

**UTRECHT
MICROPALAEONTOLOGICAL
BULLETINS**

B. STAM

**QUANTITATIVE ANALYSIS OF MIDDLE AND LATE JURASSIC
FORAMINIFERA FROM PORTUGAL AND ITS IMPLICATIONS FOR
THE GRAND BANKS OF NEWFOUNDLAND**

34

UTRECHT MICROPALAEONTOLOGICAL BULLETINS

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B. STAM

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CONTENTS

| | Page |
|--|------|
| Abstract | 5 |
| Chapter 1. Introduction | 7 |
| 1.1: Purpose of investigation | 7 |
| 1.2: Methods of faunal analysis | 9 |
| 1.3: Mathematical analysis | 11 |
| 1.4: Interpretation of the results obtained | 12 |
| 1.5: Species concept | 13 |
| 1.6: Acknowledgements | 13 |
| Chapter 2. Central Portugal | 15 |
| 2.1: Introduction | 15 |
| 2.2: Late Triassic through Late Jurassic (Kimmeridgian) paleogeography of the Lusitanian basin | 15 |
| 2.3: Cape Mondego area | 16 |
| 2.3.1: Introduction | 16 |
| 2.3.2: The Murtinheira and Brenha sections | 18 |
| 2.3.3: Faunal analysis | 19 |
| 2.3.4: Discussion | 25 |
| 2.4: Montejunto area | 33 |
| 2.4.1: Introduction | 33 |
| 2.4.2: Stratigraphic framework | 33 |
| 2.4.3: The sections | 39 |
| 2.4.4: Faunal analysis of the Tojeira 1 section | 41 |
| 2.4.5: Discussion | 43 |
| 2.4.6: Faunal analyses of the Tojeira 2 section | 48 |
| 2.4.7: The Tojeira 1 and Tojeira 2 sections, a comparison | 48 |
| 2.4.8: The planktonic/benthonic ratio | 59 |
| Chapter 3. Southern Portugal | 63 |
| 3.1: Introduction | 63 |
| 3.2: Late Triassic through Late Jurassic paleogeography of the Algarve basin | 63 |
| 3.3: The stratigraphic sections | 65 |
| 3.4: The Mareta Beach section | 65 |
| 3.4.1: Introduction | 65 |
| 3.4.2: Lithological description | 65 |
| 3.4.3: Faunal analyses | 69 |
| 3.4.4: Discussion | 72 |
| 3.5: Albufeira, Loule and Estoi | 76 |

| | |
|--|-----|
| 3.6: The Algarve and Lusitanian Basins, a comparison | 78 |
| Chapter 4. The Grand Banks of Newfoundland | 81 |
| 4.1: Introduction | 81 |
| 4.2: The wells | 82 |
| 4.3: Middle and Late Jurassic foraminifera from the Grand Banks .. | 83 |
| 4.4: Grand Banks biostratigraphy | 91 |
| 4.5: Burial, subsidence and sedimentation history | 94 |
| Chapter 5. Jurassic Planktonic foraminifera | 103 |
| 5.1: Introduction | 103 |
| 5.2: Systematics | 104 |
| 5.3: Evolutionary trends and paleoecology | 113 |
| Chapter 6. Taxonomy | 117 |
| 6.1: Introduction | 117 |
| 6.2: Taxonomic notes | 117 |
| Appendix | 129 |
| References | 134 |

ABSTRACT

Quantitative analyses were made of the foraminiferal assemblages in 137 samples from five Portuguese sections (Murtinheira, Brenha, Tojeira 1, Tojeira 2 and Mareta Beach) of Middle and Late Jurassic age. Trends in depositional environment (for example from deep to shallow water sediments) together with R- and Q-mode analyses determined three different groups of foraminifera, each group having its own bathymetric preference.

Spirillina tenuissima, *Spirillina elongata*, *Spirillina infima*, *Ophthalmidium carinatum* and *Paalzowella feifeli* preferred relatively shallow water, up to about 50 metres. *Epistomina mosquensis*, *Pseudolamarckina rjasanensis*, *Ophthalmidium strumosum* and the agglutinated foraminifera preferred relatively deep water, from about 200 to 250 metres or possibly more. *Lenticulina muensteri*, *Lenticulina* spp., *Discorbis* spp., *Eoguttulina* spp. and *Nodosaria/Dentalina* spp. filled the depth niche in between, from about 50 to over 150 metres. *Eoguttulina* spp. and *Nodosaria/Dentalina* spp. probably preferred depths closer to 150 than to 50 metres.

Coeval foraminiferal assemblages from 18 wells on the Grand Banks off Newfoundland proved to be closely similar to those of Portugal, allowing for a more precise estimate of the paleowaterdepths of Middle and Upper Jurassic sediments of the Grand Banks. Middle Jurassic representatives of the genera *Garantella*, *Reinholdella* and *Epistomina* occur in three wells on the Grand Banks, but are not known from the coeval parts of any other wells and any of the Portuguese sections. This is explained as being the result of local differences in depositional environment; the epistominids preferring relatively deep water.

Two new biostratigraphic zones are defined: (1) *Reinholdella* spp. Zone of (Late) Bathonian age, and (2) *Epistomina regularis* Zone of Callovian age. A range chart shows the stratigraphic distribution of taxa known from the Grand Banks and Portugal.

The burial history of five wells, using the specially developed Fortran 77 programs BURSUB and DEPOR, illustrates that up to 50% of the (de)compacted burial is due to tectonic subsidence. Decompacted sedimentation rates, especially during the Late Jurassic, are higher than the decompacted burial rates, resulting in a shallowing. This Late Jurassic shallowing can be recognized in all 18 wells.

Of the 14 Jurassic planktonic species described to date only three can be recognized in the Portuguese and Grand Banks strata, using type material from Poland, France and Switzerland. These three taxa have been re-defined such that they encompass the variation previously assigned to the 14 taxa listed in

the literature. The three taxa are: (1) *Globuligerina bathoniana*, ranging from ?Late Bajocian through Early Valanginian (2) *Globuligerina oxfordiana*, ranging from Middle-Late Bajocian through Early Valanginian, and (3) *Globuligerina balakhmatovae*, ranging from Late Bajocian through Late Bathonian, possibly through Early Kimmeridgian. The occurrences of these three species, which are among the oldest planktonic foraminifera known, may be ecologically controlled.

Chapter 1

INTRODUCTION

1.1: PURPOSE OF INVESTIGATION

The first objective of this investigation is to gain insight, using quantitative methods, into some paleoecological parameters that control the distribution and abundance of Jurassic benthonic foraminifera and to examine the usefulness for biostratigraphy of both Jurassic planktonic and benthonic foraminifera. The paleoecological study of Jurassic benthonic foraminifera is still in its infancy, particularly as no real quantitative analysis has been attempted so far. Integration of ammonite and foraminiferal ranges is urgently needed for regional biostratigraphical studies. The area selected, i.e. Portugal, is eminently suited for this purpose. It possesses excellent stratigraphic sections in a coastal plain setting. A second objective is to apply the results obtained in Portugal to the conjugate Grand Banks basins. A third objective is to develop and apply a suitable computer program for burial and subsidence history. Such a program, together with the improved knowledge concerning the biostratigraphy and paleoecology of Middle and Upper Jurassic foraminifera, will give better estimates for the burial, subsidence and sedimentation rates for well sections on the Grand Banks.

During the last two decades a large number of wells have been drilled in the Grand Banks basins off Newfoundland and in several of those wells Jurassic sedimentary strata have been sampled. The nature of these samples poses some problems. Cutting-samples are contaminated by downhole transportation of material. This contamination is difficult if not impossible to detect, particularly in those parts of the stratigraphic column, like the Jurassic, that from a foraminiferal point of view, are less well defined. This means that only last occurrences of fossils can be used for dating. In the case of side-wall cores sample size is usually small, which can cause additional problems, particularly in areas with a relatively high sedimentation rate. As a result the stratigraphic resolution obtained using these types of samples is limited and little insight is gained into fossil communities.

The best tools for biostratigraphy are planktonic organisms such as ammonites, planktonic foraminifera, calcareous nannoplankton, and calpionellids. Because of their planktonic nature these fossils usually are distributed over a large geographical area in a relatively short time, but ammonites are too large to be recovered from ditch-cuttings and side-wall cores and most of the the nan-

noplankton zones for the Jurassic are based on first occurrences and hence cannot be used in exploration samples. Calpionellids are stratigraphically useful but restricted, as they only occur in the uppermost Jurassic and lowermost Cretaceous (Upper Tithonian-Valanginian). Jurassic planktonic foraminifera are still too poorly understood to be used for age determinations. Benthonic organisms, foraminifera in this case, dwell on the seafloor or even within the sediment. Although restricted to shallower waters, larger benthonic foraminifera such as *Anchispirocyclus*, *Choffatella*, *Orbitoides* and *Miogypsina*, have proven to be excellent tools for regional biostratigraphic correlations of Mesozoic and Tertiary strata. Smaller benthonic foraminifera can also be used for age determinations, but this often requires the recognition of (large) assemblages rather than one or a few species.

In general, age determinations or zonations based on benthonic foraminifera have regional correlation value, because their distribution over a large geographical area is likely to be diachronous. In the case that only one or a few benthonic foraminiferal species are used (Moullade 1984, may serve as an example with the *Conorboides parapsis* total range zone of presumed Oxfordian age),

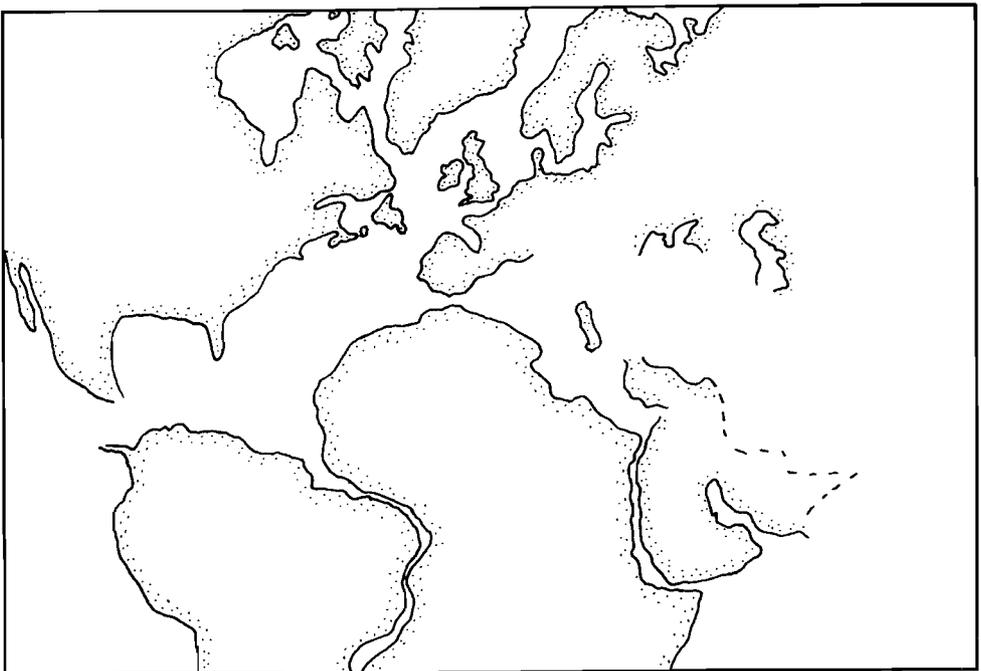


Fig. 1. Tithonian paleogeographic reconstruction of the continents bordering the North Atlantic Ocean (after Smith and Briden, 1977).

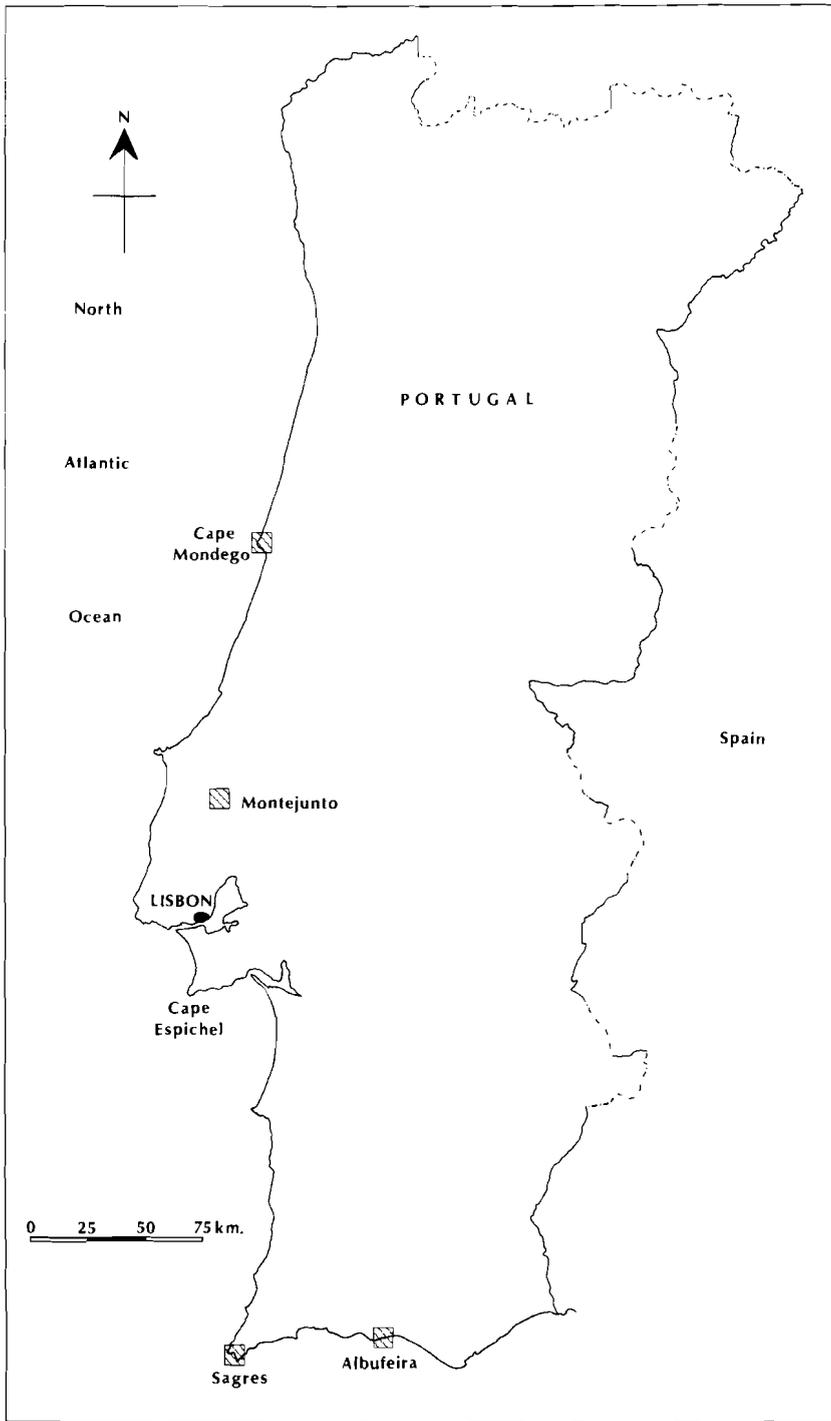


Fig. 2. Map of Portugal with the areas of interest, Cape Mondego, Montejunto, Sagres, and Albufeira.

it is necessary to understand the ecological sensitivity of the species. The disappearance of *C. parapsis* could result from extinction which is useful in biostratigraphy, or it could result from ecological exclusion which has limited meaning in biostratigraphy.

Because of the above mentioned problems concerning age assignments it is necessary to get a better understanding of the vertical (biostratigraphic) and horizontal (paleoecologic) distribution of Jurassic benthonic foraminifera. For this purpose samples were studied that firstly avoid this kind of (downhole) contamination, and that secondly come from an area not too far separated from the Grand Banks, and that thirdly have been dated by other means (e.g. planktonic organisms).

Paleogeographic reconstructions (fig. 1) (Jansa and Wade, 1975; LePichon *et al.*, 1977; Sclater *et al.*, 1977; Groupe Galice, 1979; Sibuet and Ryan, 1979; Vandenberg, 1979; Tucholke and Ludwig, 1982) of the North Atlantic continental margins suggest that prior to the beginning of seafloor-spreading, the Lusitanian and Algarve basins of Portugal and the Grand Banks basin south of Newfoundland were in close proximity. Even though the different reconstructions indicate different initial distances between these basins, it is generally accepted that active spreading did not take place before Early Cretaceous time. This suggests that the Algarve/Lusitanian basins and the Grand Banks basins should have a comparable sedimentary, tectonic and faunal history during the Jurassic. Exton and Gradstein (1984) have reported on the Early Jurassic conjugate basin (bio)stratigraphy and sedimentary history. This study focusses on the micropaleontology of Middle and Upper Jurassic sections.

Jurassic sections have been sampled from several areas in central and southern Portugal (fig. 2), including Montejunto, Cape Mondego, Sagres, and Albufeira. The foraminiferal content has been qualitatively and quantitatively examined and statistically analyzed.

1.2: METHODS OF FAUNAL ANALYSIS

The samples were processed according to the "Industrial Soap Method" of Thomas and Murney (1985) and washed over a set of sieves (500, 125 and 63 micron). The 63–125 micron size fraction has not been used for this study because the taxonomy of Middle and Late Jurassic foraminifera (especially of stratigraphically important taxa) is to a large extent based on the occurrence and type of ornamentation of the test. This is difficult to observe when dealing with juvenile specimens, leading to a high percentage of unidentified foraminifera per sample.

