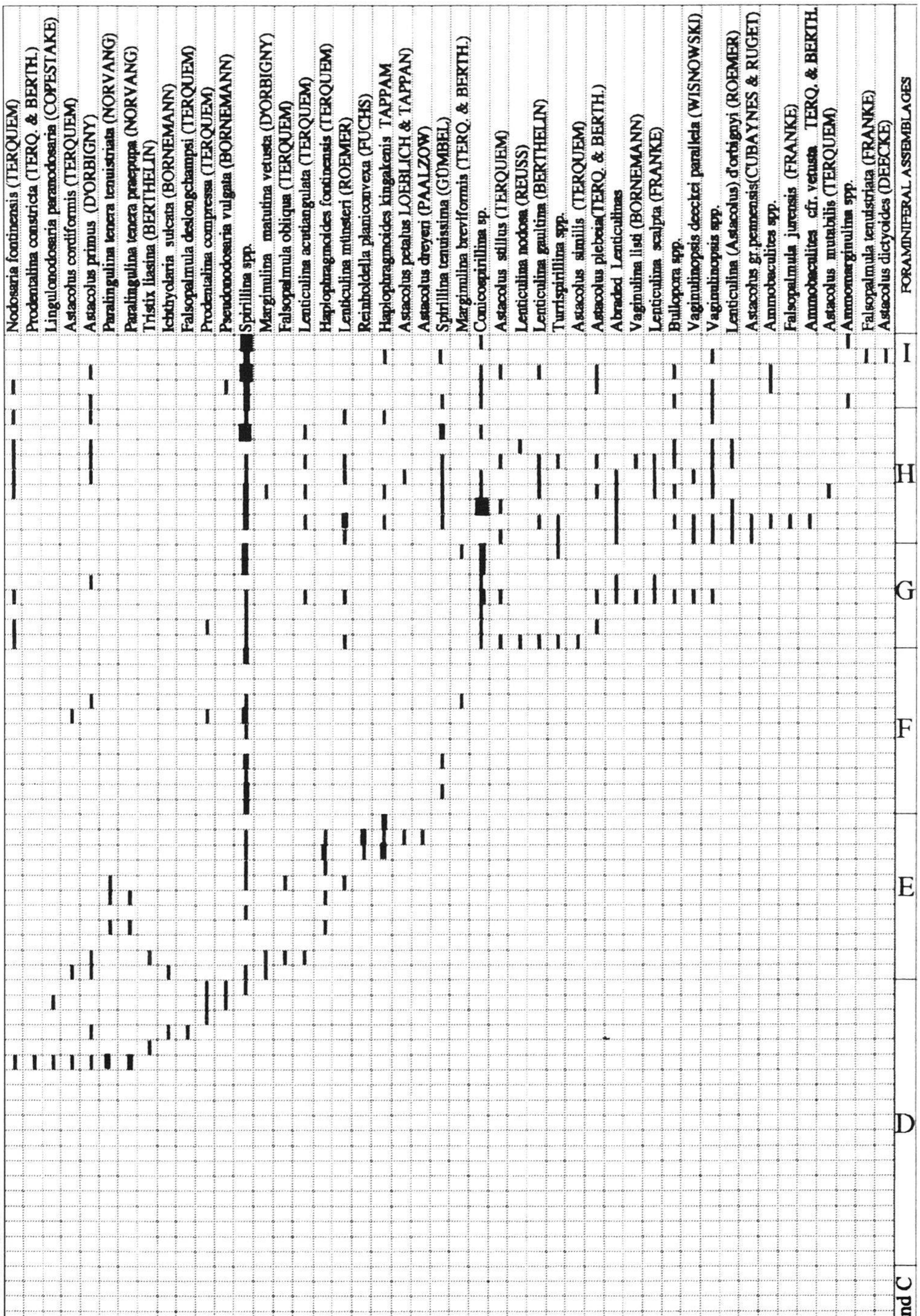


Fig. 8. Foraminifer species distribution chart.

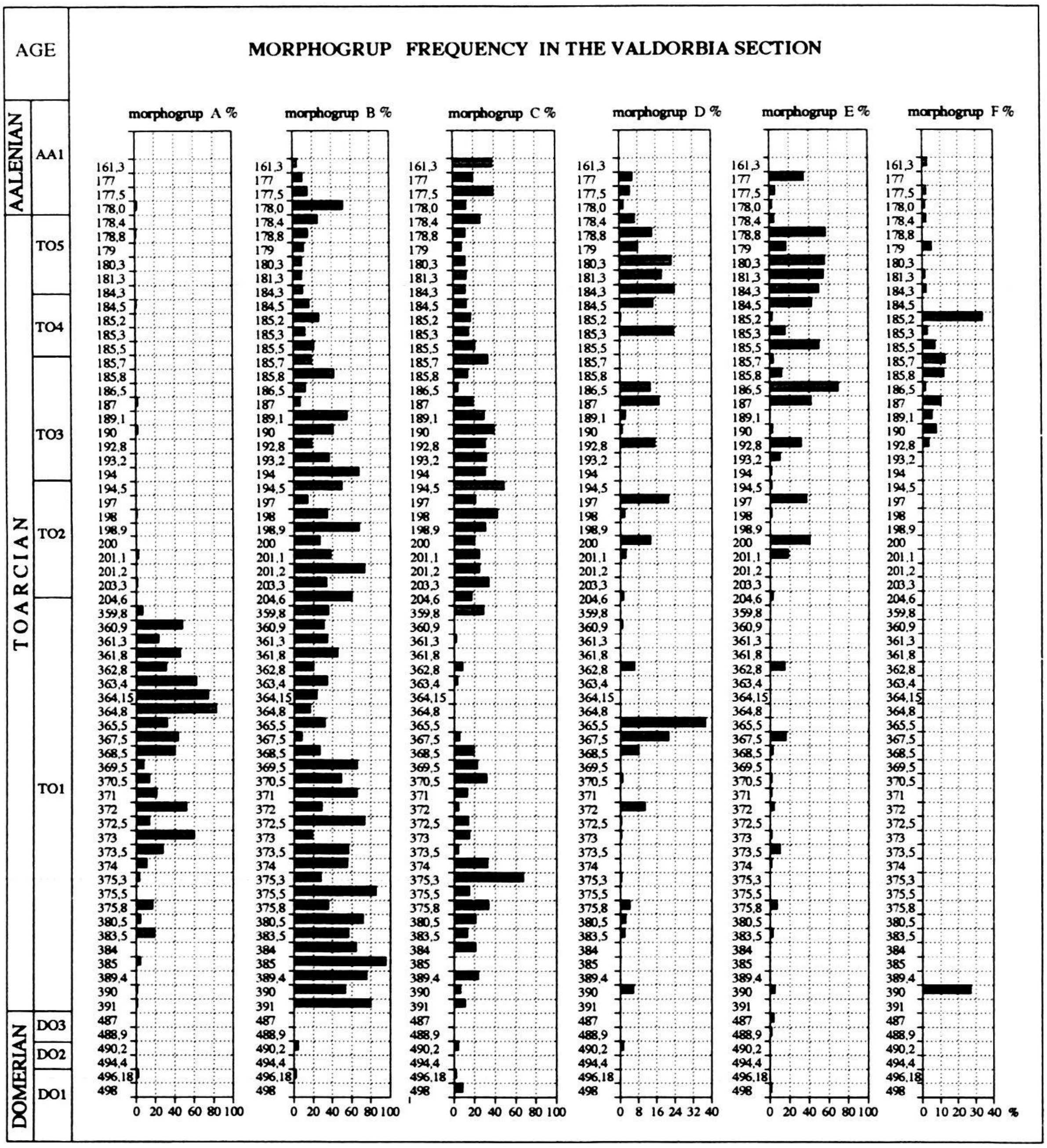


Fig. 9. Morphogroup percentages.

d Increasing in Spirillina, biconvex Lenticulina (morphogroup E) (Fig. 9) and Conicospirillina (Pl. 5, Fig. 4–6) and the occurrence of abraded and "cigar-shaped" Lenticulina's (Fig. 13, Pl. 4, Fig. 1 and 4) from the Bifrons Zone upwards.

e Decrease in the foraminiferal content in the Lower Aalenian as shown in Fig. 8.

In the UMB benthic foraminifers show a low density in the sediments, so that the species distribution depends upon the quantity of sample collected. Furthermore they are clearly related to ecological factors affecting the sea-bottom so that they can be time-transgres-

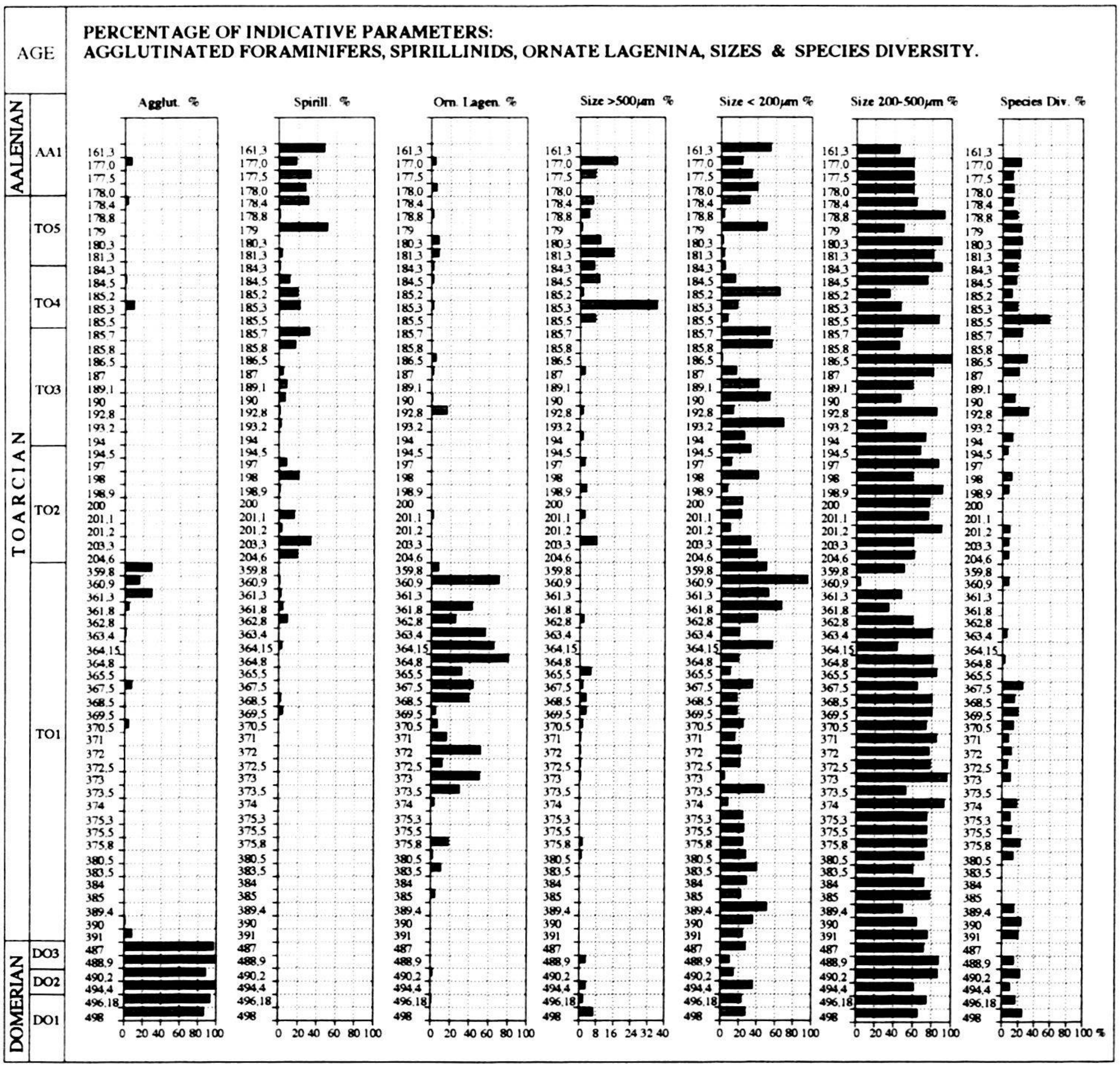


Fig. 10. Percentage of indicative parameters.

sive. However a few forms that have been calibrated by ammonite and nannofossil biostratigraphy in other UMB sections, have been found here and can be considered as good index species. These are shown in Figure 12. The disappearance of Glomospira-Glomospirella is variable between the Emaciatum and Tenuicostatum Zones. Conicospirillina first occurrence (FO) is at the boundary between Serpentinus/Bifrons Zones approximately. Lenticulina d'orbignyi (Pl. 5, Fig. 10) FO falls always within the Erbaense Zone or at the boundary between Bifrons/Erbaense while the last occurrence (LO) falls within the Meneghinii Zone.

AGE	STRATIGRAPHIC INTERVALS AND UNITS	ASSEMBL. UNITS	ANALYSIS METHODS	BENTHIC MICROFORAMINIFERAL ASSEMBLAGES	OTHER ORGANISMS
Late Toarcian - E. Aalenian (TO5 - AA1)	178,8-160 (RAUM - CP)	**I**	washed residue and thin section	DECREASING FORAMINIFERS. SPIRILLINA UNIT. Rare agglutinants. *Glomospira*' s and *Glomospirella*' s appear again. *Lenticulina*' s, *Eoguttulina*' s and *Prodentalina*' s and *Conicospirillina*' s. Microfacies **8** and **9.**	Flat and smooth bivalve accumulations and abundant echinoderm debris. Common radiolarians.Small brachiopods, microgastropods and ammonite nuclei in thin section
Late Toarcian (TO4- TO5)	185,5 - 178,8 (RAUM)	**H**	washed residue and thin section	LARGE AND ABUNDANT LAGENINA UNIT: ASTACOLUS AND VAGINULINOPSIS >1mm AND LARGE, PARTIALLY ABRADED LENTICULINA: *Lenticulina d'orbignyi* and *Lenticulina munsteri* . *Prodentalina*' s and decreasing *Eoguttulina*' s. *Spirillina*' s and *Conicospirillina*' s. *Bullopora*' s. Characteristic assemblages of nodular calcareous marly RAUM. Microfacies **7** and **8.**	Rare, large sculptured ostracods. Microgastropods posidoniids, crinoids large echinoid spines. Holothurian sclerites. Common microbrachiopods and ammonite nuclei
Middle Toarcian (TO3)	193,2-185,5 (MS -RAUM)	**G**	washed residue	LENTICULINA, PRODENTALINA AND EOGUTTULINA UNIT. Abundant foraminifers, increasing *Lenticulina*' s and *Lenticulina münsteri* . Common *Spirillina*' s. Abraded *Lenticulina*' s, *Turrispirillina*' s, *Conicospirillina*' s, *Bullopora*' s appear.	Rare sculptured ostracods. Crinoids. Echinoderms. Posidoniid lumachellas. Microbrachiopods. Holothurian sclerites.
Early - Middle Toarcian (TO2-TO3)	204,6-193,2 (MS)	**F**	washed residue	PRODENTALINA AND EOGUTTULINA UNIT. Size increasing polymorphinids which become common and abundant in sample fraction>150μm. Common *Lenticulina*' s, mainly represented by *Lenticulina varians*, *Spirillina*' s.	Smooth ostracods. rare echinoderms debris, holothurian sclerites and posidoniids. Common radiolarians
Early Toarcian (TO1)	369,5-359,2 (MS)	**E**	washed residue	SMALL PARALINGULINA GR. TENERA. UNIT. Rare or common Lagenina mainly in the sample fraction <150μm. Abundant *Eoguttulina*' s. *Prodentalina*' s, *Astacolus* and rare *Lenticulina*' s such as *Lenticulina varians*.	A.radiolarians. Small ornated ostracods, pyritized microgasteropods and bivalve prodissoconchs. Thin and transparent echinoid spines
Early Toarcian (TO1)	400-369,5 (MS)	**D**	washed residue	EOGUTTULINA UNIT. Rare or common Lagenina, mainly *Eoguttulina*' s and *Prodentalina*' s in the sample fraction <150μm. Small *Astacolus* and *Lenticulina gr. varians*. Small Lagenina showing a Pliensbachian affinity. Rare or common *Paralingulina* gr. *tenera* . *Bathysiphon* horizon in the lowerst part.	Common or abundant radiolarians. Small smooth ostracods. Very rare other organisms.
Dom.	498,6-487 (COR)	**C** and	washed residue	GLOMOSPIRELLA AND GLOMOSPIRA UNIT. *Glomospira,Glomospirella, Ammodiscus, Bathysiphon, Jaculella*	Radiolarians and rare macroinvertebrate debris
Dom. Carix.	487-500 (COR)	**B**	thin section	SMOOTH AND ORNATE LAGENINA . Rare siliceous agglutinants. Microfacies **2**	Radiolarians, gastropods, echinod., thick ostracods
Carixian	530-510 (COR)	**?A**	thin section	SCULPTURED LAGENINA AND MILIOLINA UNIT. Rare plurilocular agglutinants. Microfacies **1**	Gastropods, ehinoids, crinoids., large calcar. spicule sponge

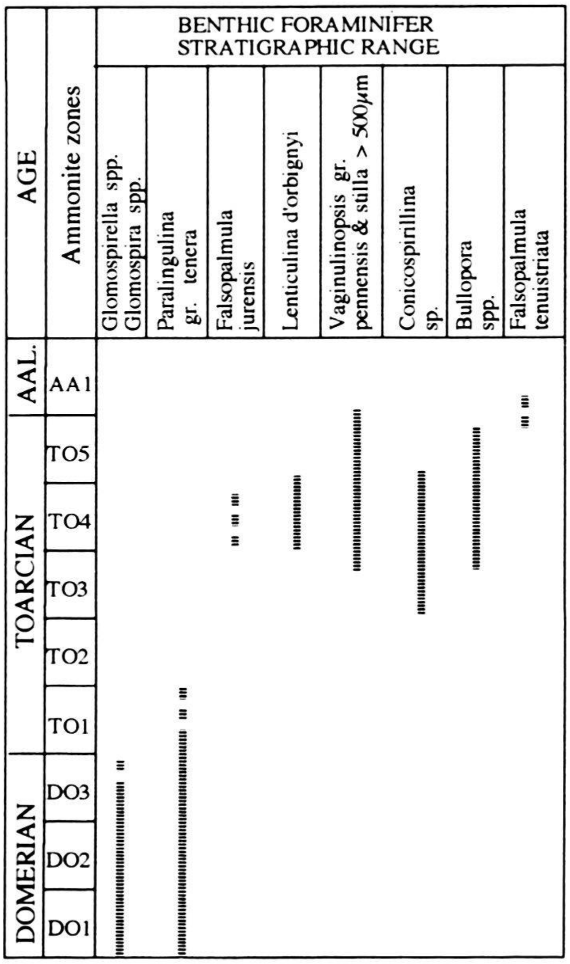


Fig. 12. Biostratigraphic value of the most indicative benthic foraminifers.