An Otto microsplitter was used to reduce the washed residue until no more

than several hundred (usually 200–300) benthonic foraminifera were left. From this split the benthonic taxa were identified, counted, and their percentages calculated. A planktonic/benthonic (P/B) ratio, if applicable, was also calculated.

1.3: MATHEMATICAL ANALYSIS

At the onset of this study three computer programs, CABFAC, FACTOR, and CLUSTR were available for mathematical analysis. CABFAC, written by Klován and Imbrie (1971), performs Q-mode (sample-sample) analysis. FACTOR and CLUSTR, written by Davis (1973), are capable of R- (species-species) and Q-mode analysis. For a detailed discussion concerning the theory behind factor analysis the reader is referred to Davis (1973). In short, the aim of factor analysis is to find meaningful axes (factors) in the multidimensional space defined by the variables and each factor must give a sufficient description of the cluster of variables in that space. This may end in the recognition of groups of variables that have a similar preference/behaviour, which is one of the objectives.

Factor analyses have certain serious drawbacks. First of all when one wishes to recognize which variables have a significant score on a certain factor one has to determine how significant the factor itself is. Usually the first factor accounts for the highest amount of variance while the amount accounted for by subsequent factors decreases, meaning that the importance of subsequent factors decreases as well. The question then is at what point do factors, apart from the first two which mostly have some significance, become unimportant. There is no real answer to this question. There are some graphical methods to determine which factors are important, but these are highly subjective.

The second drawback concerns the factor scores, which vary from -1 to $+1$. When are they significant? Again no real answer to this question exists. According to Drooger (1982) a factor score is significant when it is equal to or larger than the square root of a certain value (dependent on the number of observations) from the table of r -distributions. In fact, factor (= cluster) analyses have no foundation in the theory of mathematical statistics and should be considered as mathematical manipulations, only to be used to get a quick insight into the relationships between variables. The relationships themselves should be tested by other means (Drooger, 1982).

Recently a set of computer programs written by M.M. Drooger became available. These four programs, BALANC, DISTUR (Drooger, 1982), MATRIX, and DENDRO are only capable of R-mode analysis.

BALANC and DISTUR, certainly if used together, have some advantages

over factor analysis. First of all they have a sound basis in the theory of mathematical statistics, and secondly they avoid the so-called "closed sum" effect, which is the artificial relationship that can be created between variables if they form a closed sum (i.e. percentages).

Both BALANC and DISTUR, even though working according to different models (the "free-open-covariances" and the "zero-open-covariances" models respectively) produce a matrix of correlation coefficients. The significance of these correlation coefficients can easily be tested using the table of *r*-distributions. Special features of BALANC, DISTUR, and MATRIX include trend analysis. This allows for the recognition of variables that show a significant positive or negative trend (an increase or decrease respectively in a certain, for example stratigraphical, direction). Even though the closed sum effect is avoided, certain variables, because of their highly fluctuating proportions, can disturb the analysis. Variables with such a behaviour are recognized when using DISTUR, and can then be deleted from the data matrix. For the statistical considerations and a description of the two above-mentioned models, the reader is referred to Drooger (1982).

MATRIX and DENDRO are also written by M.M. Drooger, but not referred to in his 1982 paper. DENDRO uses the free-open-covariances model and performs a cluster analysis. BALANC, DISTUR, and DENDRO require that the values of the variables have the same dimension, meaning that when analyzing species percentages a P/B-ratio cannot be entered. The program MATRIX is used to calculate the correlation coefficients between, for example, the P/B-ratio and species percentages. Finally, in all the analyses only the correlations that met the 0.05 (95%) confidence level have been accepted as being significant.

In summary, Davis' (1973) programs FACTOR and CLUSTR have been used for Q-mode analyses and Drooger's programs BALANC, DISTUR, MATRIX, and DENDRO have been used for R-mode analyses.

1.4: INTERPRETATION OF THE RESULTS OBTAINED

Because most of the Jurassic foraminiferal species have no Recent counterparts and because of the possibility of changing niche patterns through time (van der Zwaan, 1982), no actualistic approach has been used when attempting to determine the factors that control the distribution and abundance of Jurassic foraminifera.

A comparison with the Recent will be made occasionally, for example when dealing with the factor diversity and the general distribution model of planktonic foraminifera.

The interpretations given are based on the relationships between species or

species groups and trend analyses. For example which species are positively correlated and how do they respond to a shallowing trend determined from other criteria. Furthermore a comparison is made with the relevant literature dealing with Jurassic foraminifera.

1.5: SPECIES CONCEPT

The species concept as used in this study is an assemblage species concept. All forms that form an entire but gradual morphological range from which the end members may differ considerably, are grouped together as one species. This has a sound taxonomical basis since intergradational series are defacto part of conspecificity (Mayr *et al.*, 1953), and the concept has been applied in fossil and Recent foraminifera. An example of the latter is the recent study by Medioli and Scott (1978). *Epistomina ubligi* may serve as an example. The dorsal side of this non-ornamented taxon varies from flat to convex and the ventral side from convex to high convex. The umbilical disc, visible as a glass-like mass on the ventral side, varies from relatively small and thin to so large and thick that it becomes a dominating aspect of that side. Secondary lateromarginal apertures may be visible on the last three, two or only the last of the of ca. 7 chambers which constitute the last whorl. All epistominids that fit this description are called *E. ubligi*.

In addition to this, the nodosariids can form a large part of the Jurassic microfauna. The taxonomical status of many species belonging to this group is uncertain due to stratigraphic homeomorphy, resulting in the availability of many specific names for what could well be just one single species. Since nodosariids are an important part of the microfauna, they could not be excluded.

In order not to lose too much information and introduce too much taxonomical bias, only those nodosariid species have been used that are distinct and easily recognizable, such as *Lenticulina quenstedti* and *L. muensteri*. All other nodosariid species are either grouped on the generic level (*Lenticulina* spp., *Nodosaria/Dentalina* spp.) or, because of their very low frequencies, grouped in a rest group, together with other rare species. The fact that, in all the material examined *L. muensteri* usually forms more than 80% of the nodosariid fauna, justifies this working method.

1.6: ACKNOWLEDGEMENTS

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Chapter 2

CENTRAL PORTUGAL

2.1: INTRODUCTION

In order to allow for a comparison between Jurassic microfauna from Portugal and the Grand Banks off Newfoundland, and to determine some paleoecological aspects of Middle and Upper Jurassic foraminifera, the sections to be studied had to be chosen carefully. Firstly, they had to fit into a well known biostratigraphic framework (age control), and secondly some aspects of the paleogeographic setting of the areas had to be known in order to recognize trends in basin tectonics and basin development through time.

In this respect, two areas in central Portugal were suitable for microfaunal analysis: the Cape Mondego and Montejunto areas (fig. 2). Both locations lie within what is called the Lusitanian Basin, a north-south elongated basin in west central Portugal, bordered in the east by the Iberian Meseta, with a southern limit near Cape Espichel and a northern limit just south of Porto (fig. 3). The biostratigraphic framework, based on ammonites, is well known: Chofat (1880–1893), Ruget-Perrot (1961), Mouterde *et al.* (1972), Poulton (1983, internal report Geological Survey of Canada). The paleogeographic setting of the areas has been documented by Ruget-Perrot (1961), Mouterde and Ruget (1975), Wilson (1975a) and Wilson and Exton (1979).

Reconnaissance fieldwork in 1978 by L.F. Jansa and F.M. Gradstein (Geological Survey of Canada, Dartmouth, N.S.) determined which sections in those areas were most suitable for foraminiferal analysis.

2.2: LATE TRIASSIC THROUGH LATE JURASSIC (KIMMERIDGIAN) PALEOGEOGRAPHY OF THE LUSITANIAN BASIN

The Lusitanian Basin originated in the Late Triassic-Early Jurassic as a result of normal movements along Hercynian (Paleozoic) basement faults; one of these faults is the prominent Nazare strike slip fault (fig. 3). The basins generally have a NNE axis of subsidence (Wilson and Exton, 1979). The Late Triassic through Middle Jurassic development of the basin as a whole is more or less uniform, and starts with the deposition of non-marine, marginal marine to shallow marine sands, shales and evaporites, and dolomites and dolomitic limestone (Gres de Silves, Marnes de Dagorda, Couches de Coimbra of Rhaetian through Sinemurian age; Doubinger *et al.*, 1970; Mouterde *et al.*, 1972;

Mouterde and Ruget, 1975). This is followed in the Late Sinemurian and Pliensbachian by normal marine sedimentation of shales alternating with limestone, with the first occurrence of ammonites. At the beginning of the Toarcian the shale facies becomes predominant, with an upward trend towards more calcareous sedimentation. This trend continues throughout the Aalenian and Bajocian until in the Bathonian, most of the basin is covered by carbonate shelf deposits, indicating a gradual shallowing from the middle part of the Toarcian through the Bathonian. During the Callovian, also characterized by shallow water deposits, reactivation of basement faults and halokinesis changed the basin configuration to such an extent that a northern and a southern sub-basin can be recognized, separated along the Nazare fault line.

The deposition of oolitic limestone and sandstone on shaly and “reefal” limestone (Mouterde *et al.*, 1972), together with the lack of Lower Oxfordian sediments in the northern sub-basin, indicates a Middle Callovian regression followed by an uplift (Wilson and Exton, 1979), again caused by salt movements. Sedimentation resumed in the Late Oxfordian with the deposition of marginal marine carbonates and freshwater sediments (algal marsh facies; Wilson, 1979), followed in the Kimmeridgian by fluvial clastics. Throughout the remainder of the Jurassic, the sedimentation in this northern sub-basin continued to be of a non-marine nature.

Halokinesis also caused a Late Callovian uplift of the southern sub-basin, documented by a Late Callovian-Early Oxfordian hiatus in which the Lamberti and Mariae Zones are missing. In late Early Oxfordian times more rapid subsidence than in the northern sub-basin resulted in normal marine sedimentation with abundant ammonites, shallow water and high energy carbonates (Wilson, 1975a). In Late Oxfordian time this high energy facies was gradually replaced by low energy shale sedimentation, and by the end of the Oxfordian and the beginning of the Kimmeridgian this shale facies was predominant. Reactivation of basement faults and salt movements in the Early Kimmeridgian resulted in a complex facies distribution: marine clastics in the Montejunto area, reef carbonates south of Lisbon (Cape Espichel), shelf carbonates northeast of the Montejunto area, and fluvial clastics south of Peniche (fig. 3).

2.3: CAPE MONDEGO AREA

2.3.1: Introduction

Normal marine sedimentation in the Cape Mondego area (fig. 4) started approximately in Late Sinemurian time (Oxynotum Zone, Schott and Staesche, 1957) and lasted until Middle-Late Callovian, when regression and uplift was

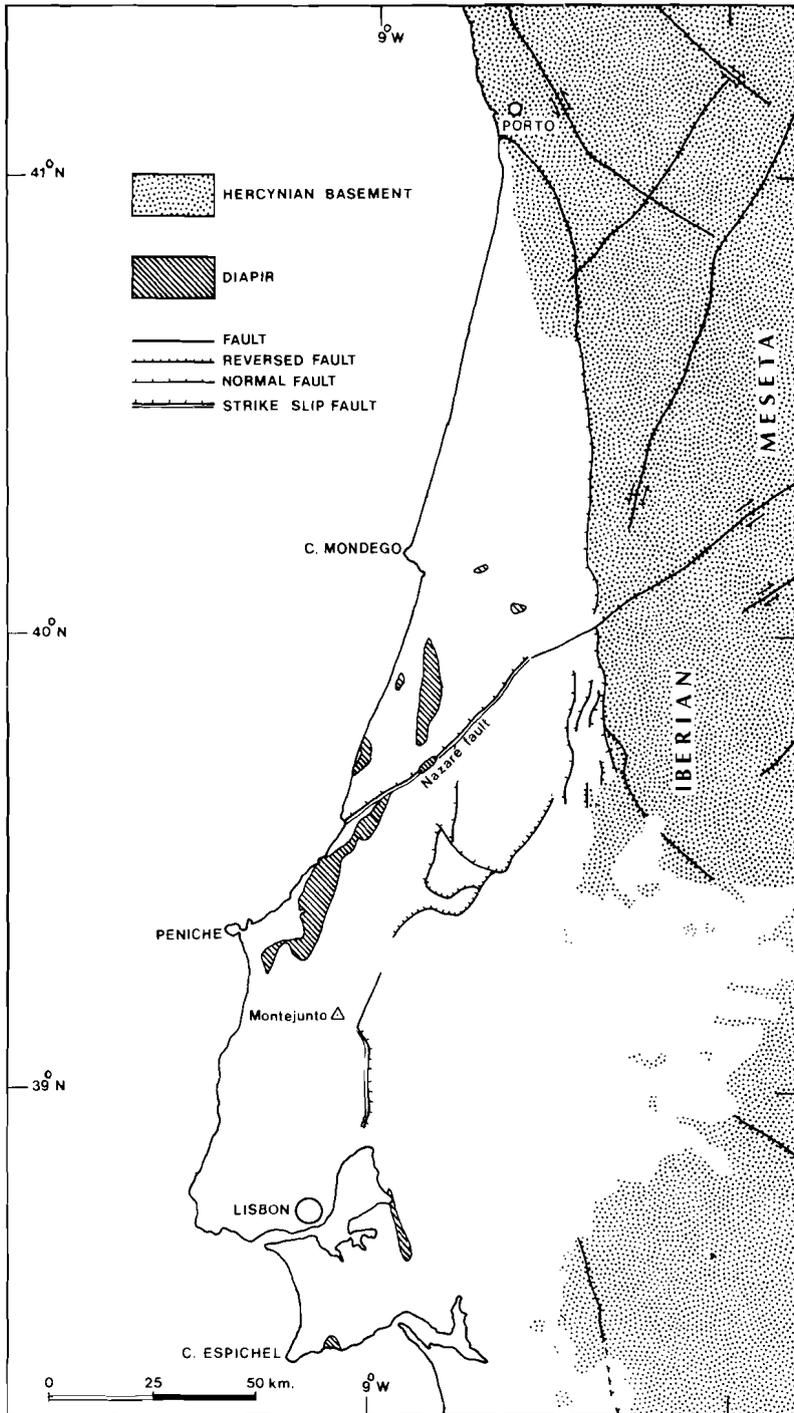


Fig. 3. Sketch map outlining the Lusitanian Basin, with some of the major faults (after Ribeiro *et al.*, 1972).

followed by the deposition of marginal to non-marine sediments in the Late Oxfordian and Kimmeridgian (see section 2.2). Most of the sediments laid down during this marine interval are rich in ammonites, resulting in a well-known biostratigraphic framework for the area (Ruget-Perrot, 1961; Rocha *et al.*, 1981).

Two sections were chosen for foraminiferal analysis: the Murtinheira section and the Brenha road section (fig. 4). Both sections have good ammonite control and are described by Ruget-Perrot (1961), Hamilton (1977, 1979), and Rocha *et al.* (1981).

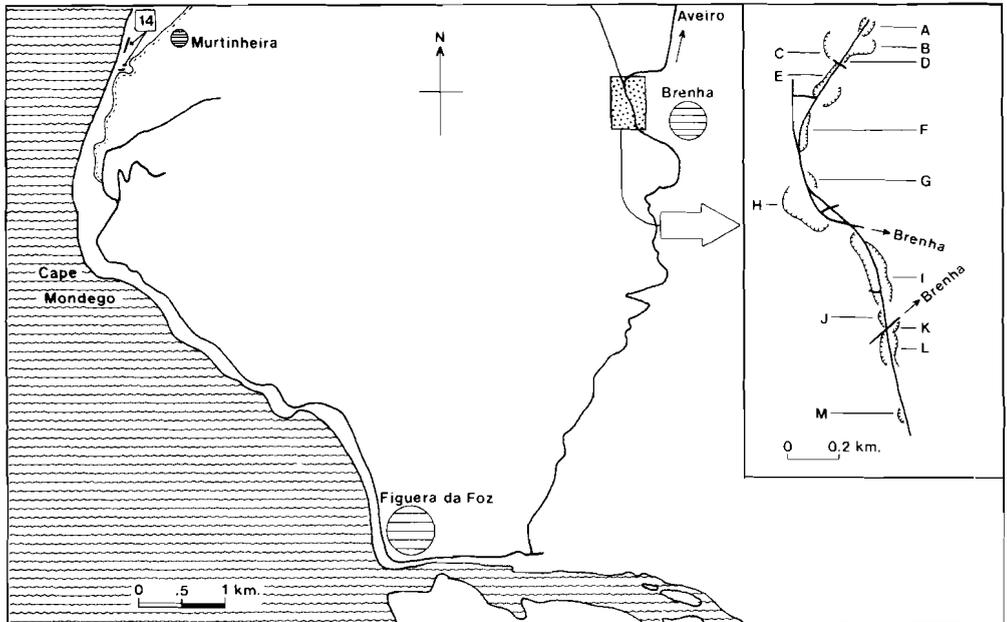


Fig. 4. Location map of the Murtinheira and Brenha sections, Cape Mondego area.

2.3.2: The Murtinheira and Brenha sections

The Murtinheira section is exposed along the beach, ca. 400 m. SW of the Village Murtinheira, and consists of some 80 metres of regularly alternating massive limestones and laminated shaly limestones (figs. 4, 5). Due to the hard nature of the massive sediments, only 8 samples were taken, all from the softer laminated lithology. Two additional samples were taken from an outcrop along the road from Murtinheira to the south (fig. 4) which consists of shale and micritic limestone.

The section along the beach is of Aalenian age (*Opalinum-Murchisonae*

Zones; Ruget-Perrot, 1961), whereas the outcrop along the road has been dated as Middle Bajocian (Sauzei Zone; Ruget-Perrot, 1961; Rocha *et al.*, 1981).

The Brenha section is located along the road from Figuera da Foz to Aveiro, close to the village of Brenha (fig. 4) and consists of an almost complete, ca. 700 m thick, sequence of Sinemurian through Oxfordian marine sediments. The litho- and chronostratigraphic framework is given in fig. 6 in which letters to the left of the column refer to outcrops as indicated by letters in fig. 4. Almost the entire section is dominated by limestone, shaly limestone, and shale. The Sinemurian, the lower part of which is equivalent to the "Couches de Coimbra" (Schott and Staesche, 1957), is dominated by limestone changing to a regular alternation of shale and limestone and shaly limestone and shale from the Pliensbachian to the Lower Bajocian. The Middle and Upper Bajocian consists mainly of limestone, whereas the Bathonian again shows a regular alternation of shales and limestone. The Callovian is dominated by limestone with minor shale intercalations and the Middle-Upper Oxfordian consists of oolitic limestone and sandy shales. The top ca. 500 m of which only a small part is shown in fig. 6 consists of non-marine red sandstone.

The age determinations are after Hamilton (1977, Lower Jurassic) and Ruget-Perrot (1961, Middle and Upper Jurassic) and in general are reliable at the (sub)stage level.

2.3.3: Faunal analysis

From the Murtinheira section eight samples were used for quantitative faunal analysis. Of the ten available samples, two (14.1 and 14.3) contained insufficient foraminifera. The frequency patterns of 10 categories were mathematically analyzed; 7 concern species or groups of benthonic foraminifera. These species or species groups are: *Eoguttulina* spp. (*E. bilocularis* and *E. oolithica*), *Lenticulina muensteri*, all other *Lenticulina* spp., miliolids (mainly *Ophthalmidium concentricum*), all *Nodosaria/Dentalina* spp., and *Spirillina* spp. (*S. elongata*, *S. infima* and *S. tenuissima*). All other species are grouped in a Restgroup, usually comprising less than 10% of the fauna. This group is mainly dominated by Lagenids (i.e. *Marginulina oolithica*, *Neoflabellina deslonchampsii*, etc.). Agglutinated foraminifera are scarce, only one genus (*Trochammina*) has been identified. As a consequence, arenaceous taxa are included in the Restgroup. The three other parameters used for the analysis are the number of species per sample, a code number indicating laminated sediments, and a code number indicating homogeneous sediments.

The faunal frequency pattern is listed in table 1. Here the spirillinids are shown separately to enable a comparison with other sections. For the computer

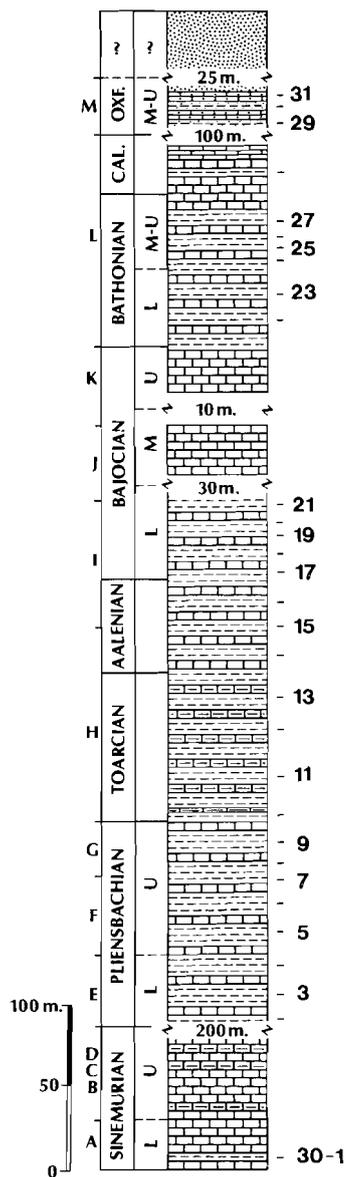
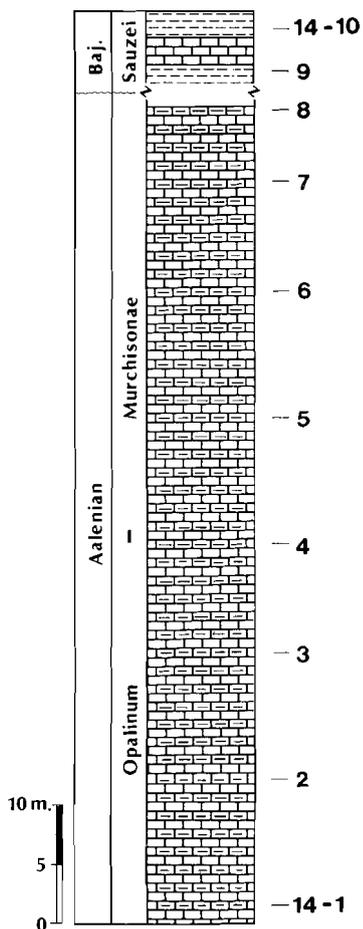


Fig. 5. Litho-, bio-, and chronostratigraphic framework for the Murtinheira section (left).

Fig. 6. Litho-, bio-, and chronostratigraphic framework for the Brenha section (right).

analysis however they were treated as one group because the relative frequencies of *S. elongata* and *S. infima* are so low, and because of a limitation of the computer programs which requires the number of variables to be less than the number of observations.

A few general trends seem apparent when examining table 1. *L. muensteri* (lower part) and *Spirillina* spp. (upper part) are the predominant faunal elements. The relative frequency (RF) of *Spirillina* spp. (mainly *S. tenuissima*) increases from bottom to top, whereas the RF of *Lenticulina muensteri* seems to decrease. The number of species per sample is fairly constant and low. Worth mentioning, but not shown in table 1, are the relative peak occurrences of *L. quenstedti* (in *Lenticulina* spp. category) in the uppermost three samples.

In the case of the Murtinheira section it should be stressed that firstly the total number of observations (8 samples) is small, secondly that the number of variables (7 species/species groups for R-mode) is low and close to the minimum number (6) required for a balanced solution using Drooger's free open covariances model (Drooger, 1982, p. 86–88), and thirdly that there is a considerable timegap between the uppermost sample from the beach section and the lowermost of the road outcrop. This could mean that the actual number of observations and variables is too low to warrant a reliable quantitative analysis, that any interpretation based on such an analysis is tentative at best, and that care should be taken in recognizing time-trends.

Significant correlations between categories are shown in fig. 7. *Spirillina* spp. has a significant positive trend (their proportion increases from bottom to top).

Table 1. Distribution chart (%) of the foraminifera from the Murtinheira section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---------------|------|------|------|------|-----|-----|----|------|------|----|-----|
| Sample number | | | | | | | | | | | |
| 14.2 | 9.2 | 65.6 | 5.9 | .0 | 1.8 | .0 | .0 | 10.6 | 6.9 | 14 | 218 |
| 14.4 | 9.0 | 56.7 | 1.7 | .0 | 6.2 | .0 | .0 | 21.3 | 5.1 | 10 | 178 |
| 14.5 | 19.4 | 26.6 | 2.4 | .0 | 5.7 | .0 | .5 | 28.5 | 16.9 | 13 | 207 |
| 14.6 | 7.0 | 58.8 | 1.8 | .4 | 3.0 | .0 | .0 | 25.9 | 3.1 | 9 | 228 |
| 14.7 | 3.4 | 31.2 | 5.4 | 29.5 | 1.7 | .0 | .0 | 22.4 | 6.4 | 15 | 295 |
| 14.8 | 3.0 | 27.4 | 1.5 | 3.5 | 1.5 | .0 | .0 | 58.2 | 4.9 | 12 | 201 |
| 14.9 | 6.1 | 6.1 | 23.4 | .3 | .5 | 2.4 | .5 | 53.1 | 7.6 | 18 | 378 |
| 14.10 | .8 | 1.5 | 7.0 | .0 | .4 | 3.5 | .0 | 80.8 | 6.0 | 13 | 258 |

1 = *Eoguttulina* spp.

2 = *L. muensteri*

3 = *Lenticulina* spp.

4 = miliolids

5 = *Nodosaria/Dentalina* spp.

6 = *S. elongata*

7 = *S. infima*

8 = *S. tenuissima*

9 = Restgroup

10 = number of species

11 = total benthos counted

quantitative analysis because of a scarce benthonic microfauna, a pyritized cast of a planktonic foram has been encountered.

Significant correlations between various categories are shown in fig. 9. Significant positive trends are found for the three *Spirillina* species, a significant negative trend is shown by *Nodosaria/Dentalina* spp. The constructed dendrogram (fig. 10) essentially shows three groups of species, group 1 consists of *Nodosaria/Dentalina* spp., *Eoguttulina* spp., *L. muensteri* and *L. quenstedti*, group 2 consists of the spirillinids and the Restgroup, and group 3 consists of *Lenticulina* spp. and the miliolids. The agglutinants have no similarity with any of these groups.

Since the Brenha section covers a large timespan, a Q-mode cluster analysis was carried out in order to determine whether or not the fauna changed through time. The analysis (fig. 11) shows that the samples indeed group more or less in stratigraphic order.

Table 2. Distribution chart (%) of the foraminifera from the Brenha section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------|------|-----|-----|------|------|------|------|------|------|------|------|----|
| Sample number | | | | | | | | | | | | |
| 30.2 | 1.5 | .4 | .4 | .7 | .4 | 5.9 | .7 | 88.9 | .0 | 1.1 | .0 | 12 |
| 30.3 | 7.5 | 1.3 | .0 | 43.4 | .0 | 9.4 | 27.0 | .6 | 1.3 | 8.7 | .6 | 15 |
| 30.4 | 5.2 | .0 | .0 | 9.0 | .0 | 18.6 | 14.1 | 10.4 | 17.9 | 17.2 | 7.4 | 18 |
| 30.5 | 5.8 | 1.4 | .0 | 60.4 | .0 | 7.0 | 5.8 | .0 | 5.1 | 14.4 | .0 | 16 |
| 30.6 | 2.9 | .0 | .6 | 31.6 | .0 | 2.8 | 9.1 | 1.1 | 31.1 | 20.5 | .0 | 15 |
| 30.7 | 5.0 | .7 | 1.4 | 35.9 | .0 | 2.1 | 5.8 | 1.4 | 37.4 | 7.2 | 3.6 | 15 |
| 30.8 | 3.4 | .9 | .0 | 8.5 | .0 | 2.4 | 32.2 | .3 | 44.5 | 4.7 | 1.9 | 19 |
| 30.9 | 1.9 | .0 | .0 | 8.2 | .0 | 11.4 | 36.0 | .0 | 34.8 | 5.7 | 1.9 | 13 |
| 30.13 | 8.3 | .0 | .0 | 71.2 | .0 | 10.6 | 1.5 | 2.3 | 3.8 | 1.5 | .8 | 12 |
| 30.14 | 8.0 | .0 | .4 | 62.2 | .0 | 8.8 | 6.3 | .0 | 6.3 | 6.8 | 1.3 | 16 |
| 30.15 | 6.9 | .0 | .0 | 40.6 | 22.8 | 18.9 | 3.0 | .0 | 3.0 | 2.0 | 3.0 | 11 |
| 30.16 | 1.6 | .0 | .0 | 64.5 | 13.7 | 6.4 | 5.6 | .0 | 4.8 | .0 | 3.2 | 13 |
| 30.18 | 7.6 | .0 | .0 | 23.4 | 45.0 | 4.7 | 5.9 | 2.4 | 8.2 | .6 | 2.3 | 12 |
| 30.19 | 28.1 | .0 | .0 | 19.7 | 11.6 | 5.2 | 5.6 | 2.8 | 16.1 | 8.8 | 1.6 | 17 |
| 30.20 | 7.0 | .0 | 1.4 | 34.1 | 9.3 | 6.9 | 15.4 | 3.2 | 8.9 | 8.4 | 5.2 | 19 |
| 30.21 | 6.5 | .0 | .6 | 44.4 | 2.4 | 7.8 | 12.4 | .0 | 7.7 | 7.8 | 10.7 | 17 |
| 30.22 | 89.3 | 3.1 | .0 | .6 | .0 | 1.3 | .0 | .0 | .0 | 4.4 | 1.3 | 7 |
| 30.23 | 72.6 | 5.1 | 2.6 | 6.0 | .9 | 2.5 | .0 | .0 | .0 | 7.7 | 2.7 | 11 |
| 30.25 | 43.6 | 6.0 | 3.4 | 22.6 | 9.4 | 5.1 | .4 | 1.3 | .0 | 2.9 | 5.1 | 19 |
| 30.27 | 51.7 | .5 | 1.2 | 19.9 | 1.0 | 7.7 | 2.7 | .0 | 3.2 | .8 | 10.3 | 20 |
| 30.28 | 86.5 | 6.0 | .7 | 2.5 | .0 | .0 | .0 | .0 | .0 | 4.3 | .0 | 6 |

1 = *S. tenuissima*
 2 = *S. elongata*
 3 = *S. infima*
 4 = *L. muensteri*
 5 = *L. quenstedti*
 6 = *Lenticulina* spp.

7 = *Nodosaria/Dentalina* spp.
 8 = miliolids
 9 = *Eoguttulina* spp.
 10 = Restgroup
 11 = Agglutinants
 12 = number of species

None of the species or species groups used for the analysis is actually known to have a preference for a certain environment. They are all, including known miliolids, known from sediments with a depositional environment suggested as ranging from shallow to abyssal water depths (Munk, 1980; Gradstein, 1983).

Since, as mentioned before, *L. muensteri* and the spirillinids are the predominant faunal elements, it seems reasonable to focus on this species/species group.

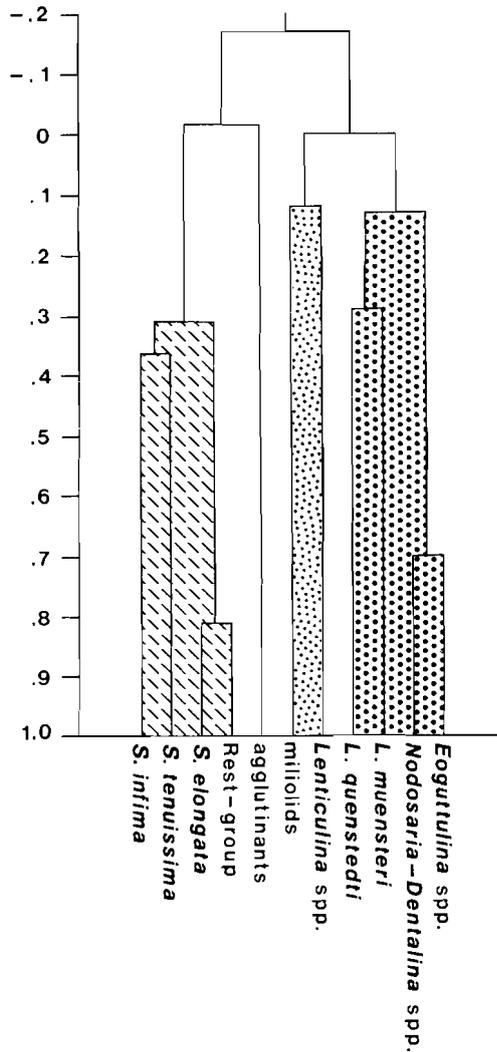


Fig. 10. R-mode dendrogram of the Brenha benthonic foraminifera.

Both *L. muensteri* and the spirillinids are common throughout the Jurassic and have been reported from various different environments: from bathyal and abyssal deposits in the North Atlantic (Luterbacher, 1972; Kuznetsova and Seibold, 1978; Gradstein, 1983) and Indian Ocean (Kuznetsova, 1974), from bathyal deposits in the French Prealps and shelf deposits in the Swiss Jura mountains (Wernli and Septfontaine, 1971), and from shelf deposits in the United Kingdom and Germany (Johnson, 1975; Lutze, 1960; and Munk, 1980 respectively).