5.2 Data discussion

5.2.1 Paleoecological inferences

Paleoecological studies concerning Jurassic benthic microforaminifers are rather scarce and controversial due to the difference between such assemblages and more recent ones. Stam (1986) discusses the two major interpretations concerning small benthic Jurassic foraminifers.

a Jurassic Spirillinina, Lagenina and simple representatives of Textulariina have been believed to be characteristic of Jurassic shelf to marginal marine deposits in the European and North African epicontinental seas (Gordon 1970; Johnson 1976; Copestake 1989; Nicolin & Ruget 1988; Stam 1986; Nagy et al. 1990; Nagy & Johansen 1991; Cubaynes et al. 1991, etc.). The two main foraminiferal components belong to the suborders Textulariina and Lagenina and occur in highly varying proportions while other groups are seldom dominant in the various marine shelf environments affected by sea-level fluctuations.

b According to Luterbacher (1972), Kuznetsova (1974), Bartenstein (1974), Kuznetsova & Seibold (1978), Sliter (1980), Basov & Krasheninnikov (1983), Gradstein (1983)

Fig. 11. Foraminiferal assemblage scheme.

and Riegraf et al. (1984), Lagenina, Spirillinina and Glomospirella-Glomospira assemblages characterize bathyal and abyssal deposits in the DSDP Sites of North Atlantic and Indian Oceans during Late Jurassic – Early Cretaceous. Most of these authors discuss the possibility of faunal reworking but they give the Jurassic UMB as an example of a deep water environment. In fact, Kimmeridgian Lagenina and Spirillinidae were found by Farinacci (1965) in the Monti Martani area and were considered by the author as deep water benthic foraminifers. After several field investigations, however, Farinacci found out that the foraminiferal assemblage described in 1965 was contained in a mass flow originating from a shallow water morpho-structural high into a depressed area that was characterized by siliceous and calcareous deposits known as the "Calcari diasprigni" stratigraphic unit (A. Farinacci, personal communication). In 1981, having collected a large amount of new paleontological and sedimentological data, Farinacci and her group revised Farinacci's original interpretations of the M. Martani Ridge, in "The Ammonitico Rosso Symposium" (Farinacci and Elmi [Eds.] 1981). They considered the M. Martani area as a shallow water area of deposition, directly affected by eustatic sea level changes during the Jurassic.

In this paper the information given by the first group of authors has been useful in interpreting the sea-bottom features of the Valdorbia area in the early Jurassic and is considered here to fit the UMB for the following reasons:

1 The assemblage variations, the recognizable trends in the microfauna related to sedimentological and geochemical changes, and the agglutinated foraminiferal turnover near the Domerian/Toarcian boundary are difficult to explain in a bathyal or abyssal environment.
2 Macroinvertebrates, although in stunted forms, occur throughout all the section exhibiting a decrease in size from Domerian to Lower Toarcian and an increase in the Middle and Upper Toarcian. On the basis of the microfacies analysis they cannot be considered as reworked fauna from a shallow water carbonate platform. Their distribution would be rather unusual in a bathyal environment.
3 In bathyal environments in the North Atlantic Ocean, during the late Jurassic the agglutinated foraminifers are always abundant and the macroinvertebrates rare or absent. In the Valdorbia area the faunal distribution is completely different.
4 Thin and small bivalves (posidoniids) have been demonstrated to be benthic organisms by Kauffman (1981), Conti & Cresta (1982) and Conti & Monari (1992). In the Valdorbia Section they are associated with common microbrachiopods and microgastropods. A trend of increasing numbers of bivalves and brachiopods, and a decrease in benthic foraminifers in a sedimentary sequence, such as has been noted in the upper part of the Valdorbia Section, is not easily explanable in a deep environment.
5 The investigated Jurassic foraminiferal assemblages have been compared with those occurring in the bathyal "Scisti a Fucoidi" Fm. of the Lower Cretaceous in the UMB, which Coccioni has been studying (R. Coccioni, personal communication). The Toarcian and the Early Cretaceous Lagenina are somewhat similar but in the Early Cretaceous the macroinvertebrates are almost absent, the ostracods rare and the Textulariina more abundant and diversified than in the Early Jurassic.

It is well known that small benthic foraminifers have adapted to a great range of environments during geological history. Lagenina, Spirillina and Glomospira-Glomospirella could have adapted to different ecological factors affecting the sea-bottom in the Early Cretaceous after the deepening of the relatively shallow-water sea-floor which persisted in a small area of the Umbria-Marche basin (topographic highs) during the Late Jurassic.

In this paper the bathymetric terminology has been taken from van Morkoven & Berggren (1986): 0–30 m inner shelf; 30–100 m middle shelf; 100–200 m outer shelf; and 200–600 m upper bathyal. These environmental interpretations have been drawn from foraminiferal studies of the Jurassic European epicontinental shelves but use of this bathymetric terminology does not imply that the Valdorbia area was an epicontinental sea during the Early Jurassic. In fact the Jurassic UMB was not near or related to a continent, because the sediments do not show any coarse terrigenous input. The micropaleontological assemblages, however, permit an acknowledgement of sea-level fluctuations in Toarcian deposits, which are poorly differentiated in lithology, as in the Western European shelves (Cubaynes et al. 1990).

- Assemblage **A**. This assemblage has been considered by Nocchi (1992) to characterize an environment of deposition corresponding to a middle shelf. In the Valdorbia Section, however, it is uncertain whether the organisms were local or have been displaced from elevated surrounding areas, although the microfacies 1 does not show clear indications of reworking. In the morphostructural highs, in fact, the isochronous lower part of COR is rich in microfossils (Nocchi 1992) some of which (Miliolina) occur in the Valdorbia section as well, while others (Involutina liassica, Trocholina etc) are rare or absent.
- Assemblages **B** and **C**. The two assemblages alternate through the whole Domerian section. Consideration of each one separately would result in an interpretation of repetitive and abrupt fluctuations in the sea-bottom depth. Assemblage B, containing mainly Lagenina associated with ammonites, echinoids and radiolarians seems to indicate open marine, distal shelves with normal salinity and oxygenation (Johnson 1976; Cubaynes et al. 1989); whereas, assemblage C (Pl. 4, Fig. 1–7) (simple Textulariina, including Glomospira and Glomospirella, associated with Verneulinoides, Haplophragmoides), is interpreted as indicative of a shallow water, restricted marginal environment, with reduced salinity and terrestrial influx, or of a lowstand of sea-level (Løfoldli & Thusu 1979; Nagy & Johansen 1991; Cubaynes et al. 1989). It is more appropriate to consider both these assemblages together in order to interpret the marine environment of deposition. The problematic assemblage C has already been discussed by Nocchi & Bartolini (in press). One of the few papers dealing with Glomospira-Glomospirella paleoecology is that of Chamney (1976). He interprets the Glomospira-Glomospirella assemblages as a response to the siliceous content in the marine waters and to the high level of current energy of the marine environment. Furthermore Chamney (1976), together with Gradstein & Berggren (1981), suggest that factors controlling agglutinated foraminiferal assemblages can be the availability of $CaCO_3$, post-depositional dissolution of calcareous-hyaline foraminifers, low salinity and/or low temperature, lack of oxygen and pH fluctuations. These factors can affect both marginal brackish waters and the deepest part of the oceans.

Following the paper of Nocchi & Bartolini (in press), further investigations have been carried out both in the UMB and in the pelagic Jurassic internal Ionic Zone of Greece. These investigations have shown that the Upper Domerian interval, consisting of thin marls interstratified with limestones and particularly rich in Glomospira-Glomospirella (assemblage C), extends to other south Tethyan areas, such as Greece. Assemblage C, therefore seems indicative of more extensive environmental conditions in the Domerian than those suggested by Nocchi & Bartolini who considered the possibility that the concentration of siliceous benthic foraminifers were due to pressure dissolution of calcium carbonate.

In the Valdorbia area the Corniola depositional environment was, probably, affected by changes of physical and chemical conditions in the water mass. These factors could have been a decrease in sea-floor temperature, an increase in silica, as indicated by radiolarian content, during a relative deepening, and an oceanic opening during the deposition of assemblage A. These water mass features could also have eliminated Miliolina and Involutinina, enhanced simple siliceous Textulariina and left unaffected the Lagenina, which inhabit deeper shelf areas as well. Other factors could be considered to be low calcareous productivity over a short period, the slow sedimentation rate causing an increase in the relative clay content, without excluding diagenetic processes and pH fluctuations.

- Assemblage **D**. This assemblage is characterized mainly by small Eoguttulina (predominantly Eoguttulina metensis) associated with Prodentalina, and by a scarcity of macroinvertebrates. Among the agglutinated foraminifers, Bathysiphon and Hyperammina are abundant and the only fauna occurring at the bottom of this stratigraphic interval. Finely agglutinated Bathysiphon can be found to a depth below 200 m (Chamney 1976; Boltvoskoy & Wright 1976). Stam (1986) suggests, moreover, that Eoguttulina's and Prodentalina's prefer relatively deep water, between 150–200 m or more. Ruget (1980) attributes a restricted environment to assemblages dominated by polymorphinids.

  In the Early Jurassic a transition from simple Textulariina and Lagenina assemblages to Lagenina-only assemblages is indicative of a deepening towards deep and distal shelf areas (Johnson 1976; Cubaynes & Ruget 1987). Simple siliceous Textulariina seem to prefer a shallower habitat than Lagenina. As a whole assemblage D is believed to indicate the deepest environment of deposition within the Valdorbia Section. Within the stratigraphic interval represented by assemblage D, Pliensbachian Lagenina, such as Marginulina gr. prima, Berthelinella paradoxa, Ichthyolaria sulcata, Pseudonodosaria vulgata, are at first small and rare and then disappear altogether. In the Valdorbia section, however, the turnover of the cosmopolitan shelf benthic foraminifers within the Tenuicostatum Zone is not obvious as in other sections of the UMB (Nocchi & Bartolini in press) due to lack of the stratigraphic interval with the assemblage BC. The earlier disappearance of Glomospirella compared to Lagenina, is odd, since factors which are favorable to their growth, such as clay and organic silica, increase. Such a disappearance could be explained by the deepening of the sea-floor (Boltovskoy & Wright 1976).
- Assemblage **E**. This assemblage characterizes the black shale lithofacies, of the middle-upper part of the Tenuicostatum Zone, and has already been discussed by Bartolini et al. (1992). It corresponds to disaerobic-anaerobic conditions on the sea-floor

which are favorable to a bloom of small and flat forms of morphogroup A (Pl. 4, Fig. 10 and 17) such as Paralingulina gr. tenera and Eoguttulina. These are considered opportunistic taxa which thrive best in poorly ventilated environments as they are infaunal organisms and already adapted to poorly oxygenated sediments. In the Valdorbia section Spirillina and Haplophragmoides (Pl. 5, Fig. 8) also occur in this stratigraphic interval while in other sections, such as Pozzale (Bartolini et al. 1992) they are almost absent. The species diversity (Fig. 10) is variable indicating that the depositional environment was probably occasionally oxygenated. Among the other organisms small pyritized ostracods belonging to Procytherura are common together with other forms (Pl. 6, Fig. 10 and 15). The other organisms (juvenile forms) characteristic of the black shales (Bartolini et al. 1992) are indicative of starved conditions unfavorable to their growth.

- Assemblage **F**. In this assemblage smooth Lagenina are almost the only group recovering from the benthic crisis of the Tenuicostatum Zone and are characterized by an irregular increase of Lenticulina. According to Cubaynes et al. (1989), Cubaynes & Ruget (1987), Bielecka & Posaryska (1954), assemblages dominated by Lagenina are indicative of distal, outer shelves or deeper shelf areas with accumulation of marly argillaceous sediments.
- Assemblages **G** and **H**. The two assemblages are considered together because they share some features which are believed to have paleoecological significance. The increase in both abundance and in size of strictly coiled lenticulinids of morphogroup E (Fig. 9 and 10) (see also Fig. 5 in Bartolini et al. 1992), the relative decrease in the Eoguttulina and Prodentalina specimens and the occurrence of abraded, stout , biconvex Lenticulina are indicative of a change in water depth and in the hydrodynamic regime. According to several authors (Lipina 1961; Chamney 1976; Cubaynes et al. 1991) large, roboust forms developing an involute, reinforced test, thick walls and closely packed chamber arrangements, indicate less favorable marine conditions due

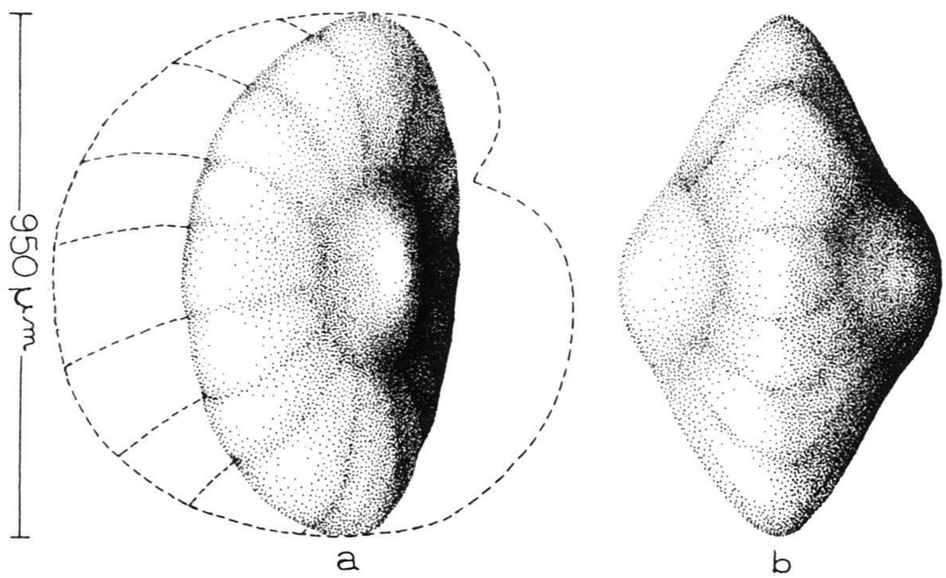


Fig. 13. Schematic drawing of a "cigar shape" Lenticulina münsteri (same specimen in Pl. 6, Fig. 1 and 2) **a** side view; **b** axial view.

to high energy level created by the action of wave base or currents. Cubaynes et al. (1990) report that lowstand sea-level benthic foraminiferal assemblages are represented almost exclusively by the morphogenus Lenticulina s.s. Moreover assemblages dominated by Spirillina and Lenticulina gr. münsteri seem characteristic of shallow marine environments (Morris 1982) while Stam (1976) suggests a depth value of 50 m – 100 m for Spirillina and Lenticulina. According to him the two groups show a significant positive correlation with a shallowing trend in the sequence. Abraded forms (Pl. 6, Fig. 1–4) can indicate areas under the influence of modest currents and waves (Murray 1984). Here the term "cigar-shaped" is attributed to stout biconvex Lenticulina's with umbilical plugs that reinforce the axial central area so that the marginal areas are more easily eroded with the rolling axis perpendicular to the coiling one (Fig. 13). This particular shape is probably due to a rolling action with a mechanical stress perpendicular to the axial area due to current or storm wave action upon epifaunal or primary weed fauna, without affecting benthic forms living inside the sediments.

The major difference between assemblages G and H consists of an abrupt increase in size within the Erbaense Zone both in tightly coiled forms, such as Lenticulina gr. munsteri, and also in well-preserved, large uncoiled forms, such as Astacolus and Vaginulinopsis (Pl. 5, Fig. 12, 13, 14 and 15) which are believed to have been dominant in distal shelves during highstand deposits (Cubaynes et al. 1989). Within assemblage H, benthic foraminifers indicative of a calm environment are mixed with foraminifers indicative of moderately agitated sea-floor conditions. An explanation may be that the remains of epifaunal organisms, such as biconvex Lenticulina, may be moved horizontally along the sea-floor and broken specimens concentrated locally while infauna specimens, such as Astacolus and Vaginulinopsis are more likely to remain undamaged and undisturbed.

As a whole the environment of deposition of the assemblages G and H, which lack Miliolina, is not a very shallow environment, such as an inner shelf, but corresponds, probably, to a transitional environment from a distal to a middle shelf with mixed fauna indicative of differentiated energy conditions on the sea-floor.

At the boundary between assemblages G and H (Erbaense Zone) the abrupt increase in Astacolus and Vaginulinopsis could indicate a sudden junction of the thermocline with the sea-floor and a consequent increase in oxygen, temperature and trophic conditions, such as the availability of grass flooring the sea-bottom. Large, flat and uncoiled foraminifers are believed to have a phytal habitat and to have thrive in an environment with increasing trophic factors which could be supported by the occurrence of microgastropods. The abraded "cigar-shaped" Lenticulina's can be related to an oscillatory flow regime near the sea-bottom at the major storm wave base as well.

The occurrence of Procytherura (Pl. 6, Fig. 7) among the ostracods is also probably indicative of a relative shallow-water environment. Procytherura multicostata is a common Toarcian species in the South West Germany (Arias 1991).

Assemblage **I** (mainly Lower Aalenian). A new crisis seems to affect the benthic foraminifers which decrease in size, abundance and species diversity, several species disappearing altogether (Fig. 8). The appearance again of Glomospira-Glomospirella could be interpreted as reflecting an increase in the silica content in the water and/or a return of shallower conditions than those in the underlying stratigraphic interval, which is borne out by the richness of macroinvertebrate organisms in the biofacies.