Quantitative and semiquantitative data concerning the relative abundance of *L. muensteri* are virtually lacking, with the exception of data in Kuznetsova and Seibold (1978) and Gradstein (1983), both studies of abyssal sediments. Kuznetsova and Seibold (1978) give quantitative data of Upper Jurassic foraminifera from which it can be seen that *L. muensteri* forms only a minor part of the total

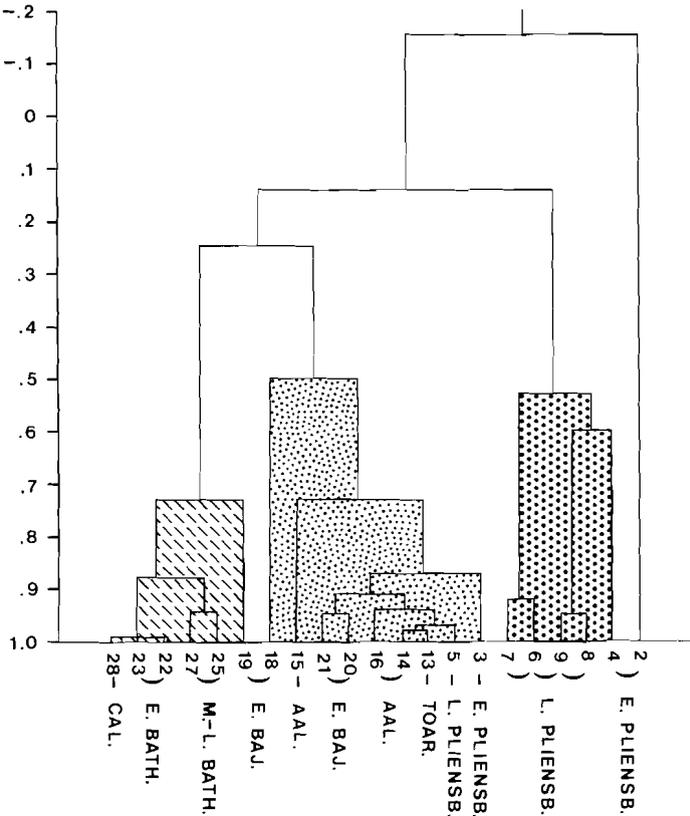


Fig. 11. Q-mode dendrogram of samples from the Brenha section.

population, with a relative frequency that, apart from one exception (their sample 36 CC; 14.6%), never exceeds 10%. *L. muensteri* occurs in only 7 out of 137 samples studied by Gradstein (1983), and he listed their frequency within those samples as being rare (1 to 5 specimens). Although Munk (1980) doesn't give any quantitative data concerning this species, she reports it to be common to abundant in shelf deposits in Western Germany.

Like *L. muensteri*, *Spirillina* spp. (especially *S. tenuissima*) are also known to occur in the above-mentioned environments. They can form a major part of the total population with up to 80% for bathyal/abyssal sediments (Kuznetsova and Seibold, 1978) and up to 90% for shallow shelf sediments (Munk, 1980).

So far when discussing environment only waterdepth has been mentioned, but depth is only one of a set of interdependent factors (which include oxygen content, food, salinity, pH, substrate, temperature) that control the distribution and abundance of benthonic foraminifera. The importance of the factor depth varies with the species, and the upper and lower depth limit of a given species can differ significantly in different areas (Bolotovskoy and Wright, 1976). This means one has to be careful in the assignment of depth estimates based on the abundance of certain foraminifera. However in the case of *L. muensteri* it seems reasonable to assume that this species probably preferred relatively shallow water depths as opposed to bathyal/abyssal depths, whereas in the case of the spirillinids no such preference is apparent. Thus, high abundance of *L. muensteri* could indicate a relatively shallow water depth.

The scarcity, less than 10% of the total benthonic microfauna per sample, and very low diversity of agglutinated foraminifera, with mainly *Reophax*, *Trochammina*, and *Verneuiliinoides* spp., is also an indication of a relatively shallow origin for the sediments. Jurassic deep-water sediments usually contain a diversified fauna of relatively small and simple arenaceous foraminifera. The diversity in relatively shallow water sediments often is much reduced with only a few taxa, which on average are larger and more complex than their oceanic counterparts (Luterbacher, 1972; Bartenstein, 1974; Gradstein, 1983). The agglutinants are positively correlated with the total number of species indicating a preference for a more diverse assemblage which is more likely to occur in relatively deeper water, rather than very shallow water.

Thus from faunal evidence alone, it seems that based on the relative abundance of *L. muensteri*, and the poor representation of arenaceous foraminifera, the water depth at time of sedimentation was relatively shallow. This fits within the paleogeographic framework, according to which the Lusitanian Basin, at least as far as the Cape Mondego area is concerned, reached its maximum waterdepth during the Toarcian. Hallam (1971) postulates that all Toarcian sediments in West-Central Portugal could have been deposited below the

wave-base at depths no greater than 100 m, well within the shelf region in most modern marine areas.

About twenty-seven species have been recognized throughout the Murтинheira section, but the number of species per sample is low, ranging from nine (sample 14.6) to eighteen (sample 14.9). If diversity reflects environment, with a favourable environment resulting in a relatively high diversity, then this low diversity would indicate a rather specialized environment, favourable to only a few species.

Although environment alone is not the only factor that determines the diversity of a fossil assemblage, other factors being diagenesis, differential dissolution, post mortem transport etc., there are indications that the environment could have been substantially responsible for the low diversity. Most of the samples have been taken from sediments that are laminated, indicating worsened bottom conditions (oxygen deficiency) at the time of deposition (there is a strong negative correlation between the number of species and laminated sediments, not significant at the 5% level). In this respect the negative correlation between the Restgroup and *L. muensteri* is of interest. The Restgroup as defined is heterogeneous. It is made up of a variety of species all of which have their own environmental requirements, which means that the group as a whole probably is not very tolerant to environmental stress. The negative correlation with *L. muensteri* then implies an opposite pattern of tolerance for this species, which is expressed in the form of a positive correlation with laminated sediments. The same line of reasoning can be applied for the positive correlations between *Lenticulina* spp. and the number of species per sample, and *Lenticulina* spp. and homogeneous sediments.

The spirillinids are also positively correlated with homogeneous sediments, suggesting that they are not very stress-tolerant. Nevertheless there are indications that to some extent they can tolerate environmental stress. Looking at depth zonations of foraminifera (van der Zwaan, 1982), two zones can be identified that are predominantly inhabited by stress-tolerant species: a very shallow water zone with sediment transport, wave action, fluctuating temperature and salinity, and a deep water zone (below 750–1000 m.) with low oxygen content and low food supply. The high percentage of *Spirillina* spp. in both environments would then classify them as stress-tolerant. This is not necessarily in conflict with their negative correlation with laminated sediments. Laminated sediments usually occur during periods of oxygen deficiency causing a lack of oxidation of organic matter and hence a slowdown in the recycling of nutrients. This implies that the amount of food available increases, but that the quality of it may change. The distribution and abundance of spirillinids then may depend not so much on the amount of food and oxygen but more on the quality of food,

which would explain their negative correlation with laminated sediments and their abundances in shallow and deep water sediments.

The top two Murtinheira samples, from non-laminated sediments, have a species diversity that on average is higher than that of the samples below. The three spirillinid species form 83.5% of the whole benthonic microfossil assemblage in sample 14.10, suggesting that the total number of species (13) is actually relatively high.

Thirty-three species have been recognized in the Brenha section and as mentioned before, the number of species is on average higher than that of the Murtinheira section. However two samples (nos. 22 and 28) have a very low number of species (7 and 6 respectively). This is thought to be due to the very high percentage of spirillinids, more than 90% in both samples.

The Q-mode cluster analysis basically shows three groups of samples (fig. 11). One sample, 30.2, has no similarity with any of these groups, which is probably caused by the anomalously high percentage of miliolids in this sample. The samples are clustered in a more or less stratigraphical position: an Early-Late Pliensbachian cluster, an Early Pliensbachian-Early Bajocian cluster, and an Early Bajocian-Callovian cluster. This may be explained by either a change through time in the environment which resulted in a change in faunal composition, or by certain fossil assemblages being typical for a certain time. In order to answer this question, a Q-mode factor analysis was needed to determine what caused the grouping of the samples.

The results of this analysis are given in table 3, where those values of the rotated factor matrix are in italics that give the highest value of a sample on one of the four factors. The samples corresponding to the italicized values of a factor appear to be exactly the same as the groups of the dendrogram. From the lower part of the table it becomes clear that *L. muensteri* is largely responsible for the composition of factor one and the Early Pliensbachian-Early Bajocian cluster, *Spirillina* spp., are responsible for the second factor and the Early Bajocian-Callovian cluster, and *Nodosaria/Dentalina* spp. and *Eoguttulina* spp. are responsible for the third factor and the Early-Late Pliensbachian cluster. The miliolids cause the separation of sample 30.2 from all others (fourth factor).

It is believed that this reflects a more or less sustained change in environment, a gradual shallowing of the basin, rather than fossil assemblages that are typical for a certain time-stratigraphic level. As mentioned before, *L. muensteri* and *Spirillina* spp. are common throughout the Jurassic, and as discussed above their distribution and abundance seem to be environmentally controlled, which means that assemblages that are characterized by high percentages of *L. muensteri* or spirillinids give more information concerning the environment than the age. This becomes clearer when one recalls that the spirillinids were

Table 3. Q-mode factor analysis Brenha section.

| Factor (U) | U1 | U2 | U3 | U4 |
|---------------|------|-----|-----|------|
| Sample number | | | | |
| 30.2 | .03 | .02 | .07 | .97 |
| 30.3 | .83 | .16 | .38 | .00 |
| 30.4 | .34 | .19 | .77 | .34 |
| 30.5 | .94 | .12 | .21 | -.03 |
| 30.6 | .62 | .08 | .71 | -.01 |
| 30.7 | .64 | .11 | .67 | -.03 |
| 30.8 | .16 | .07 | .96 | -.02 |
| 30.9 | .19 | .04 | .95 | -.00 |
| 30.13 | .96 | .13 | .09 | -.01 |
| 30.14 | .95 | .15 | .20 | -.03 |
| 30.15 | .90 | .18 | .13 | .10 |
| 30.16 | .98 | .05 | .12 | -.01 |
| 30.18 | .61 | .20 | .17 | .19 |
| 30.19 | .52 | .67 | .47 | .11 |
| 30.20 | .83 | .21 | .46 | .11 |
| 30.21 | .90 | .17 | .36 | .00 |
| 30.22 | -.01 | .99 | .03 | -.01 |
| 30.23 | .08 | .99 | .06 | .01 |
| 30.25 | .48 | .86 | .10 | .08 |
| 30.27 | .37 | .90 | .17 | .03 |
| 30.28 | .01 | .99 | .02 | -.01 |

Rotated factor matrix

| | | | | |
|---------------------------------|-------|-------|-------|-------|
| <i>S. tenuissima</i> | -5.99 | 73.01 | -2.90 | -5.17 |
| <i>S. elongata</i> | -.34 | 4.10 | -.22 | -.23 |
| <i>S. infima</i> | .21 | 1.38 | .06 | .22 |
| <i>L. muensteri</i> | 59.19 | -1.58 | -6.96 | -8.11 |
| <i>L. quenstedti</i> | 10.55 | 2.09 | -5.09 | 9.65 |
| <i>Lenticulina</i> spp. | 7.91 | 1.28 | 4.43 | 8.98 |
| <i>Nodosaria/Dentalina</i> spp. | .88 | -2.21 | 27.38 | -2.85 |
| miliolids | -.81 | -2.17 | -2.01 | 81.71 |
| <i>Eoguttulina</i> spp. | -3.00 | -1.96 | 40.59 | -6.47 |
| Restgroup | 3.39 | 3.05 | 10.66 | 1.11 |
| Agglutinants | 2.29 | 2.99 | 2.29 | 1.45 |
| Number of species | 11.16 | 9.22 | 12.92 | 11.22 |

Varimax factor scores

the predominant faunal element in the Murtinheira section in samples from the Aalenian and Lower Bajocian, whereas in the case of the Brenha section they were predominant in samples from the Bathonian-Callovian. This is illustrated in fig. 12. which shows a dendrogram based on the combined data-sets of both sections (sample numbers in italics indicate samples from Murtinheira).

If the idea of a changing environment is correct, it implies that the gradual shallowing of the basin in the Aalenian and Bajocian was faster in the Mur-

tinheira area then in the Brenha area. Another implication of this idea is that *Eoguttulina* spp. and to a lesser extent *Nodosaria/Dentalina* spp. can tentatively be described as being characteristic for the deepest water foraminiferal assemblage (?100 m, Hallam, 1971) present in the Mondego area.

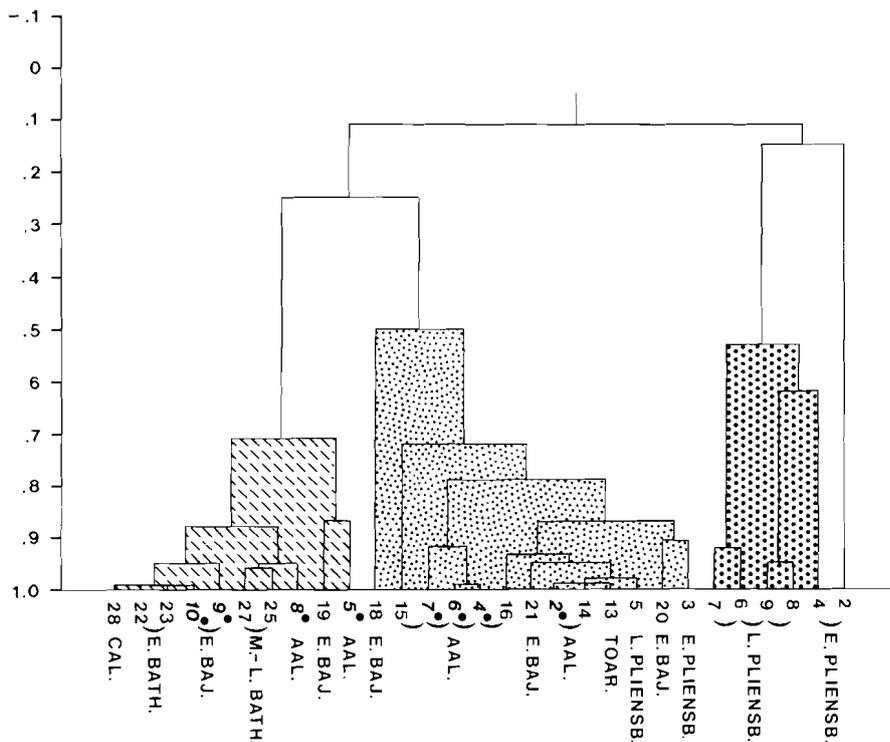


Fig. 12. Q-mode dendrogram of samples from both the Brenha and the Murtinheira sections.

In conclusion it can be said that the benthonic microfauna of both sections is very similar and shows the same overall behaviour. A relatively deep water assemblage dominated by *L. muensteri*, *Eoguttulina* spp. and *Nodosaria/Dentalina* spp. is easily distinguished from a shallow water assemblage dominated by spirillinids. There is some, although less clear, differentiation between a deep (*L. muensteri*) and a deeper(?) (*Eoguttulina* and *Nodosaria/Dentalina* spp.) assemblage. *Lenticulina* spp. and the miliolids have to be placed somewhere in between, considering their very low association with the relatively deep water assemblage in one case (Brenha) and with the shallow water assemblage in the other case (Murtinheira).

2.4: MONTEJUNTO AREA

2.4.1: Introduction

An almost complete, but folded and faulted, sequence of Bathonian through Kimmeridgian marine sediments is exposed in the Montejunto area, ca. 50 km north of Lisbon (fig. 2), on the top and on the flanks of Montejunto, a 664 m high mountain ca. 7 km east-northeast of Vila Verde (fig. 13). The geology and macro-paleontology of the area, as far as known, has been described by Choffat (1880, 1893), Ruget-Perrot (1961), and Mouterde *et al.* (1972, 1973).

Apart from the Bathonian-Callovian part of the sequence, which is indicated as “Mid-Jurassic hard limestone” in fig. 13, formation names are used for the Upper Jurassic. These names, Cabacos, Montejunto, Tojeira, Cabrito, Abadia, and Amaral Formations (fig. 16), correspond to names used in the literature, but the lithostratigraphic unit they represent may differ from the ones used here. Mempel (1955) recognized Lower, Middle and Upper Abadia Beds. His Lower Abadia Beds include the Tojeira and Cabrito Formations. Mempel’s Middle Abadia beds, consisting of fine-grained calcareous sandstone with sandy shale, and Upper Abadia Beds, consisting of sandy shales with calcareous sandstone and clay ironstone nodules, are equivalent to the Abadia Formation as used here. Ruget-Perrot (1961) and Wilson (1979) include the Tojeira Formation in the Montejunto Beds, and the Cabrito and Amaral Formation in the Abadia Beds. The subdivision as used here is similar to the one used by Mouterde *et al.* (1973), who used ammonite zones to define the lower and upper boundaries of their formations, instead of lithological characteristics as is done here.

2.4.2: Stratigraphic framework

The lithostratigraphy presented here is based on cross-sections 1 to 4 of figs. 13, 14 and 21. The whole sequence can be seen along cross-sections 1 to 3, while cross-section 4 shows essentially the same as the southern half of section 2.

Middle Jurassic

Starting on the top of the mountain, the oldest strata consist of thick bedded (0.5–2 m) beige to grey, mainly micritic, sometimes oolitic/pisolitic limestones with rare crinoids and *Ostrea*. No ammonites were observed nor are any reported from the literature. Based on the occurrence of the larger foraminifer *Meyendorffina bathonica* Bizon, Zbyszewski *et al.* (1966) believe these strata to belong to the Upper Bathonian. This is overlain by some 100 to 130 m of beige to brown oolitic, algal, and bioclastic limestone with minor shale intercala-

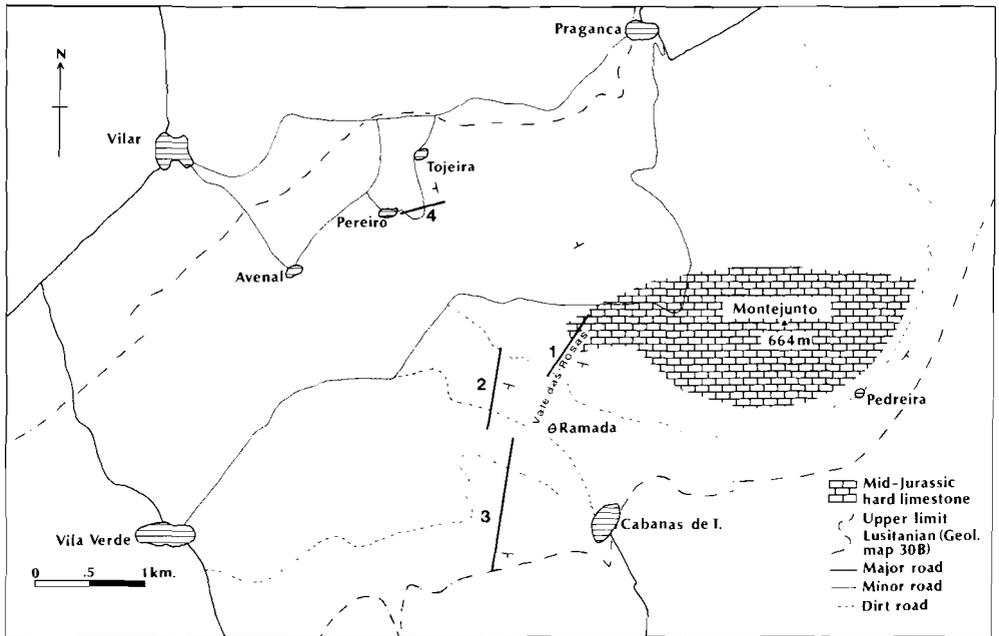


Fig. 13. Location map of the Montejunto area, with locations of cross-sections 1, 2, 3, and 4.

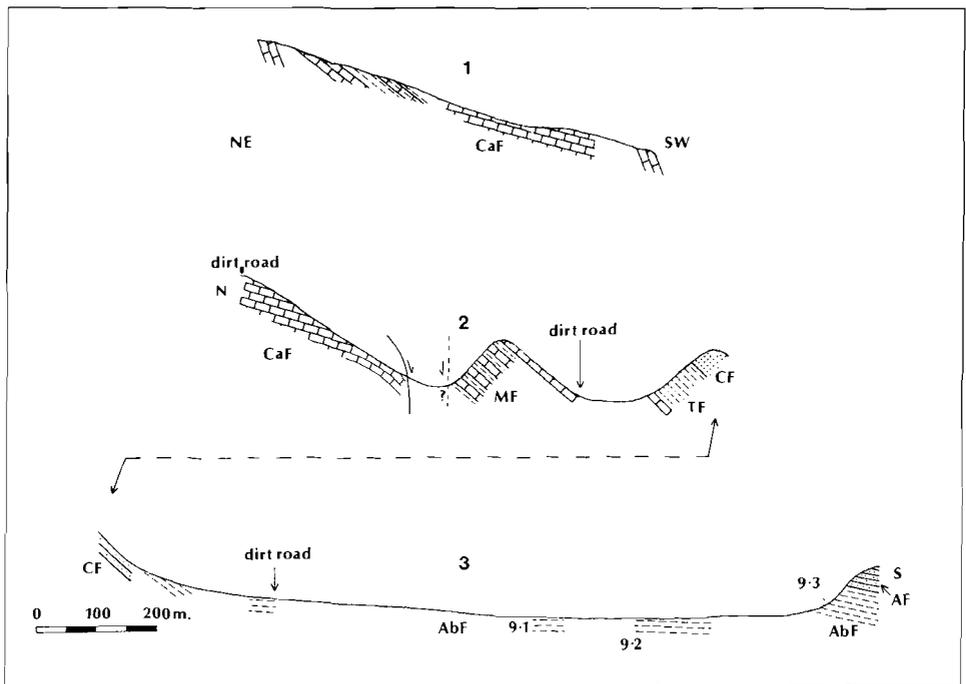


Fig. 14. Cross-sections 1, 2, and 3 of fig. 13. CaF. = Cabacos Formation; MF = Montejunto Formation; TF = Tojeira Formation; CF = Cabrito Formation; AbF = Abadia Formation; AF = Amaral Formation. 9.1, 9.2, and 9.3 are sample locations.

tions. The bed thickness is on average less than in the underlying unit, becoming thin bedded towards the top. Ammonites are present and the *Macrocephalus* through *Athleta* Zones have been recognized (Ruget-Perrot, 1961).

The Upper Jurassic formations, described next, are separated from these Middle Jurassic sediments by an hiatus: the Upper Callovian *Lamberti* Zone and the Lower Oxfordian *Mariae* Zone are missing.

Upper Jurassic

Cabacos Formation (*Cordatum-Transversarium* Zones)

The basal 30 m of this formation consists of platy, thin bedded, grey limestone and shaly limestone, which is highly bituminous. This is overlain by at least 200 m of thick bedded (0.5–2 m) yellow to dark brown bituminous limestone, which is fine-grained, micritic, and locally oolitic. There are minor dark grey to black shale intercalations. Towards the top of this formation some algal laminations, oncoliths, and chert nodules occur. Ammonites occur throughout the formation but are, especially in the lower part, rare. Some brachiopods and pelecypods have been encountered, which occasionally make up lumachelles.

Montejunto Formation (*Transversarium-Planula* Zones)

The lower part of this 150 to 250 m thick formation consists of thick bedded (up to 2 m) white to grey, micritic limestone, changing to an alternation of bluish-grey limestone (up to 50 cm thick) and grey, hard shale. At first the shale intercalations are thinner than the limestones, but towards the top the number and the thickness of these intercalations increases and their colour changes from grey to dark grey. At the top of the formation shale is the predominant lithology. Two coarse bioclastic to oolitic beds which contain crinoid-brachiopod biostromes of a few metres across have been observed in the middle part of the formation (fig. 15). Ammonites are common throughout the formation. At the top, near the covered contact with the overlying *Tojeira* Formation, several shale and limestone beds are rich in ammonites that sometimes cover an entire bedding plane.

Tojeira Formation (*Planula-Platynota* Zones)

This formation is at least 70 m thick and consists almost entirely of dark grey shales, in which limonite concretions are common. Some calcareous shale intercalations occur in the lower part of the formation. Locally in the middle part of the formation, the shale is brownish-red. Close to the boundary with the overlying *Cabrito* Formation, there is a marked increase in silt content. Pyritized ammonites are common to abundant in the lower part, but are relatively rare in the upper part of the formation. A few belemnites have been observed.

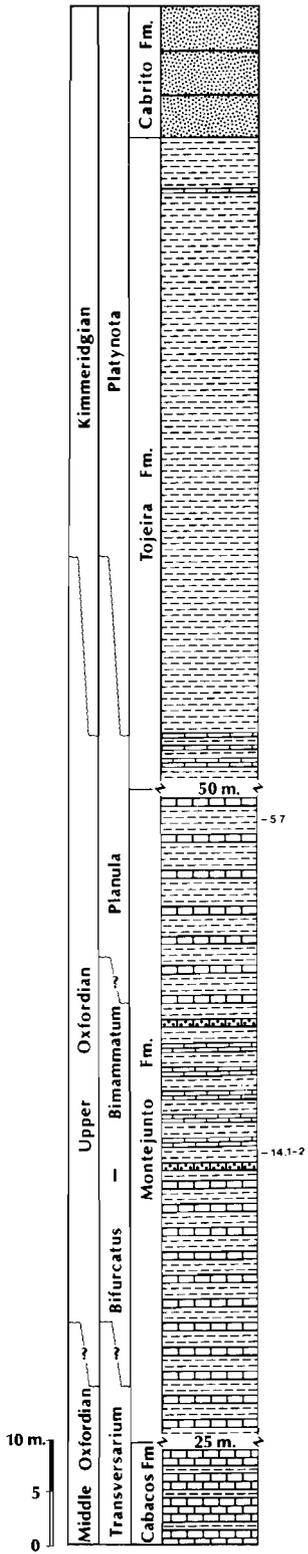


Fig. 15. Litho-, bio-, and chronostratigraphy of a section along the southern half of cross-section 1 and cross-section 2 (figs. 13, 14) (left).

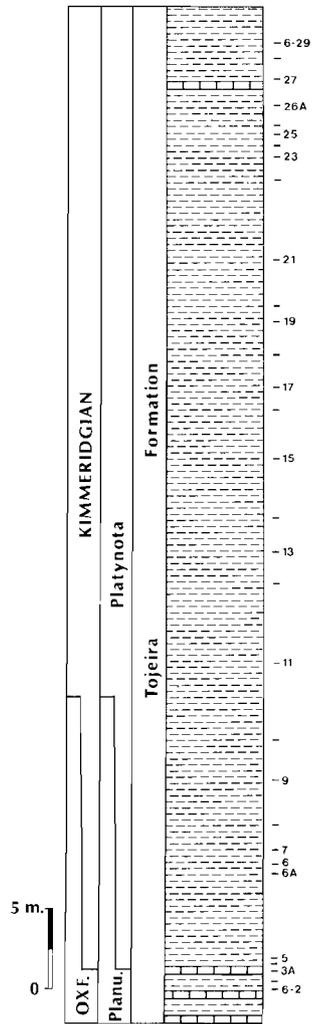


Fig. 17. The Tojeira 1 section with sample numbers, located along the southern half of cross-section 2 (figs. 13, 14) (right).

Cabrito Formation (? Platynota Zone)

To the south and southwest of Montejunto, this formation consists of massive, coarse-grained to conglomeratic, micaceous sandstone, with white quartz and pink feldspar pebbles. The sandstone is dark yellow to brown in colour, sometimes showing a weak lamination, and is in general poorly sorted, showing no grading. In isolated blocks, large (up to 40 cm) deformed inclusions of coarse-grained brown sandstone within a finer grained and lighter coloured sandstone have been observed. Crinoids, shell debris and large (up to 40 cm) parts of coral colonies are common to abundant. Tool marks, when present, suggest east-west transport. West of Montejunto, along the road from Tojeira to Pereiro (fig. 21, no. 13), the sandstone has a bright yellow colour, is coarse-grained to conglomeratic, micaceous, and shows grading. It alternates with dark micaceous silt. The sandstone beds are thick (1.5–5 m), have an erosive base, show fining upward, and channelling. Again, white quartz and pink feldspar pebbles are present. Mempel (1955) described a similar, ca. 50 m thick, sequence of the Cabrito Formation (his Lower Abadia Beds) from the same area, between Pereiro and Avenal (fig. 13), consisting of thick sandstones with channel fills, conglomerates, siltstones and shales. In the vicinity of Montejunto, the formation is about 40–50 m thick, but thickens rapidly towards the west. This was interpreted by Mouterde *et al.* (1973) as indicative of a westerly source for the influx of these clastics. Mempel (1955), based on a grainsize study of the conglomerates and their petrology, suggested an easterly source (Iberian Meseta). A few badly preserved ammonites have been reported (Mempel, 1955; Mouterde *et al.*, 1973).

Abadia Formation (? Kimmeridgian)

One of the best outcrops of this formation is located south of Vila Verde, near the intersection with the dirt road to Cabanas de Torres (fig. 13). This outcrop consists of thick (up to 4 m), coarse-grained sandstone, blue in colour, showing ripple marks and channelling. The sandstone alternates with bluish sandy siltstone/shale. This exposure represents a part of the lower Abadia Formation. It is overlain by poorly exposed blue-grey silty shales, which are rich in limonite concretions. Characteristic of this formation is the blue colour of its sediments and the presence of abundant black plant remains. Ostracods and thin-shelled bivalves are common, but no ammonites were observed. The thickness of the Abadia Formation is estimated to be approximately 750–800 m, which is in close agreement with Wilson and Exton (1979).

Amaral Formation (? Kimmeridgian)

This formation is up to 70 m thick, and consists of well sorted, brownish quartz sandstone containing plant remains, and sometimes showing low-angle of cross-

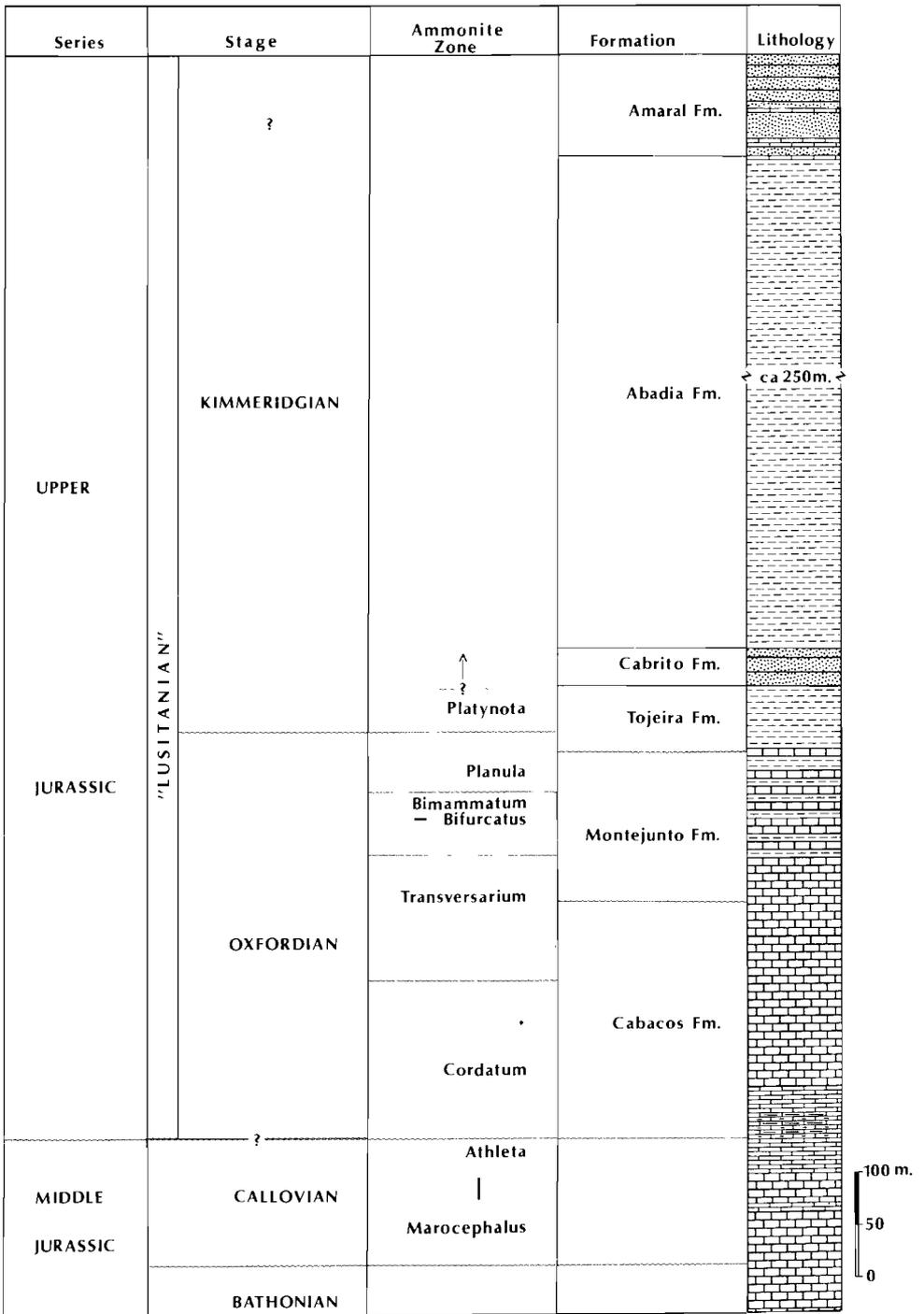


Fig. 16. Litho-, bio-, and chronostratigraphic framework for the Montejunto area.

bedding. In the lower part of the formation the sandstone alternates with oolitic limestone. A few *Ostrea* and pelecypods are present, but no ammonites were observed.

Stratigraphic summary

The litho-, bio-, and chronostratigraphy is given in fig. 16. The ammonite zonation for the Callovian through Middle Oxfordian is after Ruget-Perrot (1961) and Mouterde *et al.* (1972, 1973). The zonation for the Upper Oxfordian and Lower Kimmeridgian is after Poulton (1983, internal report Geological Survey of Canada, appendix). The stage name Lusitanian (see also fig. 13), even though still used (Rocha *et al.*, 1981), has only a historical meaning. It was introduced by Choffat in the eighties of the last century for those facies of the Upper Malm for which no suitable age determinations were available.

The paleogeographic framework, outlined in section 2.2, is well reflected by the lithologies in the Montejunto area: shallow marine carbonates (oolitic/pisolitic, algal, and bioclastic) during the Bathonian and Callovian; an Upper Callovian-Lower Oxfordian hiatus; further shallow marine carbonates (Cabacos Formation), with a trend in the Late Oxfordian towards lower energy sedimentation (deeper water, increasing shale intercalations; Montejunto Formation); and by the end of the Oxfordian deeper water sedimentation predominates (Tojeira Formation). In the Early Kimmeridgian tectonic activity and an increase in subsidence and sedimentation rates resulted in the deposition of a thick sequence of marine terrigenous, in part turbiditic clastics (Cabrito and lower part Abadia Formation), followed by shallow to marginal marine oolitic limestones and sandstones of the Amaral Formation.