6. Sedimentology

In the Valdorbia area some gravity-flow deposits and other detrital beds were deposited during the middle and upper parts of the Early Jurassic (Fig. 14). Therefore, a brief summary of the main depositional features is necessary here for interpreting the depositional setting. Such deposits can be summarized as: a) calcareous turbidites; b) hummocky cross-stratified (HCS) deposits; and c) winnowed levels.

6.1 Calcareous turbidites and associated gravity-flow deposits

6.1.1 Description

Fine-grained calcareous turbidites, slump and pebbly mud-flow deposits are common in the Valdorbia section (Elmi 1981b; Monaco 1992). Coarse-grained turbidites are very rare (Fig. 15a). The fine-grained turbidites consist of white or yellowish calcisiltites and fine-grained calcarenites, ranging in thickness from 10 to 160 cm (Fig. 15b). In the field, sharp-based turbidites show a very uniform lateral continuity. Intervals b and c of Bouma are predominant, while the normal grading (a of Bouma 1962) is rare. Unidirectional current-ripples and bottom marks (mainly scour, tool and impact marks) are locally present and indicate a prevalent SE-NW direction of turbidity-flow deposits. Water-escape structures, which are common in siliciclastic counterparts and rare in pure carbonates (Lowe 1982), are present in calcareous turbidites of Valdorbia area, since the clay content reaches about 10–15% in the finer fraction (Ortega-Huertas et al. 1993) (Fig. 15b). Amalgamation of calcareous turbidites is very common at the transition of the COR-MS; amalgamated calcarenites show parallel laminations and can reach 160–180 cm in thickness. Texturally the calcareous turbidites are packstones and rudstones with abundant muddy matrix. The carbonate grains consist mainly of echinoderm and bivalve fragments, muddy intraclasts and micritic peloids; radiolarians, oolitic and oncolitic grains and other skeletal fragments are also present in some beds.

Pebbly mud-flow deposits consist of abundant fine-grained carbonate material (calcilutite) and a varying proportion of matrix-supported muddy intraclasts, chert fragments and various type of skeletal grains (echinoderms, ammonite and belemnite remains). In the upper part of Corniola unit, debris flows and pebbly mud-flows are locally associated with muddy slumps (see Einsele 1991).

6.1.2 Age

Turbiditic deposits are abundant in the lower part of the Valdorbia section and they decrease in frequency and in thickness in the upper part of the section. They are represented mainly by low-density turbidites in the Upper Domerian, by high-density, sandy turbidites and mass-flow deposits at the Domerian/Toarcian boundary – where amalgamation phenomena are also present – and by low-density, sandy to silty turbidites in the Lower Toarcian (black shales interval). Like in the Upper Domerian (Emaciatum Zone), in the Lower Aalenian muddy slumps and "heterogeneous" pebbly mudstones (sensu Colacicchi & Baldanza 1986) are again common. At the base of the Marne del M. Serrone Formation (Domerian/Toarcian transition) planar-bedded gravity flow deposits show low-angle curvilinear lamination and HCS in the upper part of a single bed.

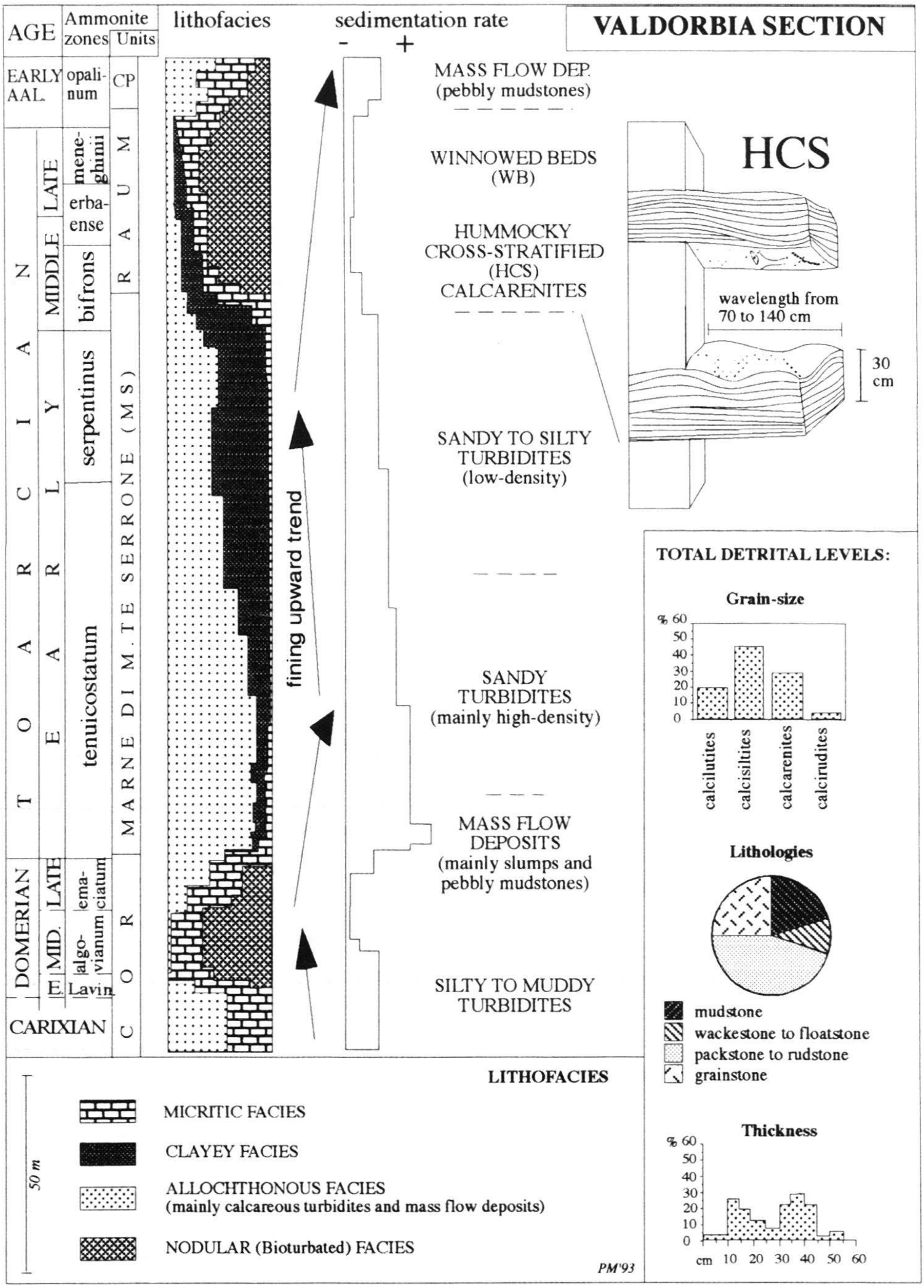
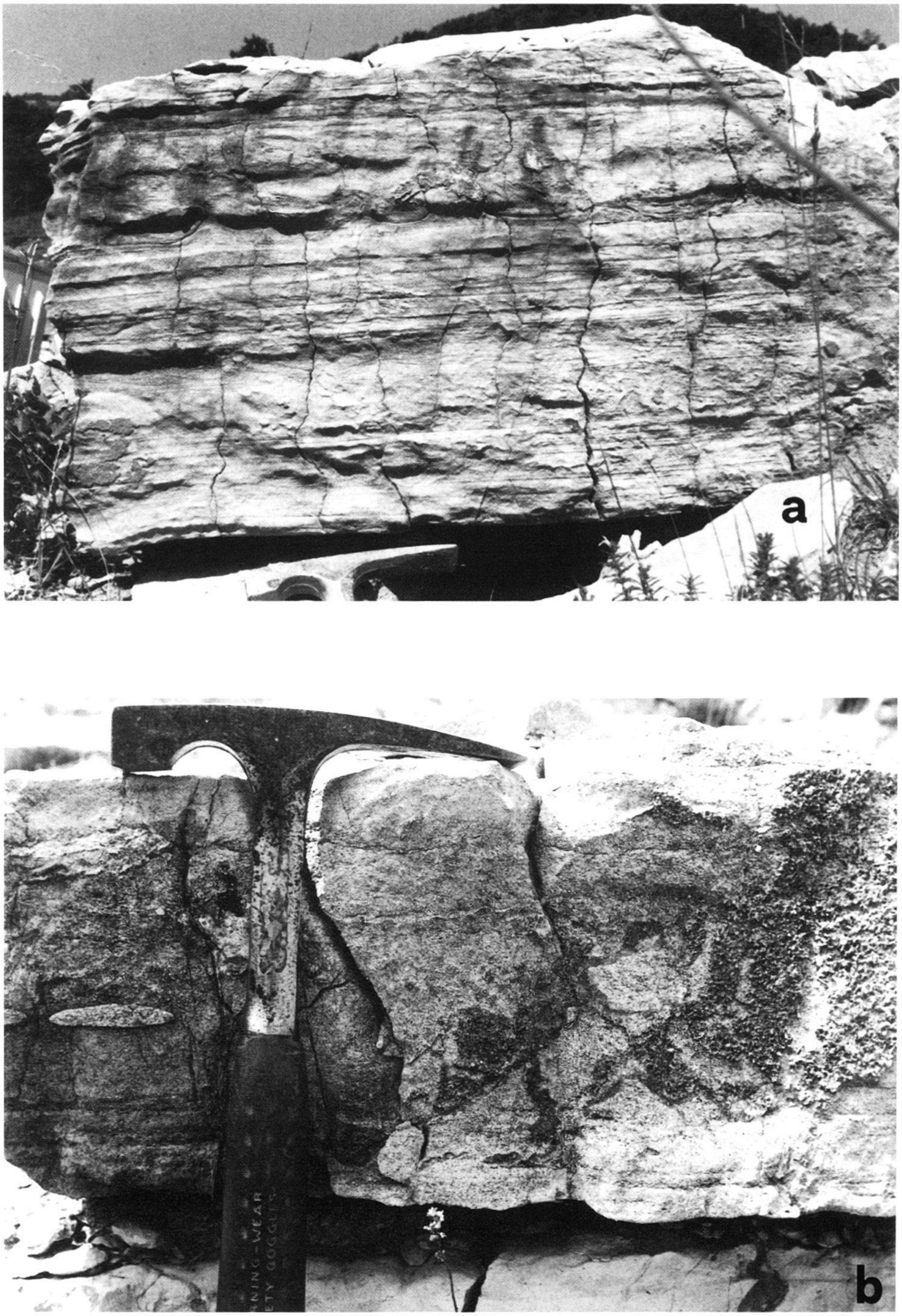


Fig. 14. Sedimentological trends and realtionship among turbidites, gravity flow deposits and HCS beds.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6.1.3 Interpretation

Turbidites and associated gravity-flow deposits indicate that extensional faulting was still active in some areas of Umbria-Marche basin during the Domerian/Toarcian boundary, the early part of the Early Toarcian and the Toarcian/Aalenian transition (Pialli 1969 a,b; Centamore et al. 1971; Elmi, 1981b; Cecca et al. 1990) causing instability of the sea floor.

The coarse-grained turbidites studied – showing a basal unit with inverse grading and/or imbrication, overlain by a planar or cross laminated arenitic layer – could have been deposited by high-density turbidity currents (Lowe 1982; Eberli 1991). In the fine-grained turbidites these features are lacking (Lowe 1982). Faint parallel laminations, overlying a short normal graded interval, seem to indicate that fine-grained turbidites were deposited from low-density turbidity currents. During deposition from such currents, only a few faint sedimentary structures are produced, which makes it difficult to distinguish them from pelagic deposits (Piper & Stow 1991). Echinoderm and peloidal calcisiltites interbedded in the upper Corniola and MS (including black shales) could be deposited from silty turbidity currents, generated by slumping of an unconsolidated material (silt and/or mud), or they may form as the end member of a long-travelled turbidity current (Einsele 1991; Eberli 1991). The planar-bedded gravity-flow deposits that show low-angle curvilinear lamination and HCS in the upper part of a bed (lower part of MS Formation, Domerian/Toarcian transition) could be referred to a new interpretation of Mutti (1992). According to Mutti somes types of hummocky cross-stratification that are located at the top of thick gravity flow beds may be related to oscillatory regimes induced by catastrophic gravity-flow deposits in confined, shallow seas, and, consequently, is it possible that these HCS are not related to meteorological phenomena (Mutti 1992).

6.2 Hummocky cross-stratified (HCS) deposits

6.2.1 Description

The Valdorbia section contains sharp-based calcarenitic beds, 15–40 cm in thickness, showing "hummocky cross-stratification" (HCS) in the sense of Harms et al. (1975) (Fig. 14).

In the Valdorbia area a complete HCS sequence consists of three divisions (Monaco 1992):

1 Bivalve and echinoderm basal lag;
2 Hummocky cross-stratified division;
3 Calcisiltite-lutite division with oscillatory ripples.

Fig. 15. Calcareous turbidites of the Upper Domerian and Lower Toarcian (Emaciatum – Serpentinus Zones). **a** Amalgamated, fine-grained calcarenite, showing repetitive intervals of planar tabular bedding and convolute laminations (divisions b and c of Bouma). Current ripples are common. Domerian/Toarcian transition. **b** High density, coarse-grained calcareous turbidite showing planar bedding (lower part of bed). In the upper part faintly laminated or massive rudite level is present. Lowermost part of the Lower Toarcian (Tenuicostatum Zone).

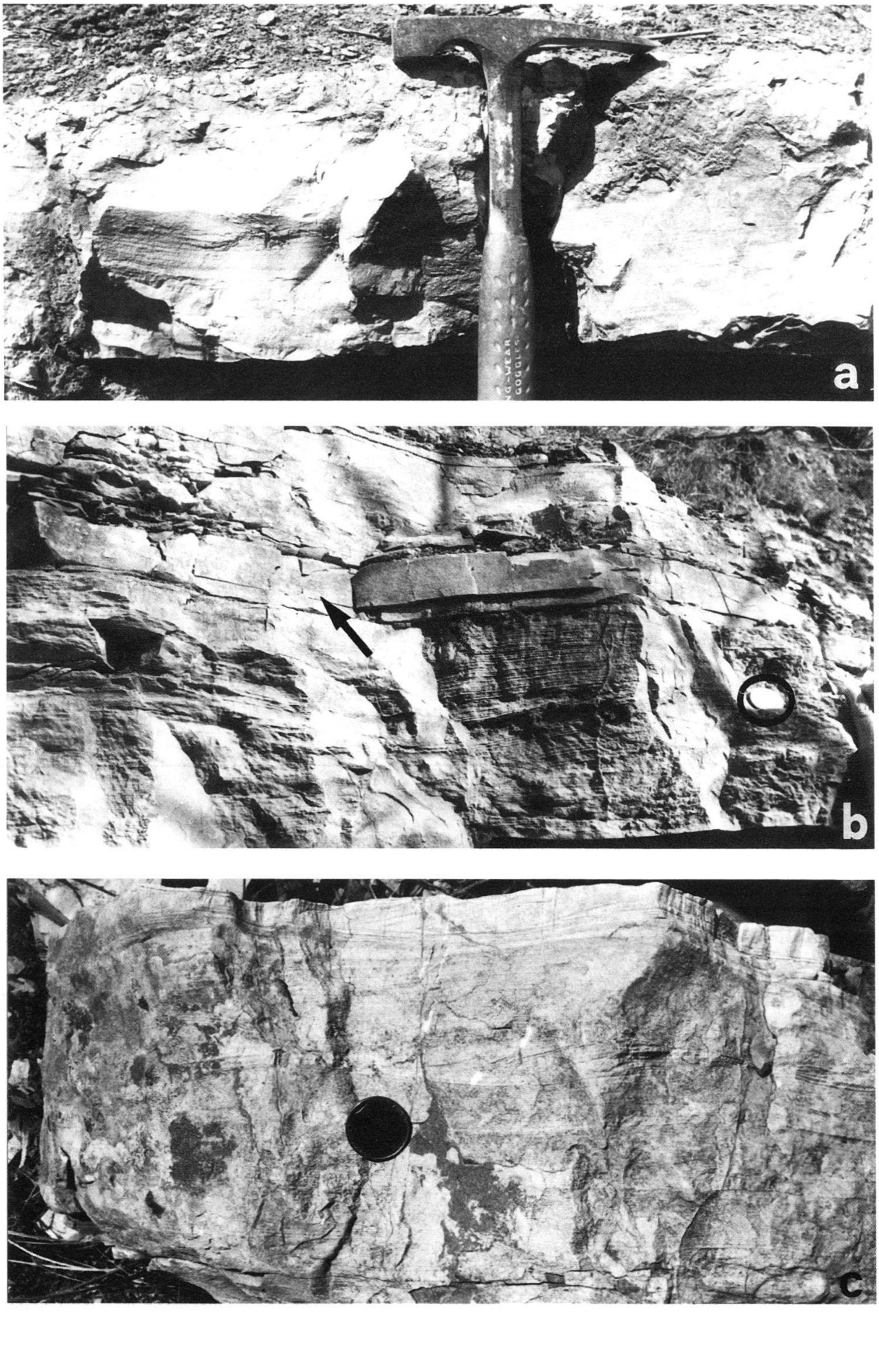
1 Coarse-grained (grain-size up to 5 cm), densely packed rudstones, and packstones (0.5 to 40 cm thick) constitute the lower part of a sequence (basal lag). The basal contact is sharp and erosive surfaces affect the underlying shales. In general the lag is discontinuous and massive, but normal grading is present. The coarse fraction is composed of bivalves (60–80% skeletal grains). At least 60% of the concave valves lie with the convexity facing up. Echinoderms, micritic lithoclasts and other invertebrate remains are also present. In thin-sections infiltration fabrics and shelter porosity occur (Kreisa 1981; Kreisa & Bambach 1982).
2 The HCS division represents the middle part of a sequence and occurs generally in thick beds (up to 60 cm thick). The elliptical domes, 50–100 cm in diameter, are generally symmetrical and display wavelengths mostly from 70 to 140 cm (Fig. 16a, b). The grain fraction consists of well-sorted, fine-grained calcareous sand and silt (average grain sizes in thin-section being between 0.05 and 0.30 mm). Texturally, they are generally matrix-poor packstones. Most grains (up to 70%) are echinoderm fragments. Micritic peloids are very abundant (locally up to 40%). Pebbles (up to 15%), fragments of benthic foraminifera, and/or radiolarians, together with thin-shelled, disarticulated bivalves ("resti filamentosi", Centamore et al. 1971) are fairly common.
3 The oscillatory ripple-bedded division (from 0.5 to about 20 cm thick) constitutes the upper part of a HCS sequence. In general it is very fine-grained (siltstone or mudstone) and pervasively bioturbated. Here trace fossils are both horizontal and vertical. The latter cut down across a bedding surface and the penetration depth can reach about 7–10 cm (Fig. 18d). Equidimensional bivalve fragments are either parallel to the bedding surfaces or were accumulated by burrowing organisms. In thin section micritic peloids and radiolarians are abundant. Oscillatory ripples, about 2–6 cm high with spacings of 6–12 cm, characterize the upper part, but asymmetrical current ripples are locally present (Fig. 16c).