2.4.3: The sections

Lithologies suitable for foraminiferal analysis (i.e. the softer ones) occur within the Montejunto, Tojeira and Abadia Formations. Two sections have been sampled in detail. One, called Tojeira 1, is located along the southern half of cross-section 2, near the hamlet of Ramada, and covers the top ca. 65 m of the Tojeira Formation. The second, Tojeira 2, is located along cross-section 4, near Pereiro, and covers the top of the Montejunto Formation and the upper part of the Tojeira Formation.

A few samples have been collected in the vicinity of cross-section 4 (stop 13, fig. 21). These few samples contain virtually no foraminifera, and hence have not been used for quantitative analyses. Five samples, taken in 1978, from the poorly exposed upper part of the Abadia Formation contain no foraminifera. Three samples (9.1–9.3) taken in 1984 from the same formation, along cross

Table 4. Distribution chart (%) of the foraminifera from the Tojeira 1 section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---------------|------|------|------|------|------|------|------|-----|------|-----|------|------|------|------|------|------|----|-----|
| Sample number | | | | | | | | | | | | | | | | | | |
| 6.2 | 5.0 | 4.1 | .0 | .0 | 1.5 | 7.9 | 6.6 | 4.8 | 10.4 | .0 | .0 | 1.8 | .9 | 45.3 | 11.7 | – | 36 | 558 |
| 6.3 | 2.5 | 14.8 | .0 | .0 | .0 | 24.7 | 5.7 | 4.9 | .2 | .0 | .0 | .9 | 18.8 | 17.9 | 9.6 | .01 | 24 | 453 |
| 6.3A | .5 | 19.0 | .0 | .5 | .0 | 22.5 | 3.8 | 4.6 | 1.1 | .0 | .0 | .0 | 26.8 | 13.6 | 7.6 | – | 22 | 369 |
| 6.4 | 5.0 | 5.4 | .2 | 1.2 | .0 | 19.8 | 10.6 | 3.4 | 4.2 | .0 | .0 | 2.4 | .4 | 26.1 | 21.3 | – | 34 | 501 |
| 6.5 | 2.6 | 1.8 | 15.1 | .0 | 13.3 | 4.7 | 4.9 | .0 | .0 | .0 | .0 | 2.9 | 7.2 | 34.8 | 11.9 | .01 | 32 | 511 |
| 6.6A | 1.2 | 13.5 | 8.4 | 1.5 | 16.2 | 5.4 | .3 | .6 | 14.4 | .0 | .0 | 13.8 | 6.0 | 11.7 | 7.0 | .09 | 21 | 333 |
| 6.6 | 2.3 | .22 | 24.2 | 11.8 | .0 | 9.9 | 4.8 | 2.5 | 3.8 | .0 | .0 | 10.8 | 3.8 | 9.1 | 14.8 | .02 | 30 | 372 |
| 6.7 | 5.4 | 3.4 | 18.1 | 3.4 | .0 | 11.1 | 3.1 | 3.8 | 3.8 | .2 | .0 | 6.9 | .6 | 29.2 | 11.0 | .09 | 32 | 524 |
| 6.8 | 4.5 | .3 | 12.4 | 1.0 | .0 | 5.6 | 2.1 | 2.0 | 35.4 | .0 | 5.1 | 5.3 | .0 | 15.4 | 10.9 | .13 | 26 | 396 |
| 6.9 | 6.4 | 2.6 | 26.1 | 4.3 | .3 | 4.6 | 4.1 | 2.6 | 3.7 | .0 | 10.9 | 5.7 | .0 | 23.2 | 5.5 | .40 | 27 | 349 |
| 6.10 | 5.1 | 1.1 | 27.6 | 2.5 | 2.5 | 1.4 | .6 | 2.2 | 1.1 | .3 | 29.6 | 1.7 | .3 | 20.7 | 3.3 | 1.19 | 27 | 362 |
| 6.11 | 3.7 | 1.1 | 13.2 | 17.6 | .0 | 23.0 | 6.1 | 2.0 | .5 | .2 | 10.9 | 1.1 | .2 | 11.1 | 9.3 | .08 | 31 | 614 |
| 6.12 | 21.6 | 1.3 | 23.6 | 3.0 | 3.0 | 9.3 | 3.3 | .0 | .0 | .0 | 12.3 | 1.3 | .0 | 15.0 | 6.3 | .17 | 27 | 301 |
| 6.13 | 3.9 | .6 | 23.3 | 5.7 | 4.8 | 8.7 | 2.7 | .3 | 1.2 | .0 | 14.0 | 1.5 | .0 | 23.0 | 10.3 | .60 | 26 | 335 |
| 6.14 | 7.6 | 1.5 | 15.5 | .7 | .9 | 4.8 | 3.8 | 1.8 | 2.4 | 2.3 | 4.8 | 5.0 | .7 | 31.3 | 6.9 | .44 | 37 | 459 |
| 6.15 | 2.4 | .3 | 35.2 | 7.8 | 6.0 | 8.1 | 7.2 | 1.5 | .6 | .3 | 10.5 | 1.5 | .0 | 15.1 | 3.5 | .41 | 30 | 332 |
| 6.16 | 7.8 | .5 | 21.4 | 3.1 | 7.7 | 15.2 | 5.5 | 1.4 | 2.1 | 2.9 | 15.0 | 1.7 | .0 | 11.2 | 4.5 | .28 | 37 | 420 |
| 6.17 | 2.9 | 1.1 | 46.3 | 2.0 | 1.9 | 5.1 | 2.8 | 1.1 | 1.4 | 8.3 | 6.4 | 4.1 | .0 | 13.2 | 3.4 | .16 | 30 | 916 |
| 6.18 | 14.0 | .3 | 18.0 | 1.7 | 5.3 | 3.9 | 7.2 | 2.8 | .8 | 6.6 | 8.0 | 4.7 | .0 | 20.8 | 5.9 | .44 | 34 | 361 |
| 6.19 | 8.5 | .8 | 39.7 | .6 | 3.5 | 3.5 | 4.4 | 2.5 | 1.0 | 1.9 | 11.6 | 4.1 | .0 | 8.3 | 9.6 | .11 | 30 | 484 |
| 6.20 | 6.0 | .8 | 30.4 | 6.0 | 1.4 | 9.1 | 7.4 | 1.5 | 1.9 | .4 | 12.6 | 4.4 | 1.0 | 9.1 | 8.0 | .06 | 35 | 517 |
| 6.21 | 11.4 | .8 | 13.5 | 1.7 | 1.2 | 15.0 | 11.3 | 1.9 | 1.9 | 7.2 | 9.3 | 4.2 | .0 | 13.5 | 7.1 | .06 | 37 | 527 |
| 6.22 | 4.6 | 3.5 | 23.0 | .3 | .8 | 11.8 | 6.6 | 1.6 | .5 | 2.4 | 11.8 | 7.6 | .0 | 22.3 | 3.2 | .30 | 35 | 382 |
| 6.23 | 3.3 | 1.5 | 33.5 | .8 | 6.2 | 11.4 | 9.3 | 2.1 | 1.6 | 1.9 | 10.9 | 4.8 | .0 | 7.7 | 5.0 | .16 | 25 | 376 |
| 6.24 | 7.1 | .6 | 37.1 | 3.2 | 3.1 | 6.6 | 3.6 | 1.5 | 1.2 | 5.8 | 1.0 | 3.4 | .0 | 9.0 | 16.8 | .11 | 35 | 412 |
| 6.25 | 7.4 | .6 | 36.6 | 7.4 | 8.4 | 9.1 | 1.2 | 3.9 | .6 | 1.9 | .0 | 1.9 | .0 | 13.6 | 7.4 | .31 | 33 | 309 |
| 6.26 | 17.1 | .9 | 38.8 | 4.9 | .6 | 6.7 | 2.7 | 1.7 | .6 | 2.9 | 3.2 | .6 | .0 | 13.3 | 6.0 | .08 | 27 | 345 |
| 6.26A | 2.2 | 1.0 | 34.8 | 3.7 | 3.4 | 16.2 | 3.3 | 2.5 | .3 | 5.2 | 9.1 | 4.6 | .0 | 7.0 | 6.7 | .02 | 43 | 767 |
| 6.27 | 10.6 | .3 | 36.5 | 1.2 | 1.8 | 11.9 | 8.8 | .3 | 1.2 | 2.7 | 6.4 | 5.5 | .0 | 8.8 | 4.0 | .34 | 28 | 329 |
| 6.28 | 11.8 | .0 | 27.4 | 3.4 | 2.3 | 14.0 | 2.4 | 2.0 | .3 | 1.1 | 17.1 | 2.3 | .0 | 9.4 | 6.5 | .70 | 28 | 351 |
| 6.29 | 6.2 | .2 | 16.7 | 3.2 | 2.5 | 6.5 | .6 | 2.5 | .0 | 5.3 | 21.6 | 4.9 | .4 | 16.0 | 13.4 | .64 | 29 | 474 |

1 = Agglutinants

2 = *Eoguttulina* spp.3 = *E. mosquensis*4 = *E. uhligi*5 = *Epistomina* spp.6 = *L. muensteri*7 = *Lenticulina* spp.8 = *Nodosaria/Dentalina* spp.9 = *O. carinatum*10 = *O. strumosum*11 = *P. rjasanensis*12 = *S. elongata*13 = *S. infima*14 = *S. tenuissima*

15 = Restgroup

16 = P/B-ratio

17 = number of species

18 = total number benthos counted

species or species groups. These species/species groups are: *Eoguttulina* spp. (*E. oolithica* and *E. metensis*), *Epistomina mosquensis*, *E. ubligi*, all other *Epistomina* spp., *L. muensteri*, all other *Lenticulina* spp., *Nodosaria/Dentalina* spp., *Pseudolamarckina rjasanensis*, *S. elongata*, *S. infima*, *S. tenuissima*, *Ophthalmidium carinatum*, *O. strumosum*, the agglutinants (*Ammobaculites* spp., *Reophax* spp., *Trochammina* spp., *Textularia* spp., *Bigenerina* spp.). All other species are grouped in a Restgroup, usually comprising less than 15% of

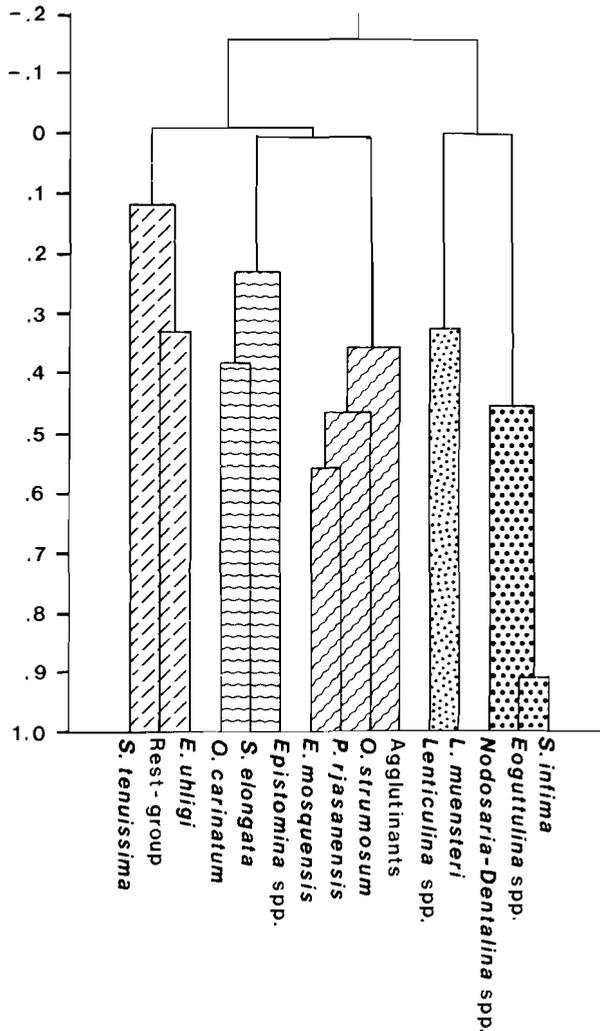


Fig. 19. R-mode dendrogram of the benthonic foraminifera from the Tojeira 1 section.

the benthonic microfauna. Two other parameters used in the analysis are the number of species and the plankton-benthos ratio.

The frequency patterns are given in table 4, from which it can be seen that *E. mosquensis*, *E. ubligi*, and *P. rjasanensis* are the predominating faunal elements and that *S. tenuissima* and *L. muensteri* have their highest relative frequency in samples from the lower part of the section. The P/B-ratio ranges from zero to 1.19, with an average of about 0.24. The number of species per sample is relatively high (certainly if compared with Murtinheira and Brenha) and ranges from 21 to 43, with an average of about 30. Trends, if any, of categories and relationships between categories are not clear from this table.

Significant positive and negative correlations between the various categories are given in fig. 18. Significant positive trends are found for *E. mosquensis*, *P. rjasanensis*, *O. strumosum* and the agglutinants, whereas *Eoguttulina* spp., *S. infima*, and *S. tenuissima* show a negative trend.

An R-mode dendrogram (fig. 19) shows five groups: group 1 consists of *E. ubligi*, the Restgroup, and *S. tenuissima*; group 2 consists of *O. carinatum*, *S. elongata*, and *Epistomina* spp.; group 3 is formed by *E. mosquensis*, *P. rjasanensis*, *O. strumosum*, and the agglutinants; group 4 consists of *L. muensteri* and *Lenticulina* spp.; and group 5 is formed by *Eoguttulina* spp., *Nodosaria/Dentalina* spp. and *S. infima*.

A Q-mode analysis shows three groups of samples (fig. 20 and table 5), one is formed by samples 2, 3, 3A, 4, and 5, a second is formed by samples 6A and 8, and the third consists of all other samples.

2.4.5: Discussion

As mentioned before, *P. rjasanensis*, *E. mosquensis*, and *E. ubligi* together form a major part of the benthonic microfauna and will for that reason be dealt with first. *P. rjasanensis* so far has only been reported from deeper shelf deposits (Uhlig, 1883; Mjatluk, 1953; Lutze, 1960; Pazdro, 1969), whereas *E. mosquensis* and *E. ubligi* have been described from bathyal/abyssal to shallow shelf deposits (Luterbacher, 1972; Sliter, 1980; Gradstein, 1983). However assemblages containing abundant epistominids and a co-occurrence of *P. rjasanensis*, *E. mosquensis* and *E. ubligi* are only known for (deeper) shelf deposits (e.g. Pazdro, 1969).

When examining some of the literature that deals with these species, especially the epistominids, an interesting picture emerges. Lloyd (1962), Guyader (1968), Gordon (1970), Corbett (1978), Munk (1980), and Barnard *et al.* (1982) all describe the occurrence of either *E. mosquensis* or *E. ubligi* (which some refer to as *E. parastelligera*) or both from sediments that range in age from Middle Callovian to Kimmeridgian and without exception their samples come from clay/shale deposits.

Lutze (1960) mentioned the co-occurrence of *E. mosquensis* and *P. rjasanensis* (which he calls *Conorboides nuda*, see taxonomic notes) from Middle Callovian shale deposits, while Mjatliuk (1953) describes *P. rjasanensis* to be rare to common in the Middle and Upper Callovian clays and abundant in Kimmeridgian clay deposits. According to Pazdro (1969, p. 36) epistominids are restricted to "silty-clayey-marly" sediments in which *E. mosquensis* and *E. ubligi* are abundant and *P. rjasanensis* is frequent.

Thus, literature suggests that the stratigraphical range of these three species is from Middle Callovian to Kimmeridgian and that their occurrence within this timespan is strongly facies controlled and restricted to deeper shelf deposits. As will be shown below, the results of the quantitative analyses fit these conclusions.

The Tojeira shale probably was deposited in a relatively deeper shelf environment. According to the paleogeographic framework this formation represents

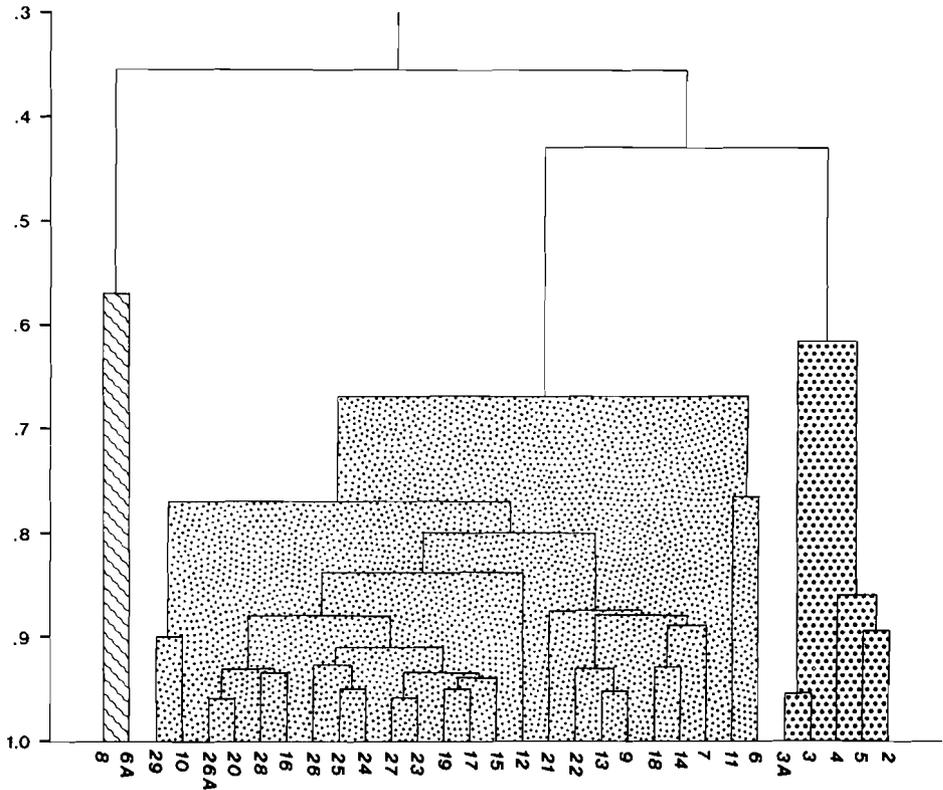


Fig. 20. Q-mode dendrogram of the samples from the Tojeira 1 section.

the deepest water deposits in the Montejunto area. This is supported by the relatively diverse (about 14 species recognized) agglutinated fauna which (see section 2.3.4) becomes more diverse with increasing water depth. This then would mean that group 3 (*E. mosquensis*, *P. rjasanensis*, *O. strumosum* and the agglutinants) of the dendrogram of fig. 19 consists of species with a preference for relatively deeper water. All species of this group are mutually positively correlated and they all show a significant positive trend, possibly meaning that the deepening of the basin that started sometime during the deposition of the Montejunto Formation, was still continuing.