6.2.2 Age

Although HCS beds are present in the upper part of gravity-flow sedimentation during the Domerian/Toarcian boundary interval, these deposits characterize the Middle Toarcian (Bifrons Zone and lower part of Erbaense Zone), when turbidites and associated gravity-flow deposits are lacking.

6.2.3 Interpretation

Hummocky cross-stratification, characterized by generally unoriented, low-relief hummocks and swales with wavelength about from 70 cm to 4 m, is considered to be diagnostic of shallow-marine storm environments, well below fair-weather wave influence and above effective storm wave base (see the extensive literature reported in Walker 1984; Duke 1985; Monaco 1992). For deep water environments see Prave & Duke (1990). In shallow, confined fan deltas, characteristic coarse-grained gravity-flow deposits with planar-bedding show hummocky cross-stratification in the upper part of a bed that is not related to meteorological phenomena such as storms that are rare in some paleolatitudes (Mutti 1992). On the basis only of primary structures of calcarenites the latter interpretation could apply to the Domerian/Toarcian transition when gravity flow deposits were abundant, but it does not apply to the Middle Toarcian in the Umbria-Marche basin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where turbidites and gravity-flow deposits are lacking. Moreover, textures of autochthonous sediments, trace fossils, microfaunal assemblages and geochemical parameters (Ortega-Huertas et al. 1993) seem to confirm a shallowing of the sea floor during the Middle/-Upper Toarcian towards the major storm wave base level where oscillatory flow was dominant. Evidence of oscillatory flow near the sea bottom is found in the shelter porosity and in characteristic abrasion surfaces on some stout biconvex benthic foraminifera (Lenticulina) in the Middle Toarcian interval.

During the early Mesozoic, the large ocean to the east of "C"-shaped landmass of Gondwana – the Tethys Ocean – was ideal for hurricane generation (Marsaglia & Klein 1983). Combined winter storm and hurricane systems dominated the shallow seas of northern Europe including Germany (Bloos 1982), southern Spain (Molina et al. 1987), Morocco (Ager 1974) and other areas (see Duke 1985) during Jurassic time. The Umbria-Marche area, during the Jurassic, was located in an intermediate paleolatitudinal position, between a hurricane-dominated system to the south, and a mixed winter storm/hurricane-dominated one to the north, and in every case was prone to large hurricanes.

6.3 Winnowed beds (WB)

6.3.1 Description

Discontinuous, matrix-poor deposits are present in the RAUM unit in the upper part of the Middle Toarcian. A vertical sequence, from 0.5 to 15 cm thick, includes (from the bottom to the top): a wackestone, a packstone level and (locally) a grainstone. This inversely graded sequence overlies, without erosional surfaces, the undisturbed, autochthonous mud of the Rosso Ammonitico unit. The grain fraction is often monotypic and formed by concentrations of whole or nearly whole, thin-shelled or costate bivalve (up to 30 mm in diameter). Bivalve shells are densely packed, directly stacked upon each other and lie parallel to the bedding, generally with concave side up (50–60% of the total shells). Shelter porosity is common and matrix/clast ratio decreases upward.

6.3.2 Age

Winnowed beds are rare at Valdorbia. They are found exclusively in the RAUM unit in the upper part of the Middle Toarcian and in the lower part of the Upper Toarcian (Monaco in press a and b).

6.3.3 Interpretation

Periodic storms produced intense bottom-shear conditions, well below the normal wave base (WB in Fig. 14). During the storm peak the soft mud of the sea-floor was eroded and scattered together with shells of living or dead organisms. This process also exhumed

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Fig. 16. Sharp-based hummocky cross-stratified calcarenites (HCS), Middle-Upper Toarcian (Bifrons-Erbaense Zones). **a** Sharp-based HCS bed displaying wavelenght of about 100–120 cm; the uppermost part is fine-grained (mud) and pervasively bioturbated. **b** Small scale and erosive HCS laminae. The cm-thick muddy level in the center (see arrow) represents the characteristic "yellow level" (185.7 m). See coin inside the circle. **c** Oscillatory ripples and erosive ondulatory laminations are present in the upper part of a HCS sequence; current ripples are also common.

the previously semi-lithified mud and buried shells. The strong oscillatory-flow regime at the sea-floor induced a winnowing of finer sediment (the matrix is moved away) and formed a sequence with a characteristic upward trend: a wackestone, a packstone and then a grainstone in the upper part (Brenner & Davies 1973; Specht & Brenner 1979; Kreisa 1981). In other cases due to continuous oscillatory flow on the sea floor, variable periods of non-sedimentation and/or erosion occurred (hiatus), with the exhumation of firmground (or hardground) during the Middle Toarcian (Monaco in press c).

Wavy laminites, interbedded with graded rhythmites, are described also in the Toarcian black shales of NW-Greece and are interpreted as storm deposits formed by direct wave action (see Walzebuck 1982).

6.4 A vertical trend from turbidites to HCS and WB deposits

In the studied section some different trends are recognized:

a The first is present in the COR unit from the Carixian to the lower part of the Lower Toarcian. Meter-scale cycles of fine-grained calcareous turbidites, due to low-density flows, evolve gradually in coarse-grained, m-thick turbidites and gravity flow deposits (Fig. 14). Amalgamated, high-density turbidites contain reworked skeletal grains of a carbonate platform environment. This detrital sedimentation represents an increase in supply in the Valdorbia area, probably related to local tectonics that influenced the M. Catria-Valdorbia area. A tectonic elevation in the M. Catria area probably involved a deepening in the Valdorbia one in the upper part of the Early Jurassic when the bottom of the Valdorbia basin reached the maximum depth (Monaco 1992, Tab. 1). Another interpretation is that the thickening and coarsening up during the Domerian (Fig. 14) could be related to a sea-level fall (Farinacci et al., 1981; Hallam 1988).

b Coarse-grained calcarenitic turbidites in the COR/MS units transition are overlain by fine-grained calcisiltitic turbidites in the upper part of the MS Fm. (Lower Toarcian, Tenuicostatum – Serpentinus Zones, Fig. 14). The thickness and the grain size of detritic beds decrease going upward. This fining-upward trend seems to indicate a reduction of a local tectonic activity and a uniform depth of the sea-floor.

c A shallowing-upward trend characterizes the Lower Toarcian – Middle/Upper Toarcian interval. Fine-grained turbidites, abundant in the MS Formation are overlain by sharp-based HCS deposits and WB beds in the RAUM unit (Fig. 14). This shallowing-upward trend may be related to a progressive sea-level fall in the Middle/Late Toarcian (Hallam 1988) that is general in the Umbria-Marche area. Microfaunal assemblages reflect this progressive shallowing-upward trend and indicate a transition from a sea-floor comparable to an upper bathyal/outer shelf environment in the Early Toarcian, to an outer- middle shelf in the Middle/Late Toarcian.

7. Trace fossil assemblages

7.1 Burrowing during authigenic sedimentation

a COR Unit. The lower part of the COR unit is very weakly bioturbated by small horizontal traces and Chondrites forms are common. During the Late Domerian, in contrast, the nodular sediments of the COR are pervasively bioturbated. Here the penetration depth reaches 7–10 mm and the maximum burrow diameter reaches 15 mm (in reddish nodular facies). Chondrites, Planolites, Thalassinoides and composite burrows represent the most important trace fossils (Fig. 17).

b MS Formation. At the beginning of the Toarcian, when medium to poorly oxygenated "Marne del M. Serrone" shales were deposited ("Toarcian Anoxic Event"), trace fossils are rare and poorly diversified. Chondrites and rare Planolites are present in laminated marly levels. The penetration depth in general is low, 3–5 mm (exceptionally 12 mm). Maximum burrow diameters reach 2–6 mm in the lower part of MS; in this interval nodular facies are absent, and, therefore, small and rare horizontal burrows are predominant (Fig. 17). Ornate burrow-systems (geometrically patterned agrichnia, mainly referred to Protopaleodictyon), of 3–8 mm in diameter, are locally present on the lower surface of such turbidite beds as "semirelief" casts (Seilacher, 1964) (Fig. 18). Planolites, Gyrochorte and Thalassinoides are also present, specially above the black shales interval (at the MS – RAUM transition) where these forms can reach 10–25 mm in diameter.

c RAUM Unit. During the deposition of well-oxygenated and nodular sediments of the RAUM unit, trace fossils increase progressively in abundance. Horizontal and vertical trace-fossils are large, diversified and fairly common in autochthonous mudstones and wackestones (Fig. 17). Thalassinoides, of 2 to 4 cm in diameter, and Planolites represent the dominant burrow systems of reddish marly deposits. These traces, and also ammonites, are reworked by Chondrites and Helminthopsis. The maximum burrow diameter rarely exceeds 30 mm and penetration depths can reach 50 – 60 mm in the reddish nodular limestones of Late Toarcian age (Fig. 17 and 18d). Subelliptical concentrations of bivalve and/or echinoderm fragments due to vertical burrowing activity are very common in this interval. In the Bifrons and lower part of Erbaense Zones (Middle Toarcian) 20 to 60 cm thick calcisiltite beds, showing HCS and oscillatory ripples, are interbedded with marls (Monaco in press c). Burrows on the lower surface of HCS beds are common. Horizontal Thalassinoides and Ophiomorpha are prevalent with diameters about 30–50 mm and Planolites is also present (Fig. 18b and c). At the top of HCS beds, oscillatory ripples become increasingly burrowed upwards by vertical traces, and Skolithos and Chondrites are the traces of the dominant firmground-burrowers (Fig. 18d). In fine-grained deposits (silts) Chondrites is represented by darker vertical traces showing upside-down Y-shaped development (Ekdale 1985). The penetration depth locally can reach 50–60 mm. Paleophycus, and Planolites, are very common when the upper part of HCS deposit is formed by a coarse-grained fraction (sand).

7.2 The significance of burrowing during turbiditic deposition (Early Toarcian)

In the turbiditic environment of the Lower Toarcian the trace fossil associations are higly diversified and burrow densities are very low (K-selected endobenthos, Ekdale 1985). Trace fossils are essentially pre-depositional traces and are produced in an equilibrium situation in the hemipelagic mud that was deposited slowly in between turbidite events (Seilacher 1962). Ornate burrow systems (e.g. geometrically patterned agrichnia such as Protopaleodictyon) that are present on the lower surface of turbiditic beds, probably reflect very specialized feeding behaviour (Bromley 1990).

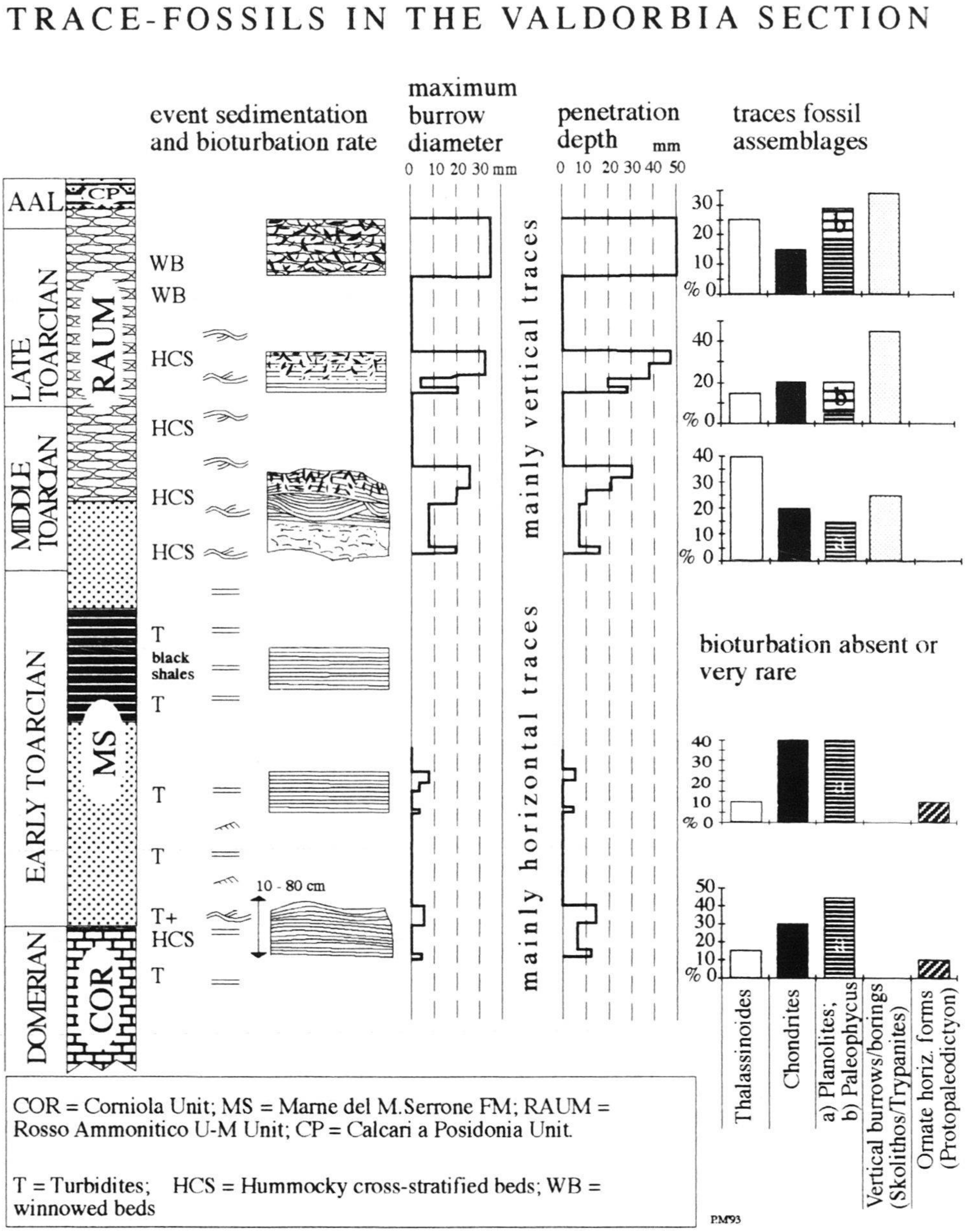
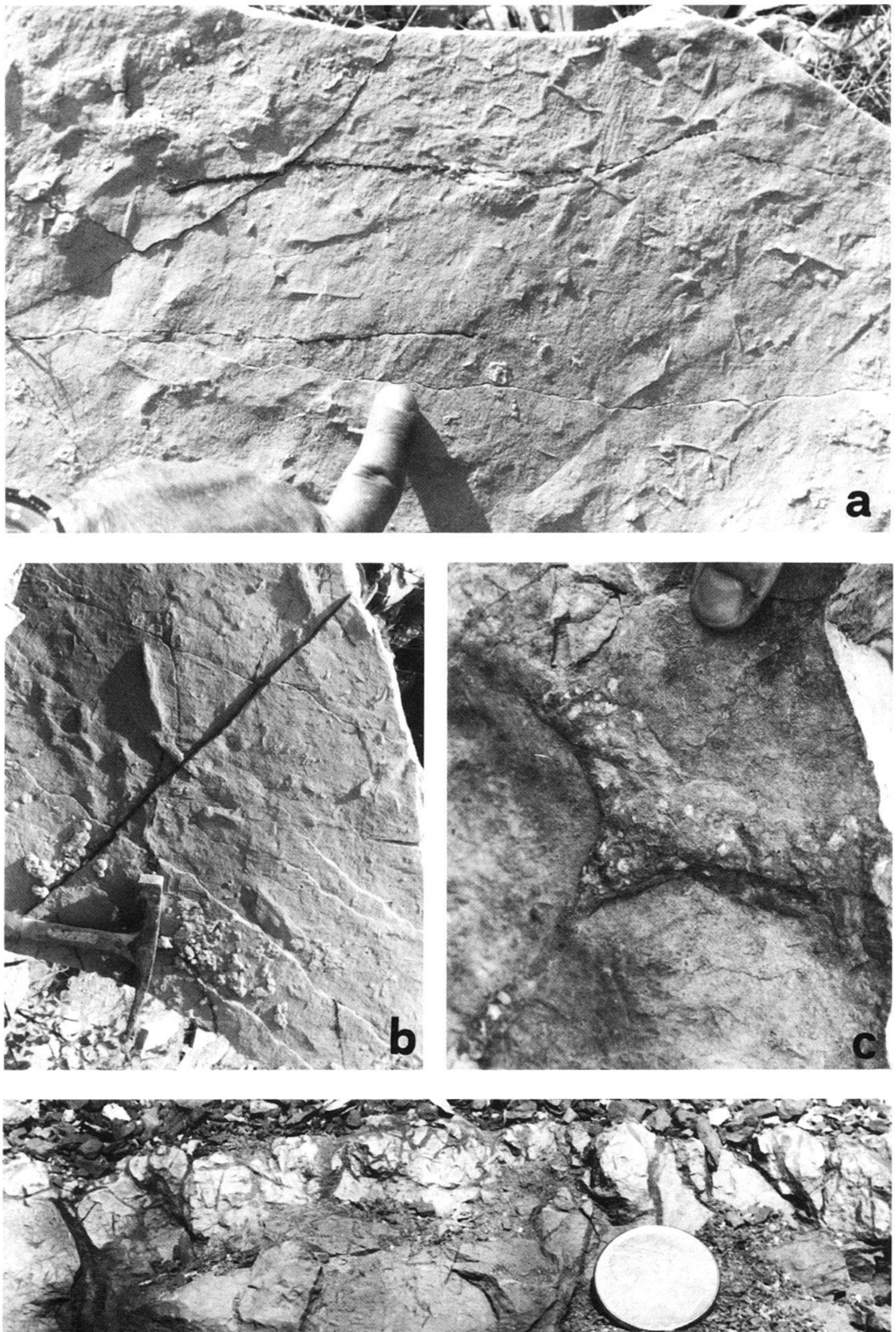


Fig. 17. Trace fossil assemblages and relationship with turbidites and HCS deposits.


a
b
c
d

During the black shale interval trace fossils became rare. In this oxygen-depleted environment the nature of the bioturbation is episodic, superficial (diameters in the range of one to few millimeters, Fig. 17) and dominated by the highly branched fodinichnial burrow Chondrites, which is characteristic of oxygen-poor interstitial conditions (Bromley & Ekdale 1984). Probably, as the concentration of dissolved oxygen in bottom waters decreases, the size of organisms capable of inhabiting underlying substrates also decreases (Rhoads & Morse 1971). Nevertheless, a very rapid and erosive sedimentation such as turbidite deposition may considerably disturb the trace-fossil record and complicate the interpretation of paleo-oxygenation (Savrda & Bottjer 1986; 1989).

7.3 The significance of burrowing during HCS deposition (Middle-Late Toarcian)

A sea-level fall during the Middle-Late Toarcian (Hallam 1988) probably favoured a sea bottom depth very close to the major storm wave base (approximately 80–100 m deep). Consequently, HCS beds may be diagnostic of an agitated, highly-oxygenated environment (Dam 1990). Trace fossils in the lower part of HCS beds are mainly monospecific and often with high burrow density (r- selected ichnotaxa of Ekdale 1985). Sedimentary structures indicate that the burrows were produced over a fairly short period of time and that the environment was inhospitable due to very uneven sediment accumulation rates and oscillatory currents. Therefore, the typical ichnocoenosis of storm-derived sediments comprises traces produced by opportunistic organisms in an unstable, high-stress, physically-controlled environment, where food supplies were abundant for short periods of time. When erosion strips away a soft and/or soupy superficial layer to expose a firmground, the sea floor can be occupied by characteristic groups of firmground-burrowers (Ekdale 1985). A progressive intensification of bioturbation levels from the MS to the RAUM units indicate that oxygen availability in bottom waters increased gradually through time (from the Lower to the Upper Toarcian) and dwelling organisms increased their penetration depth and occupied progressively deeper levels in the sediment column. Consequently, the organisms inhabiting the reddish and autochthonous nodular facies inter-HCS beds of the RAUM are large, diverse and very abundant, corresponding with the well-oxygenated conditions of Savrda & Bottjer (1986; 1989).

Fig. 18. **a** Trace fossils formed in turbiditic conditions, Lower Toarcian (Tenuicostatum Zone). A geometrically patterned burrow system (ornate horizontal forms mainly referred to Protopaleodictyon) is present as "semirelief" on the lower surface of a calcarenitic turbidite. **b** Other horizontal traces (mainly Thalassinoides) in the same turbiditic bed. **c** Ophiomorpha, Middle/Upper Toarcian transition. **d** Trace fossils formed during the waning phase of HCS event when continuous and strong oscillatory mouvements on the sea floor, involved variable periods of non-sedimentation and/or erosion, with exhumation of firmgrounds (Middle/Upper Toarcian transition, Erbaense Zone). The increasing penetration depth reflects a low sedimentation rate and testifies a favourable condition for several opportunistic firmground burrowers (mainly Skolithos, Chondrites, Planolites and Paleophycus).

8. Mineralogy and geochemistry

8.1 Methods

The following techniques were used for the mineralogical and geochemical studies:

a X-Ray diffraction. The samples were dried at room temperature. A homogeneous, representative part was ground and sieved to < 270 mesh ASTM (0.053 mm) and then used for the mineralogical study of the whole sample. Another part was used for extraction of the clay fraction. The equipment used was a Philips PW 1710 diffractometer with automatic slit (Department of Mineralogy and Petrology, University of Granada, Spain). The reflecting factors calculated for this equipment and its instrumental conditions on the basis of the data by Schultz (1964) and Barahona (1974) were: powder diffractograms (phyllosilicates, 0.09; quartz, 1.43; calcite, 1.05; feldspars, 1.03), oriented aggregate diffractograms (illite, 1; smectites, 2.80; chlorite, kaolinite, 2.75). The estimated error of the quantitative analysis is 5%.

b X-Ray fluorescence, neutron activation, inductively coupled plasma and atomic absorption spectrometry. These techniques were used for analyses of major and minor elements and rare-earth elements (REE) at the X-Ray Assay Laboratories in Ontario (Canada).

8.2 Results and the anoxic interval of deposition

The mineralogical results are shown in Figure 4, 5, 6 and 19. Table 3 and 4 show the data obtained from the chemical analyses.

The black shale levels in the Valdorbia section are located in the MS Formation, mainly in the upper part of Tenuicostatum Zone. In their description the stratigraphical intervals (s.i.) are those shown on Figure 20, related to the microfacies types. The black shale facies is mineralogically defined by an illite-smectite-quartz-feldspar major association and low contents of calcite and kaolinite. This is particularly characteristic of samples VD-359,8 to VD-375,8 (Fig. 19), especially the 369-359,2 stratigraphic interval.

The illite-smectite association, and to a lesser extent the kaolinite, should be interpreted as an indication of the detrital character of this facies. The same applies to the abundance of quartz and feldspars, the high values of the detrital index (D = 0.70–0.90) (Chamley 1989) and the Ce/Ce* ratio (0.85–1) (Courtois & Hoffert 1979).

The mineralogical associations of the layers lying above and below the most typical black shale facies are similar. The main difference is in the greater abundance of smectite in the samples from the top of 391,8-369 s.i in comparison to 204,6-190 s.i. (Fig. 20). We believe this indicates that the anoxic episode is perceptible in Tenuicostatum Zone, at least from level VD-382 up. On the other hand, black shale type facies ceased to be deposited from the beginning of 204,6-190 s.i. (Fig. 20).

From the geochemical point of view, the anoxic facies of Valdorbia is characterized by important anomalies in Ba, V, Cr, Ni, Co, Cu, Zn, As, Sb, and Pb (Tab. 3, Fig. 20). In addition they present higher contents of U (Tab. 3), REE (168–104 ppm in samples VD-368,5 and VD-371 respectively), MnO (up to 0.25%) and TiO_2 (0.41% to 0.86%). This geochemical facies therefore compares closely with that of Gavshin (1991) for Juras-

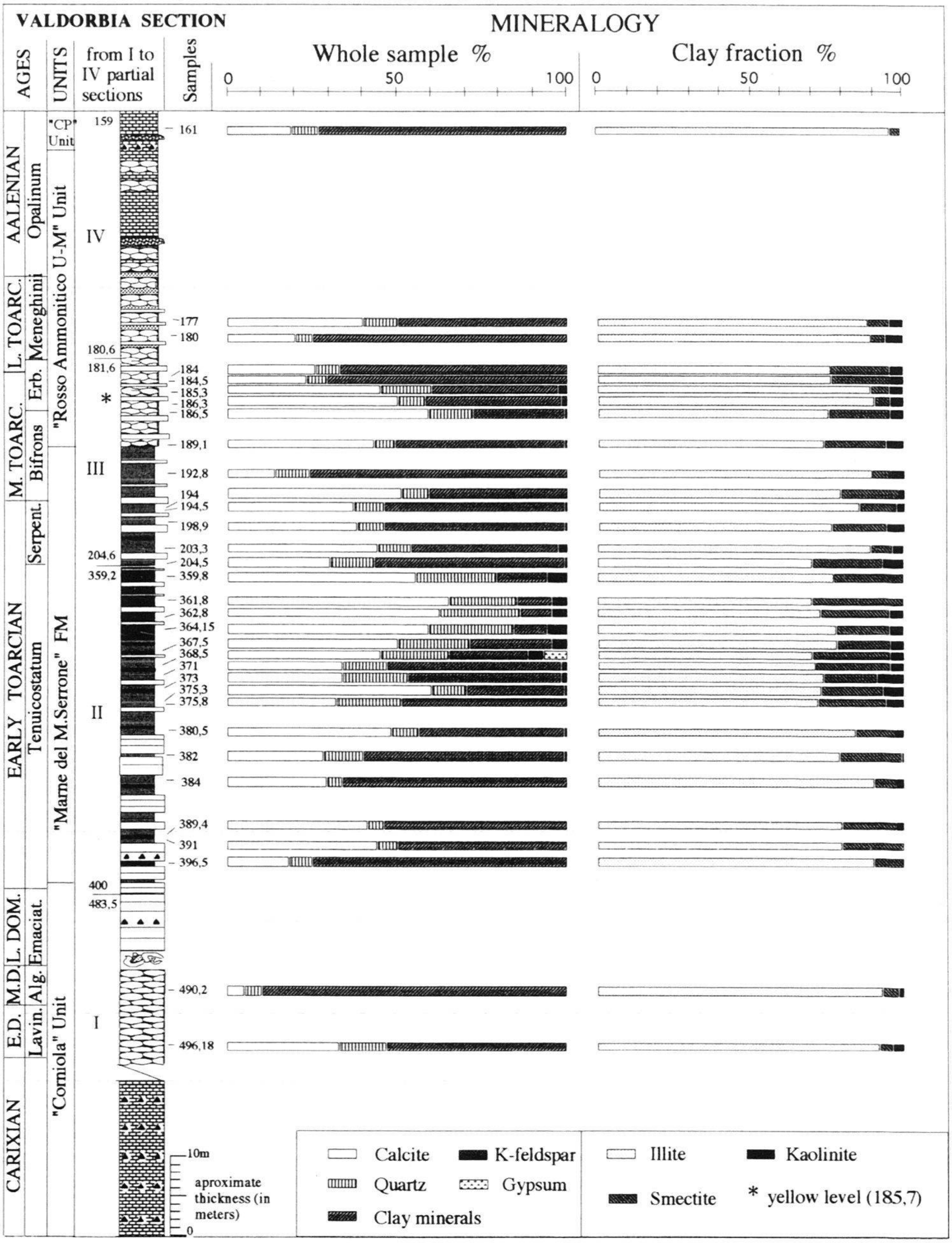


Fig. 19. Mineralogy of the studied samples.

sic black shales. This geochemical anomaly is also detected, although less strongly, down to the underlying VD-382 level.

In view of the mineralogical and geochemical data, we may conclude that the anoxic facies in the Valdorbia section begins within 391,8-369 s.i. (sample VD-382) and includes the interval up to the top of 369-359,2 s.i. (at least up to the sample VD-361,8). The degree of anoxia was not uniform, reaching maximum values in levels VD-364,15 and VD-362,8, where the organic contribution (carbonate content) is lowest. Therefore, since analysis in the field is not always sufficient, the geochemical anomalies described above are a valid chemical-stratigraphic criterion by which to delimit the anoxic levels in the Toarcian of the Apennines (central Italy). Similar anomalies have been described by Ortega-Huertas et al. (1993) for correlatable stratigraphic levels in the Pozzale and Pale Vallone sections.

The mineralogical and geochemical data indicate that these facies were deposited (Fig. 21) in a pelagic environment, in which restricted palaeogeographical subenvironments developed. It seems likely possible that the presence of physiographically subdivided environment encouraged the existence of calm subenvironments in which confined conditions formed with restricted water circulation. This agrees with the positive anomaly in B (Tab. 4), detected in the black shale samples in comparison with the other levels at Valdorbia. According to this model maximum restriction of circulation would have occurred in levels VD-364,15 and VD-362,8. Maximum anoxia conditions also occurred in these levels, according to other mineralogical and geochemical criteria mentioned above. This model also agrees with the values found for the La/Lu ratio (9.90 to 12), which are typical of pelagic environments, as indicated by Ronov et al. (1967). The ternary diagram of V-Cr-Ni, which are elements usually associated with a detrital origin, can be used to study the possible variations in input from the source area. Comparison of the V/Cr ratio in the Valdorbia (1.70), Pozzale (1.69), Monte Serrone (1.51) and Pale Vallone (1.49) sections indicates that the MS Formation as a whole was deposited under the influence of a homogeneous source area.

9. Discussion and conclusions

9.1 The Lower Toarcian anoxic event

The occurrence of black shales in the Valdorbia Section has been discussed by Baudin et al. (1990), Nocchi et al. (1991) and by Bartolini et al. (1992). These authors consider the laminated, pyrite-rich black sediments as evidence of the extension of the Early Toarcian anoxic event, widespread in the North European Jurassic shelves to the Umbria-Marche basin.

Geochemical, Total Organic Carbon content, micropaleontological data (see Fig. 9 and 5 in Bartolini et al. 1992) and trace fossils show that anoxia reaches the maximum in the upper part of the Tenuicostatum Zone, between 369 m and 360 m, with a peak around 364 m. However, the positive geochemical anomalies have revealed that the seafloor was poorly oxygenated in the older part of the Tenuicostatum Zone as well, at least from the 382 m level (Tab. 4). These data confirm that the abundance of small Eoguttulina's is indicative of a restricted and poorly ventilated environment but these forms become slightly less able to tolerate adverse bottom conditions than Paralingulina gr. tenera when the anoxia increases.

SAMPLES	Lithology	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	LOI
VD-161	CP	19,00	4,11	38,60	1,27	0,09	1,12	1,84	0,04	0,20	0,09	33,80
VD-177	RAUM	29,10	8,44	27,20	1,65	0,18	3,15	4,71	0,02	0,49	0,14	25,20
VD-180	RAUM	11,70	3,28	44,40	1,21	0,08	1,00	1,27	0,03	0,17	0,06	37,20
VD-184	RAUM	14,80	4,47	40,70	1,11	0,12	1,47	2,56	0,03	0,22	0,07	34,80
VD-184,5	RAUM	13,50	3,91	43,00	1,00	0,09	1,37	1,85	0,03	0,20	0,08	35,40
VD-185,3	RAUM	26,00	7,70	29,50	1,57	0,22	2,69	4,68	0,02	0,42	0,10	27,20
VD-186,3	RAUM	27,00	8,06	30,20	1,61	0,25	2,63	2,76	0,03	0,42	0,10	27,30
VD-186,5	RAUM	34,30	10,10	23,40	2,07	0,28	3,37	3,74	0,04	0,60	0,13	22,70
VD-189,1	RAUM	22,80	6,87	34,00	1,47	0,20	2,10	2,24	0,03	0,35	0,07	30,30
VD-194	MS	25,80	7,25	30,80	1,59	0,20	2,38	3,47	0,03	0,38	0,07	28,50
VD-198,9	MS	22,80	5,99	34,70	1,40	0,23	1,88	2,34	0,04	0,32	0,07	30,70
VD-203,3	MS	30,10	7,91	27,00	1,71	0,24	2,66	3,19	0,03	0,43	0,08	26,80
VD-361,8	MS	54,20	13,80	5,37	2,26	0,29	4,64	5,75	0,11	0,86	0,11	12,70
VD-362,8	MS	51,10	12,90	6,83	2,11	0,29	4,49	5,11	0,04	0,76	0,09	16,50
VD-364,15	MS	48,50	12,30	7,44	2,05	0,28	4,79	5,13	0,06	0,76	0,11	17,60
VD-368,5	MS	41,70	10,50	14,90	1,97	0,28	3,99	5,10	0,15	0,61	0,19	18,60
VD-371	MS	29,10	7,19	29,10	1,41	0,17	2,74	2,98	0,25	0,41	0,07	25,20
VD-375,8	MS	39,20	10,30	19,50	2,30	0,25	3,36	3,81	0,19	0,63	0,08	20,60
VD-380,5	MS	25,40	6,47	33,50	1,71	0,22	2,14	2,39	0,06	0,34	0,08	27,20
VD-382	MS	24,90	5,37	34,80	1,61	0,24	1,79	2,07	0,05	0,30	0,10	29,10
VD-384	MS	17,30	4,05	40,50	1,35	0,11	1,30	1,85	0,04	0,20	0,05	33,40
VD-391	MS	20,00	5,39	37,00	1,34	0,11	1,68	2,09	0,03	0,29	0,06	32,30
VD-396,5	MS	13,60	3,10	43,70	0,99	0,05	0,73	1,21	0,02	0,15	0,06	36,90
VD-490,2	COR	7,81	2,09	48,00	1,09	0,06	0,78	1,12	0,02	0,10	0,06	39,10
VD-496,18	COR	15,80	4,39	39,80	1,43	0,10	1,35	2,31	0,02	0,25	0,09	34,40

Tab. 3. Chemical analyses of the whole samples (%). LOI = Loss on ignition.