The negative trend as shown by *S. tenuissima* fits in well and actually confirms the idea of this species preferring shallow water (see prior discussion of the Murтинheira and Brenha sections). Negative trends are also shown by *S. infima* and *Eoguttulina* spp. In the case of *S. infima* this is not really surprising considering the results of the two other sections. In the Brenha and Murтинheira sections *Eoguttulina* spp. was tentatively described as characteristic for the deepest foraminiferal assemblage and a negative trend was not really expected. Unexpected also is the behaviour of *S. infima* and *S. elongata*, which for the Murтинheira and Brenha sections were positively correlated with *S. tenuissima*. A possible cause of this will be discussed when comparing the Tojeira 1 and Tojeira 2 sections.

L. muensteri (see fig. 18) is positively correlated with the other lenticulinids, *S. infima*, and *Eoguttulina* spp. and negatively correlated with *Epistomina* spp., *S. elongata*, and *S. tenuissima* which puts it approximately among the same species as in the analysis of the other two sections. *Epistomina* spp., although not significant, has a high positive correlation with *E. mosquensis* and a significant negative correlation with *L. muensteri* and *Nodosaria/Dentalina* spp., which indicates that they are closer to the deep water association rather than the shallow water one. To some extent the opposite is true for *E. ubligi* which has a high but not significant correlation with *L. muensteri*.

In terms of depth there is an assemblage consisting of *E. mosquensis*, *P. rjasanensis*, *O. strumosum*, and the agglutinants which preferred relatively deeper water, and an assemblage consisting of *L. muensteri*, *S. infima*, *Eoguttulina* spp., *Nodosaria/Dentalina* spp., and *Lenticulina* spp. which preferred relatively shallower water. The group formed by *Epistomina* spp., *O. carinatum*, and *S. elongata* is, considering their negative correlations with the shallow water group, closer to the deeper group, whereas *E. ubligi* and the Restgroup are probably closer to the shallow water assemblage. *S. tenuissima* does not show a clear association with any of these groups and probably takes the same ecological position as in the case of Murтинheira and Brenha, preferring very shallow water.

Table 5. Q-mode factor analysis Tojeira 1 section

| Sample number | Factor (U) | U1 | U2 | U3 | U4 |
|---------------|------------|-----|-----|------|-----|
| 6.2 | | .23 | .40 | -.81 | .33 |
| 6.3 | | .23 | .89 | -.33 | .15 |
| 6.3A | | .18 | .91 | -.18 | .16 |
| 6.4 | | .32 | .61 | -.62 | .24 |
| 6.5 | | .29 | .57 | -.70 | .17 |
| 6.6A | | .37 | .43 | -.27 | .69 |
| 6.6 | | .74 | .41 | -.25 | .35 |
| 6.7 | | .58 | .41 | -.59 | .33 |
| 6.8 | | .39 | .18 | -.44 | .68 |
| 6.9 | | .77 | .21 | -.52 | .25 |
| 6.10 | | .79 | .07 | -.50 | .05 |
| 6.11 | | .65 | .55 | -.39 | .04 |
| 6.12 | | .80 | .24 | -.44 | .09 |
| 6.13 | | .75 | .27 | -.54 | .17 |
| 6.14 | | .57 | .31 | -.68 | .25 |
| 6.15 | | .89 | .21 | -.31 | .18 |
| 6.16 | | .80 | .37 | -.39 | .13 |
| 6.17 | | .92 | .11 | -.19 | .24 |
| 6.18 | | .71 | .27 | -.58 | .21 |
| 6.19 | | .93 | .12 | -.21 | .21 |
| 6.20 | | .88 | .28 | -.30 | .18 |
| 6.21 | | .68 | .45 | -.49 | .14 |
| 6.22 | | .74 | .35 | -.51 | .18 |
| 6.23 | | .92 | .24 | -.18 | .20 |
| 6.24 | | .86 | .24 | -.22 | .29 |
| 6.25 | | .86 | .25 | -.25 | .28 |
| 6.26 | | .90 | .16 | -.25 | .19 |
| 6.26A | | .87 | .34 | -.22 | .19 |
| 6.27 | | .92 | .23 | -.19 | .19 |
| 6.28 | | .88 | .27 | -.32 | .06 |
| 6.29 | | .73 | .26 | -.55 | .09 |

Rotated factor matrix

| Species/species group | U1 | U2 | U3 | U4 |
|---------------------------------|-------|--------|--------|--------|
| <i>Eoguttulina</i> spp. | -2.92 | 16.60 | 6.35 | 7.02 |
| <i>E. mosquensis</i> | 43.30 | -10.19 | 15.28 | 8.95 |
| <i>E. ubligi</i> | 3.68 | 4.64 | -1.55 | -3.75 |
| <i>Epistomina</i> spp. | 3.07 | -.27 | 3.30 | 9.30 |
| <i>L. muensteri</i> | 5.53 | 30.08 | 4.31 | -8.12 |
| <i>Lenticulina</i> spp. | 3.31 | 6.10 | -2.38 | -2.40 |
| <i>Nodosaria/Dentalina</i> spp. | .02 | 3.95 | -2.09 | .38 |
| <i>P. rjasanensis</i> | 13.37 | -6.57 | -12.05 | -17.91 |
| <i>S. elongata</i> | 1.85 | -.22 | .39 | 13.17 |
| <i>S. infima</i> | -3.13 | 22.75 | 9.39 | .78 |
| <i>S. tenuissima</i> | -3.63 | 1.89 | -43.90 | 5.15 |
| <i>O. carinatum</i> | -5.74 | -6.34 | -3.52 | 34.80 |
| <i>O. strumosum</i> | 3.08 | -1.74 | -2.36 | -.83 |
| agglutinants | 7.90 | -2.47 | -7.24 | -4.47 |
| Restgroup | 1.55 | 8.42 | -6.56 | 7.95 |
| P/B-ratio | .33 | -.39 | -.58 | -.40 |
| number of species | 22.37 | 15.99 | -20.32 | 7.72 |

Varimax factor scores

The number of species is positively correlated (fig. 18) with a species (*O. strumosum*) that probably preferred relatively deeper water, and negatively correlated with a species and species group (*S. infima* and *Eoguttulina* spp.) that probably preferred relatively shallower water. The meaning of this is not understood, a possibility is that this is some sort of expression of the generalized depth zonation of benthonic foraminifera, according to which (see section 2.3.4) shallow and very deep water environments are inhabited by stress tolerant species and hence have a lower diversity than depth niches in-between (Tojeira).

Eoguttulina spp. and *S. infima* (the spirillinids as a group for Murtinheira) do not show a correlation with diversity in the case of the two other sections. Diversity is a function of many factors, and a simple relationship between diversity and the occurrence and abundance of certain species is not expected. In this respect it is worth mentioning that, in case of the Murtinheira section, there was no significant negative correlation between the number of species and laminated sediments.

The Q-mode analysis (fig. 20 and table 5) essentially confirms the conclusions based on R-mode analysis. The cluster of the lowermost samples (2, 3, 3A, 4 and 5) is caused by *S. tenuissima* (2, 4, 5) and *L. muensteri* (3, 3A). The cluster consisting of all other samples except 6A and 8, is mainly caused by *E. mosquensis*. Generally speaking this again shows a continued trend towards a greater depth. The separation of samples 6A and 8 is due to the relatively high percen-

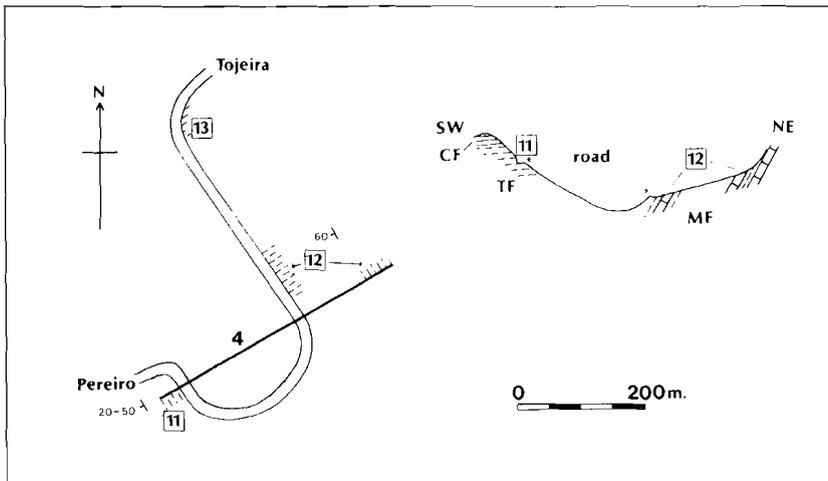


Fig. 21. Location of the Tojeira 2 section (nrs. 11 and 12) along cross-section 4 (fig. 13), and sample location nr. 13. MF = Montejunto Formation, TF = Tojeira Formation, CF = Cabrito Formation.

tage of *O. carinatum*, the meaning of which is not clear. One thing that is clear when examining the Q-mode dendrogram is that the similarities between clusters are high. In fact, without exception all samples are significantly positively correlated, meaning that the differences between samples are small and the deepening trend probably was gradual.

2.4.6: Faunal analyses of the Tojeira 2 section

Thirty samples, 12.1–12.11 and 11.1–11.19, were used for quantitative faunal analyses. Four samples, 11.20–11.23, contained too few foraminifera. The seventeen categories used for the analyses are exactly the same as those used for the Tojeira 1 section (see 2.4.4).

The frequency patterns of the categories are given in table 6, from which it can be seen that *S. tenuissima* is the predominant faunal element in the lower part of the section (samples 12.1–12.11). *E. mosquensis*, *O. strumosum*, and the agglutinants form the predominant faunal elements in the upper part (samples 11.1–11.19) of the section. The P/B-ratio ranges from zero to 0.93, with an average of about 0.37. The number of species ranges from 21 to 32, with an average of about 26.

Significant positive and negative correlations are given in fig. 23. Significant positive trends are shown by *E. mosquensis*, *P. rjasanensis*, *O. strumosum*, and the agglutinants. *Eoguttulina* spp., *S. infima*, *S. tenuissima*, and the Restgroup show a significant negative trend.

An R-mode dendrogram (fig. 24) shows four groups: group 1 consists of *Epistomina* spp. and *E. ubligi*; group 2 is formed by *S. infima*, *S. tenuissima*, *O. carinatum*, *Eoguttulina* spp., and the restgroup; group 3 consists of *P. rjasanensis*, *E. mosquensis*, *O. strumosum*, and the agglutinants; group 4 consists of *L. muensteri* and *Lenticulina* spp. *Nodosaria/Dentalina* spp. and *S. elongata* show a low association with group 1 and group 3 respectively.

A Q-mode analysis (fig. 25 and table 7) shows two groups of samples, one formed by all 11 and one formed by all 12 numbered samples.

2.4.7: The Tojeira 1 and Tojeira 2 sections, a comparison

The results of the quantitative analyses of the Tojeira 2 section will not be discussed separately. Instead a comparison will be made with the already discussed results of the Tojeira 1 section.

Qualitatively speaking, the benthonic and planktonic foraminiferal micro-fauna is the same for both sections, and, as mentioned, the same categories have been used for quantitative analysis. First of all, what do the results of the quantitative analyses of both sections have in common (figs. 18, 19, 23, 24)? Consis-

Table 6. Distribution chart (%) of the foraminifera from the Tojeira 2 section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---------------|-----|------|------|-----|------|-----|-----|-----|-----|------|------|-----|------|------|------|-----|----|
| Sample number | | | | | | | | | | | | | | | | | |
| 12.1 | 4.4 | .0 | 2.8 | 1.2 | 2.3 | 3.7 | 4.6 | .0 | 1.2 | 1.6 | 57.7 | 2.3 | .2 | 7.5 | 10.5 | .02 | 31 |
| 12.2 | 2.4 | 1.9 | 34.6 | 6.2 | 1.9 | 5.4 | 3.3 | .0 | 2.9 | 1.9 | 24.0 | 1.4 | .5 | 3.9 | 9.7 | .01 | 27 |
| 12.3 | 3.8 | 1.0 | 4.8 | 1.0 | 1.9 | 3.4 | 5.3 | .0 | 7.1 | 13.3 | 44.8 | .0 | .0 | 3.5 | 10.1 | .01 | 28 |
| 12.4 | 2.3 | .0 | .0 | .5 | 10.3 | 3.3 | .9 | .0 | 2.8 | 2.3 | 61.0 | 3.3 | .0 | 3.3 | 10.0 | .00 | 21 |
| 12.5 | 4.2 | 1.1 | 3.2 | 2.7 | 10.1 | 7.0 | 7.4 | .0 | 2.7 | 3.2 | 42.0 | 1.1 | 1.1 | 4.2 | 9.4 | .05 | 25 |
| 12.6 | 4.8 | 1.6 | .0 | .4 | 1.2 | 3.2 | 1.6 | .0 | 4.8 | 3.2 | 64.1 | 6.5 | .0 | 2.4 | 6.2 | .00 | 21 |
| 12.7 | 3.8 | 2.4 | 3.8 | .5 | 4.3 | 8.7 | 4.3 | .5 | 1.0 | 1.0 | 38.6 | 5.7 | 1.0 | 12.2 | 14.2 | .04 | 32 |
| 12.8 | 3.1 | 5.2 | 5.2 | 1.3 | 6.5 | 1.3 | .4 | .4 | 4.3 | 3.9 | 30.9 | 3.9 | .9 | 7.3 | 25.4 | .00 | 28 |
| 12.9 | 4.2 | .5 | .0 | .5 | 4.6 | 4.7 | .5 | .0 | 4.1 | 1.8 | 46.8 | 8.3 | 2.8 | 7.9 | 13.3 | .01 | 27 |
| 12.10 | 3.0 | .0 | .0 | .4 | 4.6 | 6.8 | 2.1 | .0 | 3.4 | 3.8 | 52.7 | 3.8 | .4 | 7.1 | 11.9 | .03 | 26 |
| 12.11 | 4.1 | 1.8 | 5.4 | 1.4 | 5.0 | 1.9 | 3.2 | .5 | 2.3 | 3.2 | 46.8 | 8.3 | 1.8 | 6.6 | 10.1 | .03 | 28 |
| 11.1 | 2.8 | 19.0 | 8.3 | .8 | 5.6 | 5.2 | .4 | 7.9 | 2.0 | 1.6 | 19.4 | 2.0 | 5.2 | 11.2 | 8.6 | .76 | 27 |
| 11.2 | 2.7 | 17.9 | 5.0 | .4 | 2.7 | 3.0 | 1.1 | 2.7 | 2.3 | 1.9 | 14.9 | 3.4 | 14.9 | 14.9 | 12.2 | .66 | 27 |
| 11.3 | 4.2 | 26.3 | 2.5 | .4 | 5.0 | 2.5 | 1.3 | .8 | 2.9 | 1.3 | 15.0 | 2.1 | 16.3 | 13.4 | 6.0 | .84 | 25 |
| 11.4 | 6.9 | 16.6 | 3.7 | .4 | 2.4 | 2.8 | 2.0 | 7.3 | 4.1 | .4 | 13.8 | 3.7 | 22.4 | 5.6 | 7.9 | .24 | 28 |
| 11.5 | 3.4 | 13.8 | 3.8 | .0 | 1.9 | 4.8 | 3.8 | 2.9 | 3.8 | 1.9 | 16.2 | 1.9 | 16.7 | 14.8 | 10.3 | .34 | 30 |
| 11.6 | 2.5 | 19.0 | 5.0 | .0 | 3.0 | 3.0 | 3.0 | 6.5 | 2.5 | 1.0 | 17.0 | 1.5 | 12.0 | 13.5 | 10.5 | .93 | 23 |
| 11.7 | 1.1 | 18.6 | 3.8 | .4 | 4.6 | .3 | 2.3 | 4.2 | 1.9 | .8 | 16.7 | 4.2 | 19.4 | 10.3 | 8.7 | .40 | 26 |
| 11.8 | 3.6 | 16.4 | 2.5 | .4 | 4.3 | 2.5 | 2.9 | 2.5 | 1.4 | 1.1 | 12.5 | 3.6 | 27.5 | 9.3 | 9.5 | .44 | 26 |
| 11.9 | 3.7 | 6.7 | 5.2 | 1.5 | 5.2 | 3.7 | 4.4 | 8.9 | 3.7 | .0 | 11.9 | 5.2 | 14.8 | 7.4 | 17.7 | .11 | 21 |
| 11.10 | 2.2 | 31.1 | 1.9 | .0 | 3.0 | 2.7 | 1.5 | .7 | 3.4 | .4 | 17.6 | 1.5 | 16.5 | 11.0 | 6.5 | .75 | 26 |
| 11.11 | 1.9 | 16.7 | 2.7 | .0 | 3.8 | 1.2 | 4.2 | .8 | 3.0 | .8 | 11.4 | 6.1 | 27.4 | 16.7 | 3.3 | .29 | 24 |
| 11.12 | 1.7 | 10.9 | 1.1 | .0 | 5.7 | 5.2 | 2.3 | 2.6 | 1.7 | .3 | 15.2 | 4.0 | 29.8 | 11.8 | 7.7 | .16 | 29 |
| 11.13 | .4 | 23.2 | 1.1 | .0 | 6.4 | 9.7 | 2.2 | 2.5 | 4.6 | .7 | 16.4 | .4 | 16.1 | 10.5 | 5.8 | .78 | 26 |
| 11.14 | 2.4 | 22.8 | 1.6 | .0 | 5.3 | 3.2 | 2.0 | .8 | 6.1 | .0 | 13.4 | 1.2 | 18.3 | 17.8 | 5.1 | .81 | 26 |
| 11.15 | .7 | 21.5 | 1.7 | .0 | 4.3 | 2.3 | 3.6 | 6.3 | 3.0 | .3 | 7.3 | 1.3 | 20.9 | 20.8 | 6.0 | .80 | 25 |
| 11.16 | .4 | 37.6 | 1.4 | .0 | 2.2 | 3.6 | 2.5 | 9.0 | 3.2 | .4 | 10.4 | .7 | 11.5 | 12.3 | 4.8 | .47 | 21 |
| 11.17 | 1.4 | 24.9 | 2.8 | .5 | 5.1 | 3.7 | 4.6 | 8.8 | 3.2 | .0 | 8.8 | .5 | 8.3 | 20.9 | 6.5 | .61 | 25 |
| 11.18 | 1.4 | 31.7 | 1.6 | 1.3 | 5.2 | 5.2 | 2.3 | 2.3 | 1.6 | .0 | 11.8 | 2.6 | 15.4 | 13.7 | 3.9 | .90 | 27 |
| 11.19 | 1.9 | 25.0 | 2.3 | 1.2 | 6.5 | 3.1 | 2.7 | 3.1 | 5.8 | .4 | 13.5 | 1.5 | 15.4 | 10.7 | 7.2 | .51 | 28 |