SAMPLES	Lithology	Ba	V	Cr	Ni	Cs	Hf	Ta	W	Pb	Th	Ge	Br	Mo	Ag	Cd
VD-161	CP	100	62	25	36	3	1,20	<1	<3	<2	2,90	20	4	<5	<0,5	<1
VD-177	RAUM	120	76	61	60	4	2,70	<1	<3	<2	6,20	<10	5	<5	<0,5	<1
VD-180	RAUM	100	38	26	21	2	1,00	<1	<3	<2	2,20	<10	6	<5	<0,5	<1
VD-184	RAUM	50	35	21	28	2	1,30	<1	<3	<2	2,90	<10	3	<5	<0,5	<1
VD-184,5	RAUM	60	29	27	22	2	0,90	<1	<3	7	2,80	<10	3	<5	<0,5	<1
VD-185,3	RAUM	127	78	46	30	4	2,20	<1	<3	<2	5,60	<10	2	<5	<0,5	<1
VD-186,3	RAUM	129	55	42	28	4	2,30	<1	<3	3	5,80	<10	3	<5	<0,5	<1
VD-186,5	RAUM	104	75	61	37	4	3,50	<1	<3	<2	8,00	15	3	<5	<0,5	<1
VD-189,1	RAUM	139	45	37	26	3	2,00	<1	<3	6	4,70	23	3	<5	<0,5	<1
VD-194	MS	137	47	35	26	3	2,00	1	<3	7	5,30	11	4	<5	<0,5	<1
VD-198,9	MS	117	40	30	27	2	1,80	<1	<3	5	4,50	<10	2	<5	<0,5	<1
VD-203,3	MS	162	76	46	19	3	2,50	<1	<3	4	5,70	<10	3	<5	<0,5	<1
VD-361,8	MS	314	112	74	54	5	4,20	1	<3	13	9,70	<10	4	<5	<0,5	<1
VD-362,8	MS	752	140	83	53	6	4,50	1	<3	8	10,00	<10	4	<5	<0,5	1
VD-364,15	MS	989	160	85	44	5	4,20	1	<3	8	9,30	<10	3	<5	<0,5	1
VD-368,5	MS	166	100	68	49	5	3,60	1	<3	4	1,80	<10	4	<5	<0,5	<1
VD-371	MS	157	76	42	22	3	2,60	1	<3	2	5,20	<10	3	<5	<0,5	<1
VD-375,8	MS	69	66	58	40	4	3,40	1	3	8	7,20	<10	3	<5	<0,5	<1
VD-380,5	MS	103	46	33	33	4	1,90	<1	<3	8	4,30	11	3	<5	<0,5	<1
VD-382	MS	119	43	29	24	3	1,90	<1	<3	<2	4,00	<10	2	<5	<0,5	1
VD-384	MS	42	32	21	22	2	1,10	<1	<3	<2	2,60	11	3	<5	<0,5	<1
VD-391	MS	85	38	30	23	3	1,50	<1	<3	<2	3,40	<10	3	<5	<0,5	<1
VD-396,5	MS	57	31	17	18	2	0,50	<1	<3	<2	1,80	16	3	<5	<0,5	<1
VD-490,2	COR	28	17	11	18	1	0,50	<1	<3	<2	1,40	10	2	<5	<0,5	<1
VD-496,18	COR	100	50	26	26	2	1,50	<1	<3	<2	3,20	<10	2	<5	<0,5	<1

SAMPLES	Lithology	Co	Cu	Zn	As	Se	Sb	B	U	Pb	Rb	Sr	Y	Zr	Nb	
VD-161	CP	11	16	32,00	<2	<3	0,5	50	0,60	<2	40	407	12	26	13	
VD-177	RAUM	12	20	69,00	2	<3	0,7	60	1,00	<2	80	204	40	89	15	
VD-180	RAUM	9	12	33,00	<2	<3	0,5	20	0,60	<2	30	252	<10	25	<10	
VD-184	RAUM	4	11	47,70	<10	<3	0,3	39	0,80	<2	40	270	<10	40	39	
VD-184,5	RAUM	5	10	31,70	<10	<3	0,5	44	0,90	7	33	243	<10	31	39	
VD-185,3	RAUM	7	9	45,00	3	<3	0,9	70	1,00	<2	62	201	<10	72	17	
VD-186,3	RAUM	6	104	39,80	<10	<3	0,4	60	1,70	3	58	187	20	82	31	
VD-186,5	RAUM	8	30	68,70	15	<3	0,5	102	1,70	<2	85	194	23	106	37	
VD-189,1	RAUM	7	26	112,00	23	<3	0,4	56	1,60	6	47	229	16	55	27	
VD-194	MS	6	16	46,70	11	<3	0,4	74	1,10	7	56	268	<10	68	25	
VD-198,9	MS	8	16	42,20	<10	<3	0,3	43	1,10	5	43	321	<10	67	33	
VD-203,3	MS	7	16	37,00	<2	<3	0,4	60	1,00	4	72	294	15	861	26	
VD-361,8	MS	19	56	58,90	<10	<3	1,4	96	2,30	13	109	151	32	67	42	
VD-362,8	MS	18	47	92,00	11	<3	1,7	100	2,50	8	95	233	12	162	24	
VD-364,15	MS	19	46	69,00	12	<3	1,8	110	2,50	8	100	180	26	142	16	
VD-368,5	MS	19	46	71,00	11	<3	1,3	80	1,80	4	74	241	<10	121	<10	
VD-371	MS	10	22	37,00	4	<3	0,8	60	1,10	2	52	353	26	70	15	
VD-375,8	MS	14	32	32,00	<10	<3	0,6	79	1,90	8	81	295	24	131	31	
VD-380,5	MS	7	24	125,00	11	<3	0,7	69	1,40	8	54	331	<10	53	32	
VD-382	MS	7	21	37,10	<10	<3	0,5	78	1,40	<2	42	314	<10	62	30	
VD-384	MS	6	14	22,80	11	<3	0,3	81	0,70	<2	26	349	<10	32	11	
VD-391	MS	7	23	31,70	<10	<3	0,3	64	1,20	<2	39	311	<10	40	24	
VD-396,5	MS								0,90	<2	19	315	11	21	30	
VD-490,2	COR	3	18	41,70	10	<3	0,3	34	<0,5	<2	18	222	<10	19	21	
VD-496,18	COR	6	11	36,00	<2	<3	0,4	50	0,60	<2	40	213	<10	47	15	

Tab. 4. Chemical analyses of the whole samples (ppm).

AGE	Stratigraphic units	microfacies	Stratigr. interv. (m)	Characteristics	Turbidites	Gravity flow dep.	HCS beds	Winnowed beds	Trace fossils	Mineralogy	Geochemical anomalies	Autochthonous organisms	Allochthonous organisms
				LITHOFACIES and BIOFACIES									
AA1	CP – RAUM	9	159 – 174,5	well-bedded mudstones & sporadic floatstones	fine-grained turbidites very rare	pebbly mud-flows prevailing	absent	absent	rare *Chondrites*	Cal - Ill	absent	filaments (bivalves) and radiolarians	intraclasts with ammonites, microgastropods and brachiopods, large ostracods & *Lenticulina*; radiolarians
AA 1 – TO 5	RAUM	8	174,5 – 179	well-bedded mudstones with nodular horizons	absent	absent	sharp-based HCS (20 - 40 cm thick); oscillatory ripples	thin WB (3 - 8 cm thick) in the lower part	*Thalassinoides*, *Ophiomorpha*, *Chondrites*, *Paleophycus*, *Planolites*. Vertical tr. abundant.	Cal - Ill - (Sm - Kln - Qz - K feldspar)	absent	Bivalves with shelter porosity; microgastropods and brachiopods, ammonites, echinoderms, *Lenticulina*, radiolarians	absent
TO 5 – TO 3	RAUM	7	179 – 190	nodular bioturbated mudstones; fine-grained packstones	absent	absent	sharp-based HCS (20 - 40 cm thick); oscillatory ripples	thin WB (3 - 8 cm thick)	*Thalassinoides*, *Ophiomorpha*, *Chondrites*, *Paleophycus*, *Planolites*. Vertical tr. abundant.			echinoderms, filaments (bivalves) from m 189 going upwards. Globochaete, Lagenina, *Haplophragmoides*	rare *Planiinvoluta*, Verneulinidae. *Paralingulina* gr. *tenera*, Cornuspiracea, fecal pellets, small oolites in the lower part
TO 3 – TO 2	MS	6	190 – 204,6	fine-grained packstones interbedded with shales	low-density turbidites (calcisiltites)	absent	absent	absent	*Chondrites*. Prevailing horizontal traces on the bottom of turbidites	Cal - Ill - (Sm - Qz)	absent		
TO 1	MS	5	359,2 – 369	black shales	low-density turbidites (calcilutites)	absent	absent	absent	Very rare or absent	Ill - Sm - Qz - K feldspar - (Cal - Kln)	Strong positive anomalie in Ba, V, Cr, Ni, Co, Cu, Zn, As, Sb and Pb.	radiolarians; rare echinoderms and Lagenina	absent
TO 1	MS	4	369 – 391,8	fine- to coarse-grained packstones interbedded with shales	low- to high-density turbidites (calcarenite/rudites)	mud flow deposits (rare)	absent	absent	*Chondrites*. Ornate horiz. forms (*Protopaleodictyon*) on the bottom of turbidites	Cal - Ill - Sm - Qz - (Kln)	Weak positive anomalie in Ba, V, Cr, Ni, Co, Cu, Zn, As, Sb and Pb at the top of this interval	only radiolarians at m 378,8 and 375,5; rare Lagenina, *Prodentalina*, *Marginulina*, large vaginulinids, *Lenticulina*	Miliolina, Cornuspiracea, *Agerina martana*, *Ophthalmidium*, *Planiinvoluta*, Verneulinidae; oolites and coated grains, fecal pellets, green algae
TO 1 – DO 3	MS – COR	3	391,8 – 488,9	homogeneous, fine-grained packstones	low to high-density turbidites (calcisiltite/arenite)	debris flows, pebbly mud flows & slumps	HCS in the upper part of some high-density turbiditic beds	absent	*Chondrites*. Ornate horiz. forms (*Protopaleodictyon*) on the bottom of turbidites	Cal - Ill - (Sm - Qz)	absent	rare organisms: calcispherulids, radiolar., Lagenina (*Paralingulina*), echinoderms, ostracods, belemnites (rare)	crinoid fragments and peloids
DO 2 – DO 1	COR	2	488,9 – 500	nodular bioturbated mudstones	absent	thin debris flows (20 cm thick)	absent	absent	Prevailing *Chondrites* and *Planolites*	Cal - Ill	absent	decrease in the organic content, *Ammodiscus*, Lagenina, gastropods, ostracods, ammonites, radiolarians, echinoderms	absent
CAR IX.	COR	1	510 – 530	well bedded wackestones / packstones with chert	low-density turbidites very rare	absent	absent	absent	rare *Chondrites*	without data	without data	Lagenina, *Paralingulina*, *Marginulina* gr. *prima*, Miliolina, gastropods, large echinoid spines, radiolarians, ostracods	large calcareous sponge spicules, crinoid articles, scattered peloids

Fig. 20. Comparative scheme between lithofacies and biofacies, including selected mineralogical and geochemical data.

Therefore the reduced oxygenation conditions are more extensive in time than is indicated by the extent of the black shales facies. Calm, confined environments with restricted circulation are therefore represented also by sediments other than those containing black shales.

9.2 Reworking

The Valdorbia area, during the Early Jurassic, was a depressed area where detrital material accumulated by means of different types of transport. Thus the study of the micropaleontological and sedimentological features provides useful information concerning the reworking mechanisms that occurred, throughout the time, and the original environment of the microfossils (Fig. 20). By comparing of the organic content of the microfacies with that of the incoherent sediments, it can be seen that porcellaneous foraminifers, occurring within the detrital limestones, are absent in the marls and hence are allochthonous.

a Carixian – Early Domerian. Episodic muddy turbidites occur and microfaunal content could be autochthonous or from surrounding elevated areas or both. During the Middle Domerian nodular bioturbated facies testify to a normal pelagic deposition with low sedimentation rates and autochthonous faunas.
b Middle/Late Domerian. An abrupt increase in detrital supply due to mass flow deposits and slumping occurs at this time. These deposits contain intrabasinal microfossils indicating that reworking was local and isochronous. These features are probably linked to local sea-floor instability in the Valdorbia area.
c Early Toarcian (Tenuicostatum Zone). An increase in the thickness of detrital beds, and in the grain fraction of calcarenites/rudites occur. Moreover these beds contain oolites, coated grains and calcareous algae fragments. They are reworked from a (older?) carbonate platform, mixed with other fossils characteristic of shallow-water areas such as Miliolina (Fig. 20). The porcellaneous microforaminifers occurring within the detrital limestones are not present in the soft sediments such as marls. Ophthalmidium, Agerina martana and other Cornuspiracea are allochthonous within the Toarcian interval of time, and probably derive from the Pliensbachian assemblage A, characteristic of the relatively shallow water sediments, deposited after the drowning of the "Calcare Massicio" carbonate platform. Agerina martana, in fact, is considered a Pliensbachian microfossil. In the upper part of the Tenuicostatum Zone the detrital supply decreases considerably, corresponding to the black shale deposition. The arenitic fraction consists mainly of radiolarians.
d Early/Middle Toarcian (Serpentinus – Bifrons Zones). Low-density, fine-grained calcarenites still contain reworked microfossils and rare, small oolites. Reworked material decreases in the upper part of this interval.
e Middle/Late Toarcian (Bifrons and Erbaense Zones). HCS calcarenites are characterized by crinoidal fragments, peloids and porcellaneous foraminifers, such as Planiinvoluta. The depositional environment of Planiinvoluta (Leischner 1961) is rather uncertain. This sessile foraminifer was cited as Glomospira by Radoicic (1966) in the shallow-water carbonate platform of the external Dinarids, middle-upper Early Jurassic in age. Wernli (1971) on the other hand, does not exclude a deeper distribution of

this form in his discussion on the paleoecology of Planiinvoluta. In the Valdorbia Section, it has been found associated with Ophthalmididae and Agerina both in the Carixian and in the reworked microfauna within Lower-Middle Toarcian sediments. The source of this material could be either an open platform or structural highs in the surrounding area, although Planiinvoluta and Miliolina have never been found in the Toarcian of the Umbria-Marche area.

f Late Toarcian-Early Aalenian (Meneghinii-base of Opalinum Zones). Nodular and autochthonous bioturbated facies containing abundant bivalve concentrations with shelter porosity. Winnowed beds, and large trace fossils are common and abraded Lenticulina's seem to indicate a high energy or well oxygenated sea-bottom, due to proximity to a major storm wave base, lacking in extrabasinal detrital input.

g Early Aalenian (Opalinum Zone). Reworking phenomena are confined to the local area and pebbly mudstone deposits seem to be connected with local sea-floor instability. Turbidites are very rare.

9.3 Depositional trends

In the Valdorbia Section different trends are recognized in the sedimentological, microfaunal and geochemical studies (Fig. 21).

a The microfaunal assemblages indicate a deepening trend from Carixian – Early Domerian to the early part of the Toarcian (base of Tenuicostatum Zone), where the microfaunal assemblage and the presence of the illite-smectite association give indications of the maximum depth (and reworking) reached by the basin at the beginning of the Toarcian (Fig. 21). The absence of kaolinite supports the hypothesis of a relatively deep marine environment.

b The major factor affecting the microfauna within the Tenuicostatum Zone is a lack of oxygen which prevents recognition of any depositional trend. A fining-upward trend is recognizable, by means of sedimentological analysis, from the Tenuicostatum to the Serpentinus Zones. Coarse-grained, high-density calcarenitic turbidites were overlain by thin, fine-grained planar-bedded calcisiltitic turbidites during the maximum black shale deposition (see Fig. 14, 20 and 21). The persistent, relative deep conditions during the black shale deposition is indicated by the greater abundance of smectite and the continuing scarcity of kaolinite and by the ornate burrow-systems. As mentioned in 9.1, it is clear that, together with the continuity of a deep depositional environment, confined areas of restricted water circulation also existed in which the black shales were deposited.

c After the period of poorly ventilated sea-bottom conditions (Serpentinus Zone), the microfaunal assemblages indicate a slow improvement in the oxygenation level. A relative shallowing began from the lower part of the Bifrons Zone and reached a maximum at the end of the Toarcian (Meneghinii Zone) (Fig. 21), as shown by the continuous reduction in smectite content. An abrupt change in the environmental conditions is evident at the Bifrons/Erbaense zonal boundary. From the sedimentological point of view a shallowing-upward trend from the Serpentinus Zone to the the upper part of the Toarcian (Meneghinii Zone) is observed. Planar-bedded calcisiltitic turbidites are overlain by sharp-based HCS calcarenites and, finally, by winnowed beds

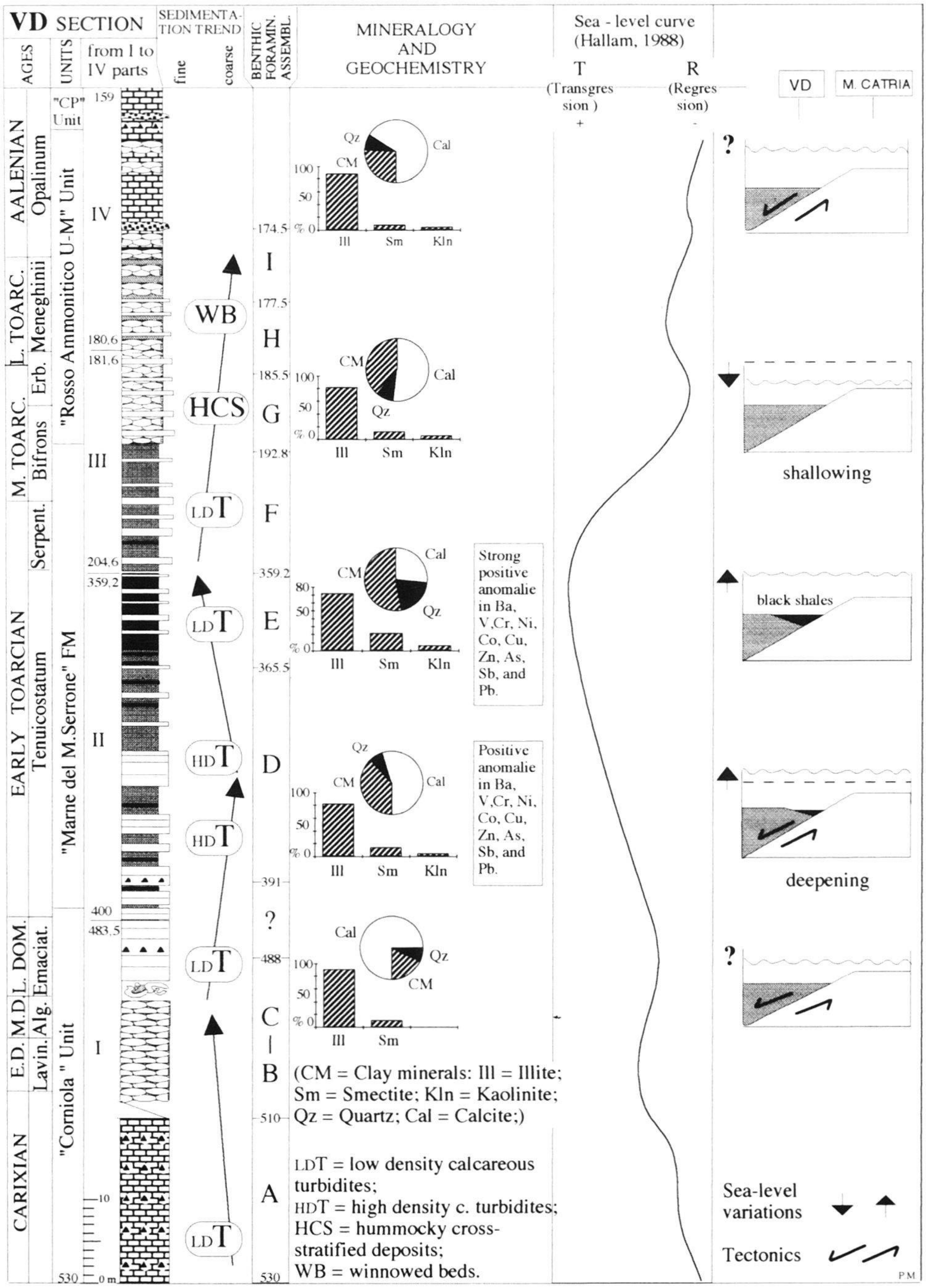


Fig. 21. Valdorbia Section related to the Hallam (1988) eustatic curve. Tectonic and eustacy interpretations have been reported on the right side, according to despositional trends, mineralogy and geochemistry.

(Fig. 14, 20 and 21). The sharp-based HCS calcarenites were probably formed under very rare, unusually stormy conditions that caused a strong oscillatory flow regime near the bottom during the Middle and Upper Toarcian. Characteristic abrasion surfaces on some benthic foraminiferal tests seem to be due to oscillatory conditions at the sediment/water interface during the deposition of the winnowed beds (Fig. 13). The minimum depth and sedimentation rate of the depositional environment was reached in the upper part of the Toarcian and corresponds roughly to an outer/middle shelf environment, near the major storm wave base (Fig. 21). Moreover in the Erbaense-Meneghinii Zones the succession is strongly condensed – testified by repeated hardgrounds – and represented by sediments only 7.5 m thick, in comparison with the Tenuicostatum-Bifrons Zones where deposits 60 m thick occur.

9.4 Tectonics and eustacy

The microforaminiferal assemblage BC present at the boundary between Corniola and Marne del M. Serrone is lacking in the Valdorbia area where Glomospirella disappears in the Upper Domerian, earlier than in the other areas. At the Domerian/Toarcian boundary slumps, mass-flow and calcareous turbidites occur. These sedimentary features can be interpreted as indicative of regional synsedimentary tectonics rather than a eustatic lowstand phase because this sedimentological character seems to be relatively local. Hence, the Domerian regressive stage expressed in the eustatic curve of Hallam (1988) is not evident in this area, probably because of local tectonic activity of M.Catria-Valdorbia area (Fig. 21).

The deepening found in the Tenuicostatum Zone can be connected to sea-level rise (Hallam 1967), according to the Jurassic eustatic curve of Hallam (1988), and/or to an increase in the rate of the subsidence (Fig. 21). In fact the degree of reworking reaches its maximum intensity in the Lower Toarcian.

The shallowing trend suggested for the Middle/Late Toarcian fits better into a geological context clearly affected by a regressive phase (Hallam 1988), than into one affected by tectonic activity (Fig. 21). In fact a regressive-shallowing can be considered to be widespread in the central Apennines, as in the Umbria-Marche basin and the Lazio-Abruzzi carbonate platform area (Giannini et al. 1970; Colacicchi & Bigozzi 1992). Mass-flow deposits which occurred in the Lower Aalenian are widely scattered in the Umbria-Marche area (M. Cucco, M. Serrone, Narni-Amelia ridge, M. Martani) and seem to reflect regional sea-floor instability. The cause of these features is still uncertain, although the Aalenian regression is probably the result of Western Tethys tectonics (Hallam 1988).

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Plate 1

Fig. 1. Wackestone with large calcareous sponge spicules and Lingulonodosaria cf. ovalis. Sample VD 514 (Carixian). × 80.

Fig. 2. Wackestone with large recrystallized echinoid remains and Paralingulina cf. pupiformis (axial lateral view). S. VD 510 (Carixian). × 95.

Fig. 3. Echinoid remains and calcareous sponge spicules. Same sample. × 10.

Fig. 4. High-spired sculptured gastropods. S. VD 499 (Carixian). × 95.

Fig. 5. Finely agglutinated Ammodiscidae (Usbekistaniinae?) with a calcitic cement. S. VD 530 (Carixian). × 85.

Fig. 6. Palniinvoluta aff. P. carinata Leischner. S. VD 525 (Carixian). × 85.

Fig. 7. Verneulinidae. S. VD 511 (Carixian). × 90.

Fig. 8. Miliolidae (Quinqueloculina). S. VD 519 (Carixian). × 105.

Fig. 9. Planiinvoluta aff. P. carinata. S. VD 521 (Carixian). × 85.

Fig. 10. Agerina martana. S. VD 511 (Carixian). × 100.

Fig. 11. Ophthalmidium sp.. S. VD 521 (Carixian). × 85.

Fig. 12. Paralingulina tenera tenera (transverse section). S VD 527 (Carixian). × 70.

Fig. 13 and 14. Paralingulina cf. pupiformis (lateral and frontal sections). S. VD 511 (Carixian). × 85.

Fig. 15. Thick ostracod carapace (tranverse section). S. VD 495 (Lower Domerian). × 45.

Fig. 16. Icthyolaridae. S. VD 491 (Middle Domerian). × 70.

Fig. 17. Repmanina charoides corona (siliceous test). S. 492 (Middle Domerian). × 105.

Fig. 18. Ammodiscus cf. siliceous (siliceous test). S. VD 493 (Middle Domerian). × 80.

Fig. 19. Mudstone-wackestone yielding ammonite nuclei, small gastropods and echinoid remains. S. VD 498 (Carixian/Domerian transition). × 10.

Fig. 20. Bioturbated mudstone, wackestone with ostracods. lenticulinas and echinoderm remains. S. VD 494.4 (Lower/Middle Domerian). × 10.

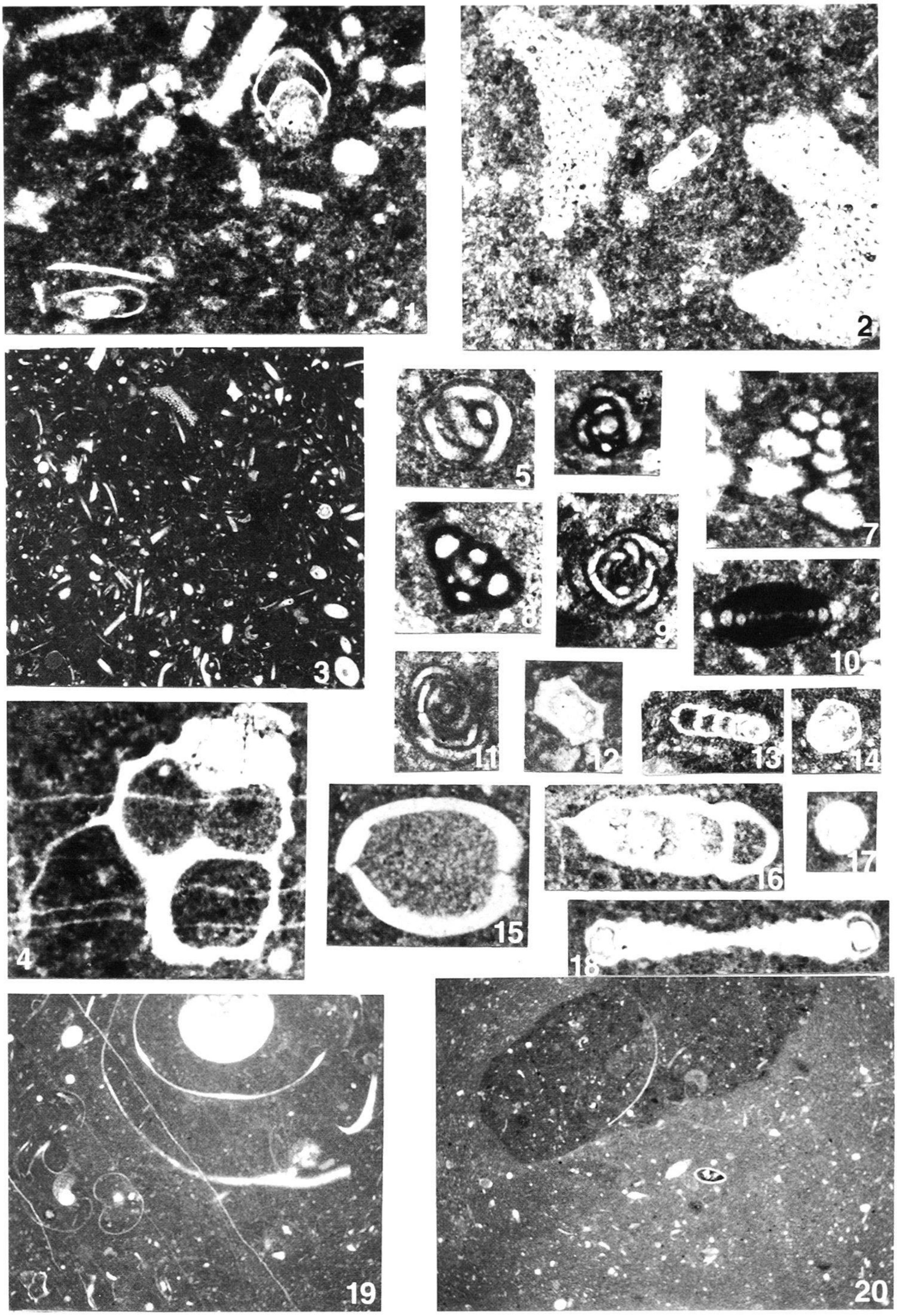

Plate 1: Microfacies 1 (Fig. 1, 2, 3, 5–14) and 2 (Fig. 4, 15–20).

Plate 2

Fig. 1. Planar-bedded and densely packed echinoderm and peloidal calcarenite. Sample VD 399 (Lower Toarcian). × 25.

Fig. 2. Fine-grained packstone. S. VD 399.6 (Lower Toarcian). × 25.

Fi.g 3. Grainstone with coated grains and Planiinvoluta (?). S. VD 389 (Lower Toarcian). × 35.

Fig. 4. Grainstone with coated grains and fecal pellets. S. VD 375,1 (Lower Toarcian). × 35.

Fig. 5. Recrystalized bioclastic packstone containing large lituolidae and echinoid fragments. S. VD 389 (Lower Toarcian). × 30.

Fig. 6. Green alga bioclast. Same sample. × 25.

Fig. 7. Ataxophragmiidae, Planiinvoluta (?) and other bioclasts. Same sample. × 30.

Fig. 8. Graded wackestone-packstone with radiolarians and flat, thin bivalves. S. VD 378,8 (Lower Toarcian). × 20.

Fig. 9. Grainstone containing ooids, peloids and skeletal fragments. S. VD 389 (Lower Toarcian). × 35.

Fig. 10. Calcified radiolarians and pyritized grains. S. VD 363 (Lower Toarcian). × 115.

Fig. 11 and 12. Planiinvoluta sp. S. VD 375,10 (Lower Toarcian). × 70.

Fig. 13. Planiinvoluta sp. (attached side of the right). S. VD 387 (Lower Toarcian). × 100.

Fig. 14. Radiolarian packstone. S. VD 368 (Lower Toarcian). × 25.

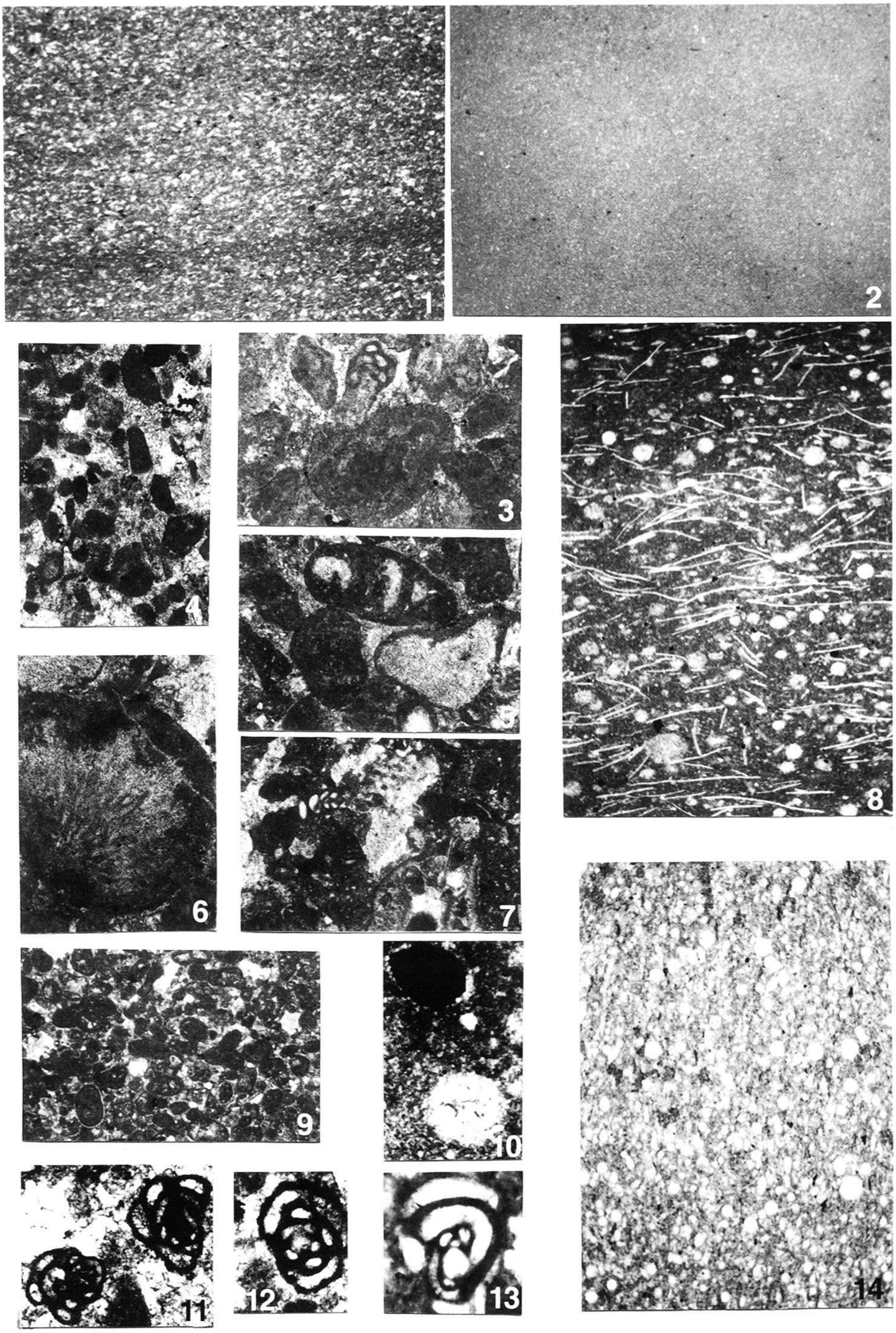

Plate 2: Microfacies 3 (Fig. 1 and 2), 4 (Fig. 3–9, 11–13) and 5 (Fig. 10 and 14).

Plate 3

Fig. 1. Bivalve and peloidal packstone. Sample VD 189 (Middle Toarcian). × 80.

Fig. 2. Planiinvoluta aff. P. carinata. S. VD 204 (Lower Toarcian). × 85.

Fig. 3. Planiinvoluta (?). S. VD 180 (Upper Toarcian). × 85.

Fig. 4. Peloidal grainstone with Earlandia sp. S. VD 189 (Middle Toarcian). × 100.

Fig. 5 and 6. Wackestone-packstone containing bivalve shells, small gastropods, echinoderm remains and ammonite nuclei. Geopetal fabrics (shelter porosity) are common below convexly embedded shells. S. VD 177 (Upper Toarcian). × 15.

Fig. 7, 8 and 9. Wackestone-packstone similar to the sample VD 177. Radiolarians are common. S. VD 178 (Upper Toarcian). × 15.

Fig. 10. Bivalve packstone containing large (1 to 3 cm) intraclast with radiolarian and bivalve remains. S. VD 174,5 (Aalenian). × 10.

Fig. 11. Densely packed flat bivalve deposits. S. VD 161,5 (Aalenian). × 10.

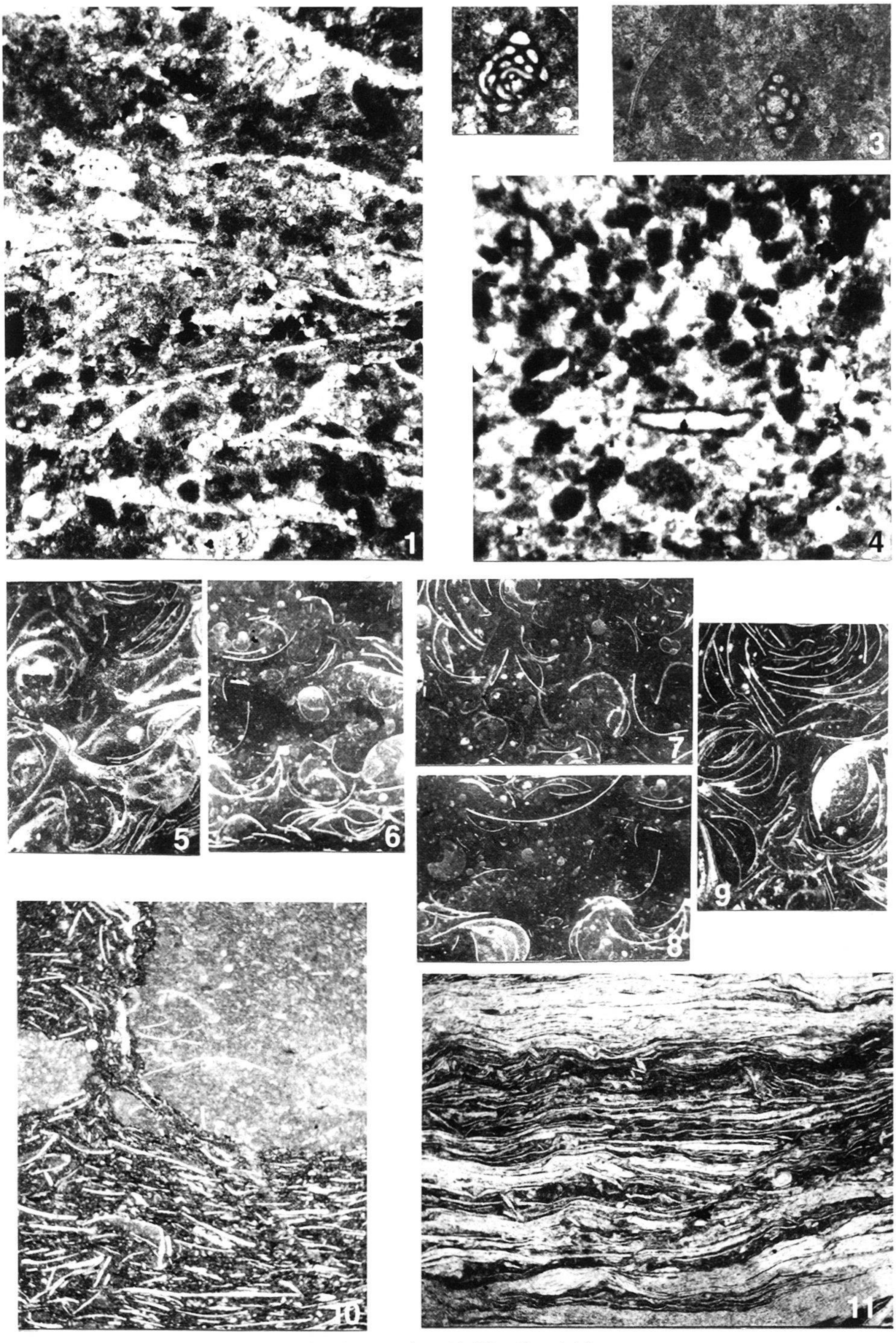

Plate 3: Microfacies 6 (Fig. 1, 3 and 4), 8 (Fig. 5–9) and 9 (Fig. 10 and 11).

Plate 4

Fig. 1. Jaculella liasica. Sample VD 496.18 (Lower Domerian). × 111.

Fig. 2. Repmania charoides corona. S. VD 498 (Carixian/Domerian transition). × 200.

Fig. 3. Glomospira variabilis. S. VD 496.18 (Lower Domerian). × 121.

Fig. 4. Jaculella anulata (side view). S. VD 488.9 (Upper Domerian). × 64.

Fig. 5. Same specimen (oblique apertural view).

Fig. 6. Glomospirella gaultina. S. VD 496.18 (Lower Domerian). × 127.

Fig. 7. Glomospirella sp. 1. S. VD 488.9 (Upper Domerian). × 121.

Fig. 8. Prodentalina cf. constricta (side view). S. VD 373 (Lower Toarcian). × 140.

Fig. 9. Same specimen (apertural view).

Fig. 10. Paralingulina tenera praepupa (oblique apertural view). S. VD 373 (Lower Toarcian).

Fig. 11. Same specimen (side view) × 147.

Fig. 12. Tristix liasina (side view). S. VD 372.5 (Lower Toarcian). × 272.

Fig. 13. Same specimen (lateral face view).

Fig. 14. Prodentalina compressa (side view). S. VD 371 (Lower Toarcian). × 123.

Fig. 15. Same specimen (front view).

Fig. 16. Same specimen (dorso-apertural view).

Fig. 17. Lingulonodosaria dentaliniformis (side view). S. VD 373 (Lower Toarcian). × 126.

Fig. 18. Same specimen (oblique apertural view).

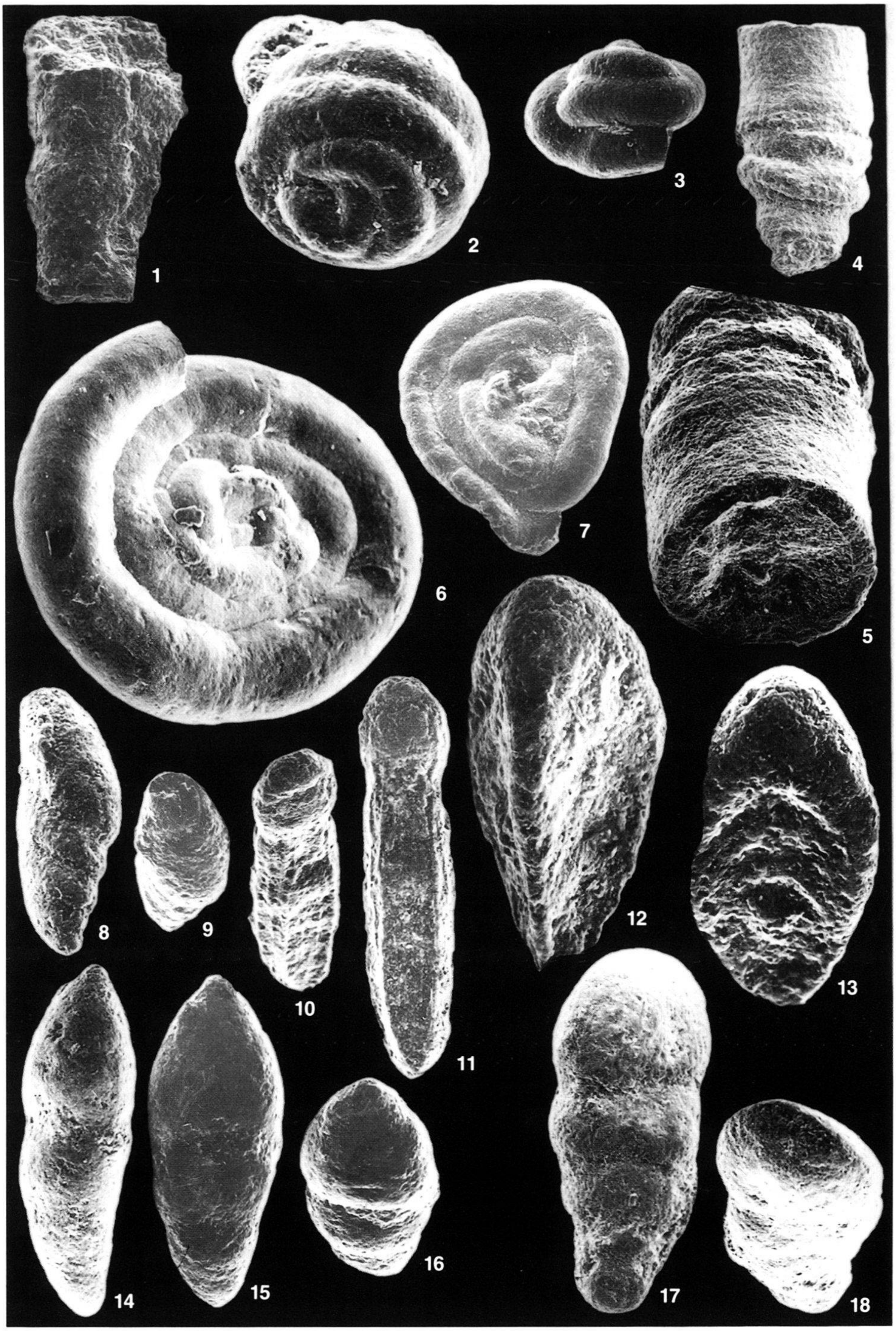

Plate 4: Carixian, Domerian and Lower Toarcian (Tenuicostatum Zone) microforaminifers.

Plate 5

Fig. 1. Reinholdella planiconvexa (dorsal view). S. VD 360.9 (Lower Toarcian, Tenuicostatum Zone). × 131.

Fig. 2. Same species (side view), second specimen. Same sample.

Fig. 3. Same species (ventral view), third specimen. Same sample.

Fig. 4. Conicospirillina sp. (dorsal view). S. VD 185.2 (Middle Toarcian, Erbaense Zone). × 130.

Fig. 5. Same specimen (edge view).

Fig. 6. Same specimen (ventral view).

Fig. 7. Ammobaculites cfr. vetusta, S. VD 185.3 (Middle Toarcian, Erbaense Zone). × 128.

Fig. 8. Haplophragmoides kingakensis (side view). S. VD 185.3 (Middle Toarcian, Erbaense Zone). × 61.

Fig. 9. Same specimen (apertural view).

Fig. 10. Lenticulina (Astacolus) d'orbignyi (side view). S. VD 185.5 (Middle Toarcian, Erbaense Zone). × 55.

Fig. 11. Same specimen (edge view).

Fig. 12. Astacolus cf. stilla. S. VD 185.5 (Middle Toarcian, Erbaense Zone). × 38.

Fig. 13. Astacolus gr. pennensis. Same sample × 67.

Fig. 14. Vaginulinopsis deeckei parallela. S. VD 185.3 (Middle Toarcian, Erbaense Zone). × 62.

Fig. 15. Vaginulinopsis sp. (edge view). S. VD 185.5 (Middle Toarcian, Bifrons Zone).

Fig. 16. Same specimen (side view). × 52.

Fig. 17. Falsopalmula tenuistriata. S. VD 177 (Lower Aalenian). × 54.

Fig. 18. Astacolus dictyoides (side view). Same sample. × 62.

Fig. 19. Same specimen (oblique apertural view).

Fig. 20. Lenticulina (Astacolus) d'orbignyi. S. VD 181.3 (Upper Toarcian, Meneghinii Zone). × 51.

Fig. 21. Astacolus similis. S. VD 192.8 (Middle Toarcian, Bifrons Zone). × 107.

Fig. 22. Astacolus mutabilis. S. VD 184.5 (Middle/Upper Toarcian, Erbaense). × 66.

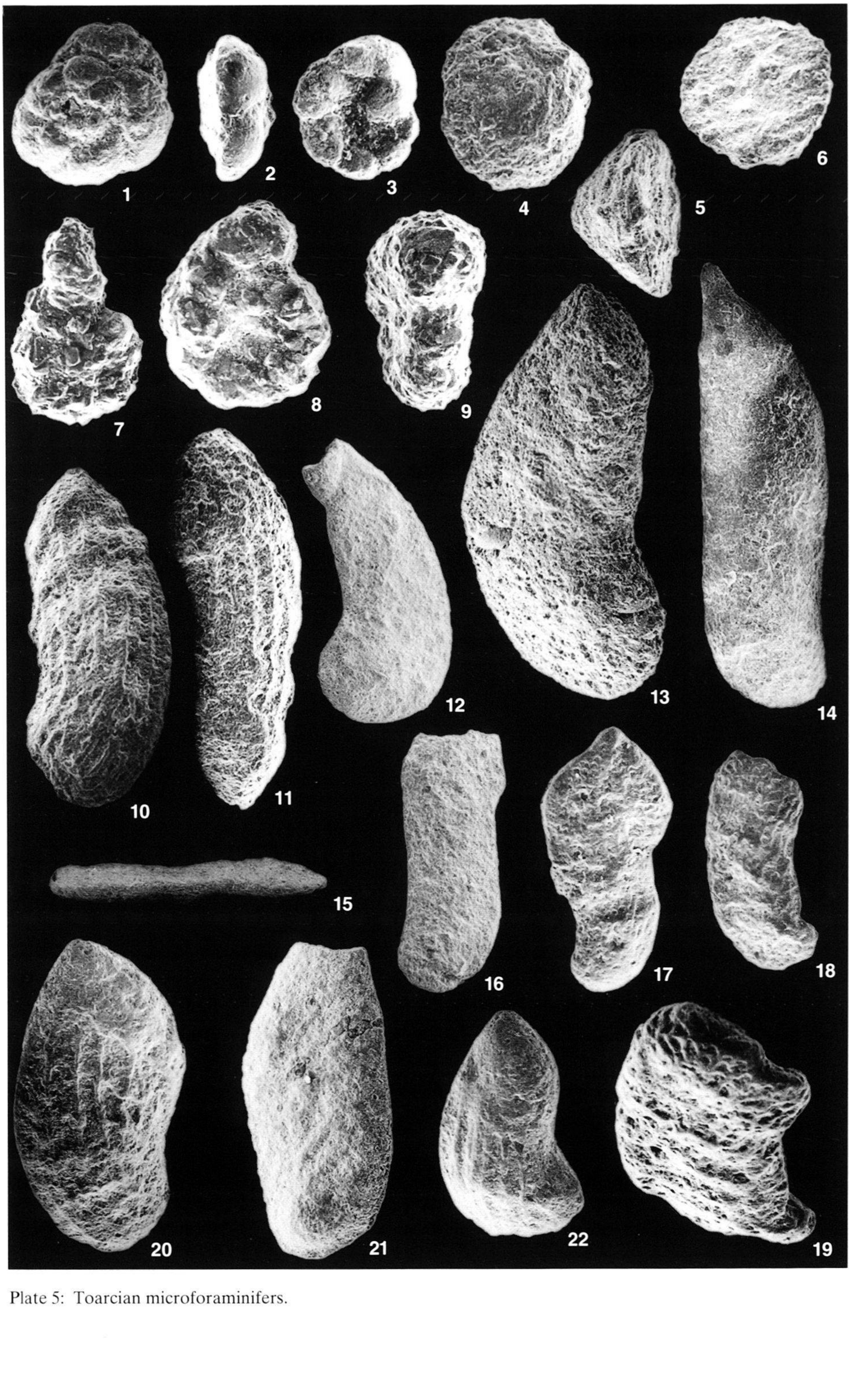

Plate 5: Toarcian microforaminifers.

Plate 6

Fig. 1. "Cigar-shaped" Lenticulina münsteri (axial view). Sample VD 184.3 (Upper Toarcian, Erbaense Zone). × 45.

Fig. 2. Same specimen (oblique view).

Fig. 3. Abraded Lenticulina sp. Sample VD 184.3 (Upper Toarcian, Erbaense Zone). × 73.

Fig. 4. "Cigar-shaped" Lenticulina sp.. Same sample. × 60.

Fig. 5. Spiriferiina (?) (brachial valve). S. VD 185.3 (Middle Toarcian, Erbaense Zone). × 30.

Fig. 6. Camptocythere toarciana (left side). S. VD 184.5 (Middle/Upper Toarcian, Erbaense Zone). × 50.

Fig. 7. Procytherura multicostata (left side). Same sample. × 190.

Fig. 8. Low-trochospiral gastropod. S. VD 186.5 (Middle Toarcian, Brifrons Zone). × 100.

Fig. 9. Bivalve (Posidonidae). S. VD 185.3 (Middle Toarcian, Erbaense Zone). × 30.

Fig. 10. Stenestroemia (?) sp. (left side). S. VD 373 (Lower Toarcian, Tenuicostatum Zone). × 240.

Fig. 11. Monoceratina sp (left side). Same sample. × 154.

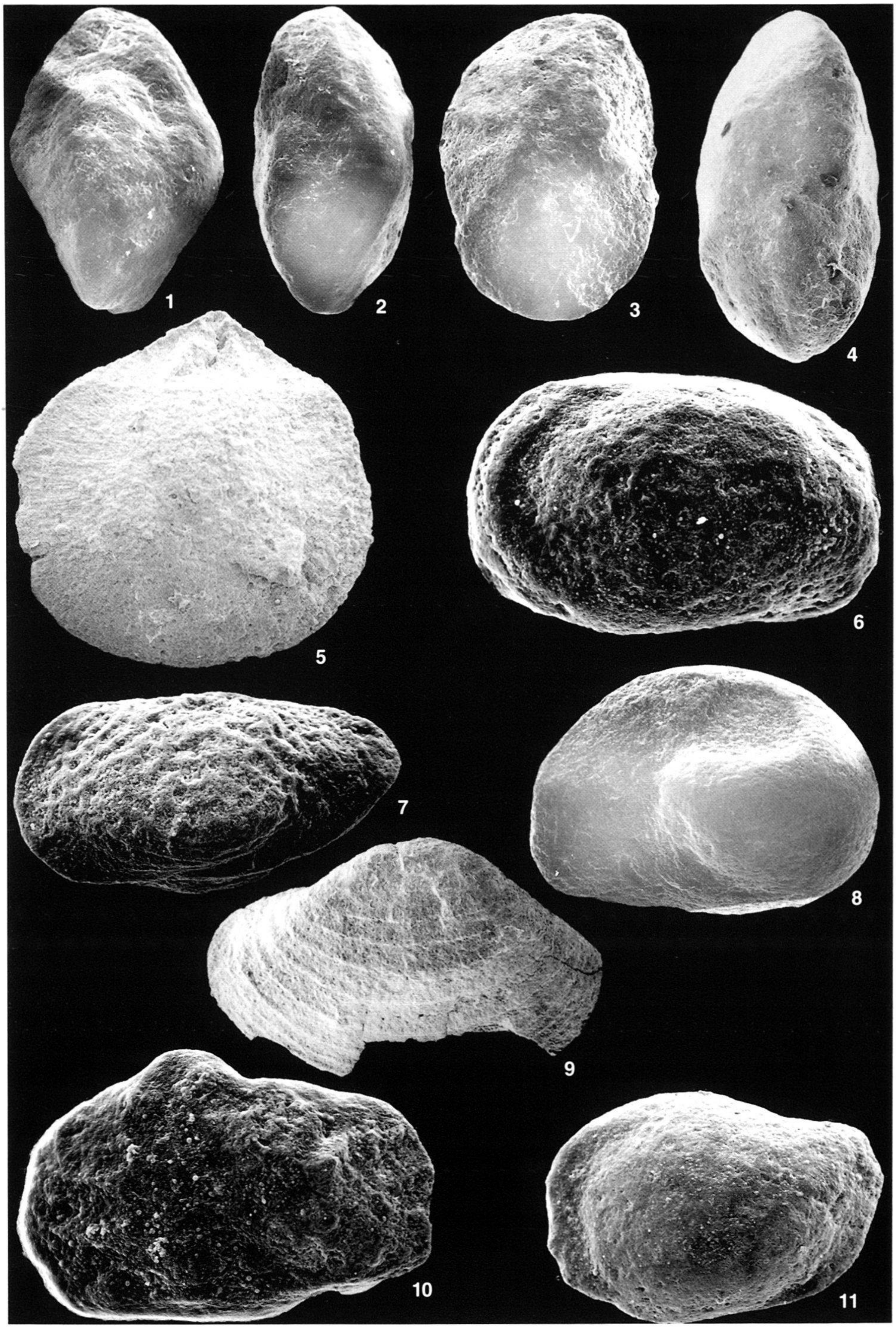

Plate 6: Abraded Lenticulina and other organisms.