| | | | | | |
|-----------------------------|-----------------------------|-------------------------------------|---------------------------|--------------------------|------------------------|
| 1 = <i>Eoguttulina</i> spp. | 4 = <i>Epistomina</i> spp. | 7 = <i>Nodosaria/Dentalina</i> spp. | 10 = <i>S. infima</i> | 13 = <i>O. strumosum</i> | 16 = P/B-ratio |
| 2 = <i>E. mosquensis</i> | 5 = <i>L. muensteri</i> | 8 = <i>P. rjasanensis</i> | 11 = <i>S. tenuissima</i> | 14 = Agglutinants | 17 = number of species |
| 3 = <i>E. ubligi</i> | 6 = <i>Lenticulina</i> spp. | 9 = <i>S. elongata</i> | 12 = <i>O. carinatum</i> | 15 = Restgroup | |

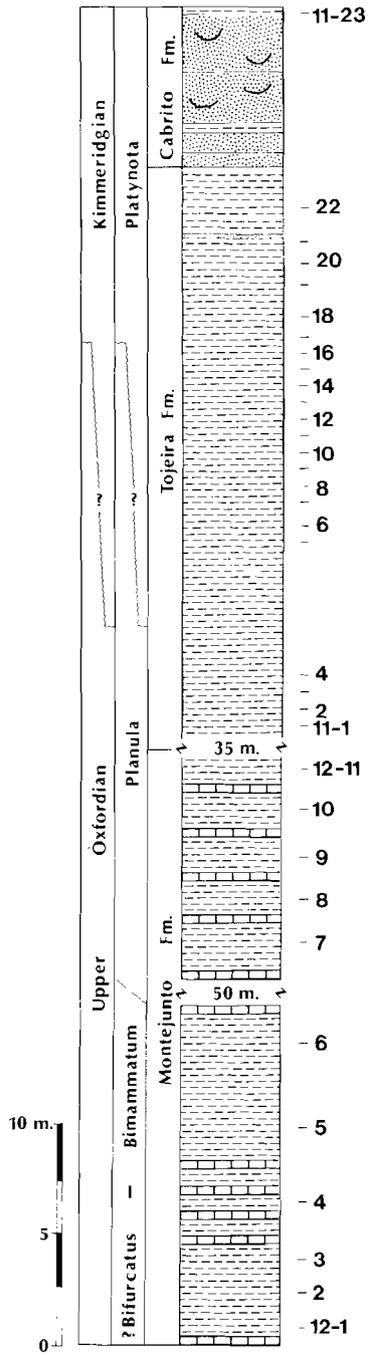


Fig. 22. The Tojeira 2 section with sample numbers 12.1–12.11 and 11.1–11.23.

Table 7. Q-mode factor analysis Tojeira 2 section

| | Factor (U) | U1 | U2 | U3 | U4 |
|---------------------------------|------------|-------|-------|--------|--------|
| Sample number | | | | | |
| 12.1 | | .30 | .94 | -.03 | .08 |
| 12.2 | | .33 | .58 | -.02 | .69 |
| 12.3 | | .31 | .91 | -.02 | .16 |
| 12.4 | | .22 | .97 | -.01 | -.01 |
| 12.5 | | .34 | .92 | -.04 | .13 |
| 12.6 | | .21 | .97 | .01 | -.04 |
| 12.7 | | .44 | .86 | -.07 | .21 |
| 12.8 | | .46 | .78 | -.08 | .31 |
| 12.9 | | .35 | .92 | .09 | .08 |
| 12.10 | | .30 | .95 | -.03 | .06 |
| 12.11 | | .36 | .92 | -.05 | .14 |
| 11.1 | | .78 | .53 | .11 | .29 |
| 11.2 | | .87 | .41 | -.09 | .21 |
| 11.3 | | .93 | .34 | .03 | .06 |
| 11.4 | | .87 | .36 | -.24 | .14 |
| 11.5 | | .84 | .45 | -.17 | .20 |
| 11.6 | | .86 | .45 | -.00 | .19 |
| 11.7 | | .88 | .41 | -.15 | .12 |
| 11.8 | | .89 | .31 | -.31 | .08 |
| 11.9 | | .72 | .44 | -.32 | .33 |
| 11.10 | | .92 | .35 | .08 | .03 |
| 11.11 | | .91 | .25 | -.27 | .02 |
| 11.12 | | .84 | .37 | -.39 | .05 |
| 11.13 | | .90 | .40 | .00 | .06 |
| 11.14 | | .94 | .31 | -.04 | .05 |
| 11.15 | | .96 | .18 | -.10 | .09 |
| 11.16 | | .94 | .17 | .26 | .03 |
| 11.17 | | .92 | .24 | .15 | .17 |
| 11.18 | | .96 | .25 | .11 | .05 |
| 11.19 | | .93 | .34 | .01 | .11 |
| Rotated factor matrix | | | | | |
| Species/species group | | | | | |
| <i>Eoguttulina</i> spp. | | .93 | 3.60 | -3.09 | .61 |
| <i>E. mosquensis</i> | | 29.93 | -.70 | 30.01 | -7.76 |
| <i>E. ubligi</i> | | -1.21 | -1.03 | 3.25 | 39.66 |
| <i>Epistomina</i> spp. | | -.58 | .55 | .80 | 6.58 |
| <i>L. muensteri</i> | | 3.38 | 4.44 | -.32 | -1.76 |
| <i>Lenticulina</i> spp. | | 2.36 | 3.90 | 2.30 | 2.24 |
| <i>Nodosaria/Dentalina</i> spp. | | 1.70 | 2.25 | -1.50 | .90 |
| <i>P. rjasanensis</i> | | 4.91 | -2.12 | 2.57 | 4.93 |
| <i>S. elongata</i> | | 2.56 | 2.79 | 1.13 | .09 |
| <i>S. infima</i> | | -.89 | 4.22 | .76 | .86 |
| <i>S. tenuissima</i> | | -3.28 | 58.20 | 7.99 | -23.72 |
| <i>O. carinatum</i> | | 1.03 | 3.98 | -7.20 | -2.23 |
| <i>O. strumosum</i> | | 21.22 | -6.32 | -31.67 | -12.63 |
| Agglutinants | | 14.79 | 1.06 | 3.69 | -.92 |
| Restgroup | | 2.63 | 9.54 | -7.73 | 14.09 |
| P/B-ratio | | .79 | -.19 | .85 | -.14 |
| number of species | | 19.82 | 20.55 | -3.03 | 9.14 |

Varimax factor scores

of the Tojeira 2 section, two-thirds of the samples have been taken from the same Tojeira Formation, and one-third of the samples come from the Montejunto Formation, which represents a relatively shallower water environment (see 2.4.3). The transition from relatively shallow to relatively deep is gradual but not exposed, and hence not sampled (fig. 22).

In view of this difference in sample distribution, it is expected that species preferring relatively shallow water are better represented in case of the Tojeira 2 section, whereas species preferring relatively deeper water are well represented in both sections. This means that both sections will give sufficient and comparable information concerning the foraminifera that prefer deeper water, but that shallow water species are probably best inferred from the Tojeira 2 section. *S. tenuissima* may serve as an example. This species shows a negative trend in both sections, confirming its preference for shallow water. One would expect a species with a certain preference to be negatively correlated with a species that has an opposite preference. In case of the Tojeira 1 section, *S. tenuissima* is not negatively correlated with any of the deep water species (*E.*

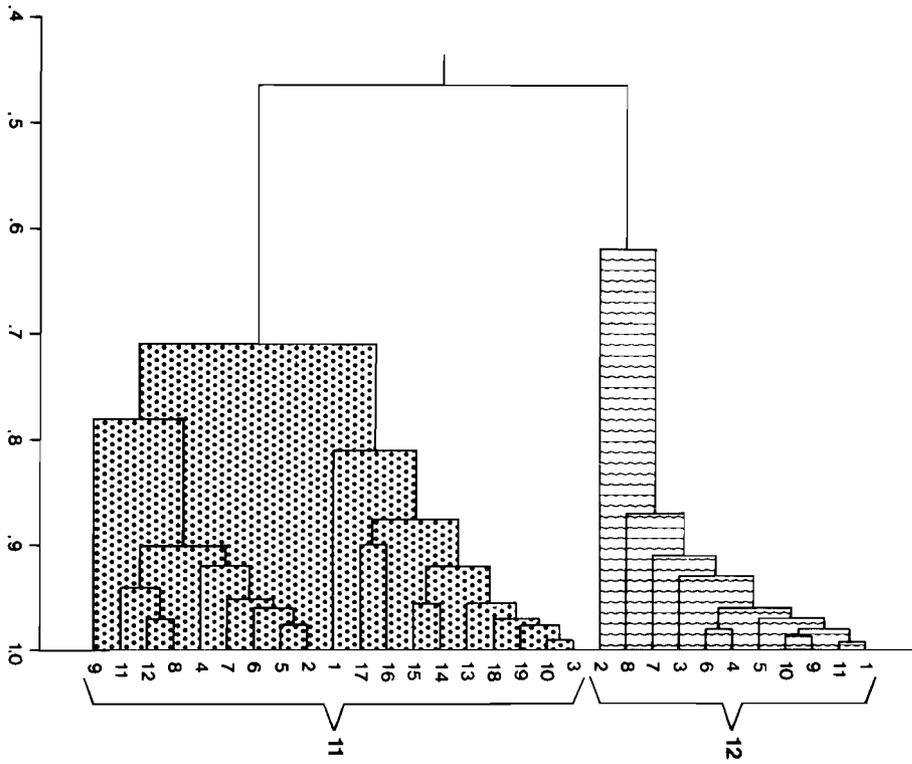


Fig. 25. Q-mode dendrogram of the samples from the Tojeira 2 section.

mosquensis etc.). However, for the Tojeira 2 section *S. tenuissima* is negatively correlated with all deep water species. Thus, apart from an interpretation based on consistent correlations and trends, it is believed that the Tojeira 2 section may be used to obtain a better insight as to which species are representative for shallow water.

Based on the analysis of the Tojeira 2 section, a group consisting of foraminifera with a preference for shallow water consists of *Eoguttulina* spp., *O. carinatum*, *S. tenuissima*, *S. infima*, *S. elongata*, and the Restgroup. All three *Spirillina* species are grouped together which was to be expected in view of the results of the Brenha section (see discussion Tojeira 1 section). Note that the R-mode dendrogram of fig. 24 shows very low association between *S. elongata* and the deep water species. However, *S. elongata* is not significantly (either negatively or positively) correlated with any of the deep water species. The fact that there is a significant positive correlation between *S. elongata* and *S. infima*, and no significant negative correlations between *S. elongata* and any of the other shallow water species lead to the decision to include this species in the shallow water group. The position of *Nodosaria/Dentalina* spp., *E. ubligi*, and *Epistomina* spp. remains uncertain.

The Q-mode analysis of the Tojeira 2 section (fig. 25) shows a clear separation of the "11" and "12" samples. This is due to the fact that the transition from relatively shallow water to relatively deep water strata has not been sampled.

| | Tojeira 1 | Tojeira 2 |
|---------------------------------|-----------|-----------|
| <i>Eoguttulina</i> spp. | - | - |
| <i>E. mosquensis</i> | + | + |
| <i>E. ubligi</i> | | |
| <i>Epistomina</i> spp. | | - |
| <i>L. muensteri</i> | | |
| <i>Lenticulina</i> spp. | | |
| <i>Nodosaria/Dentalina</i> spp. | | |
| <i>P. rjasanensis</i> | + | + |
| <i>S. elongata</i> | | |
| <i>S. infima</i> | - | - |
| <i>S. tenuissima</i> | - | - |
| <i>O. carinatum</i> | | |
| <i>O. strumosum</i> | + | + |
| Agglutinants | + | + |
| Restgroup | | - |
| P/B-ratio | | + |
| number of species | | |

Fig. 26. Trend analyses for the Tojeira 1 and Tojeira 2 sections.

which is rich in ammonites (and the upper part of the Montejunto Formation) is lacking in section Tojeira 2.

Finally, analyses have been made on the combined data sets of both sections. It should be realized that when doing this, the total number of samples is 61, of which only 11 come from the relatively shallower water Montejunto Formation. This would mean that, as in the case of the Tojeira 1 section, the foraminifera preferring relatively shallow water are again not well represented.

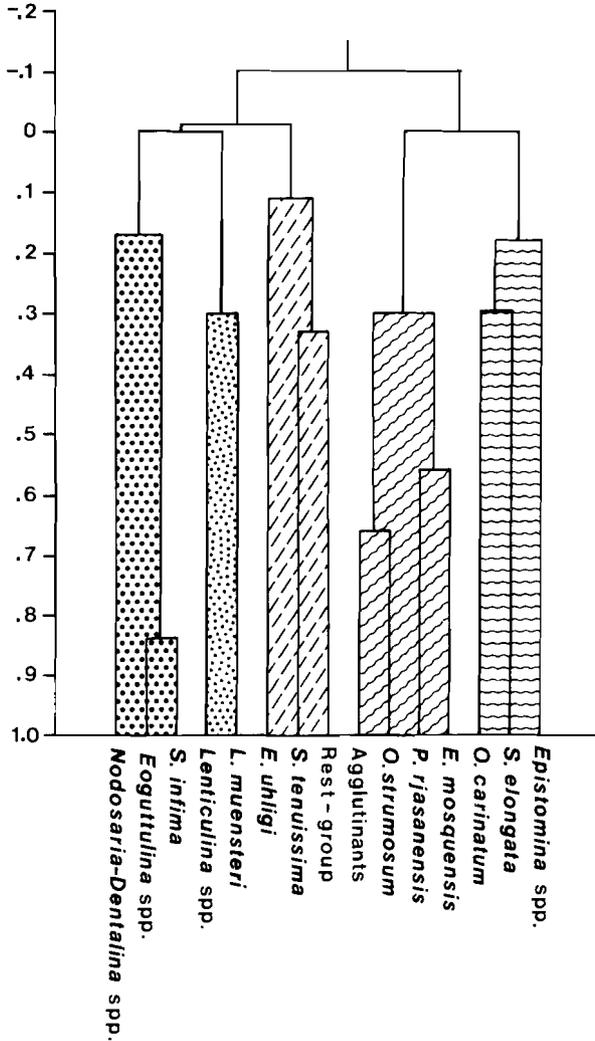


Fig. 28. R-mode dendrogram of the benthonic foraminifera of both Tojeira sections.

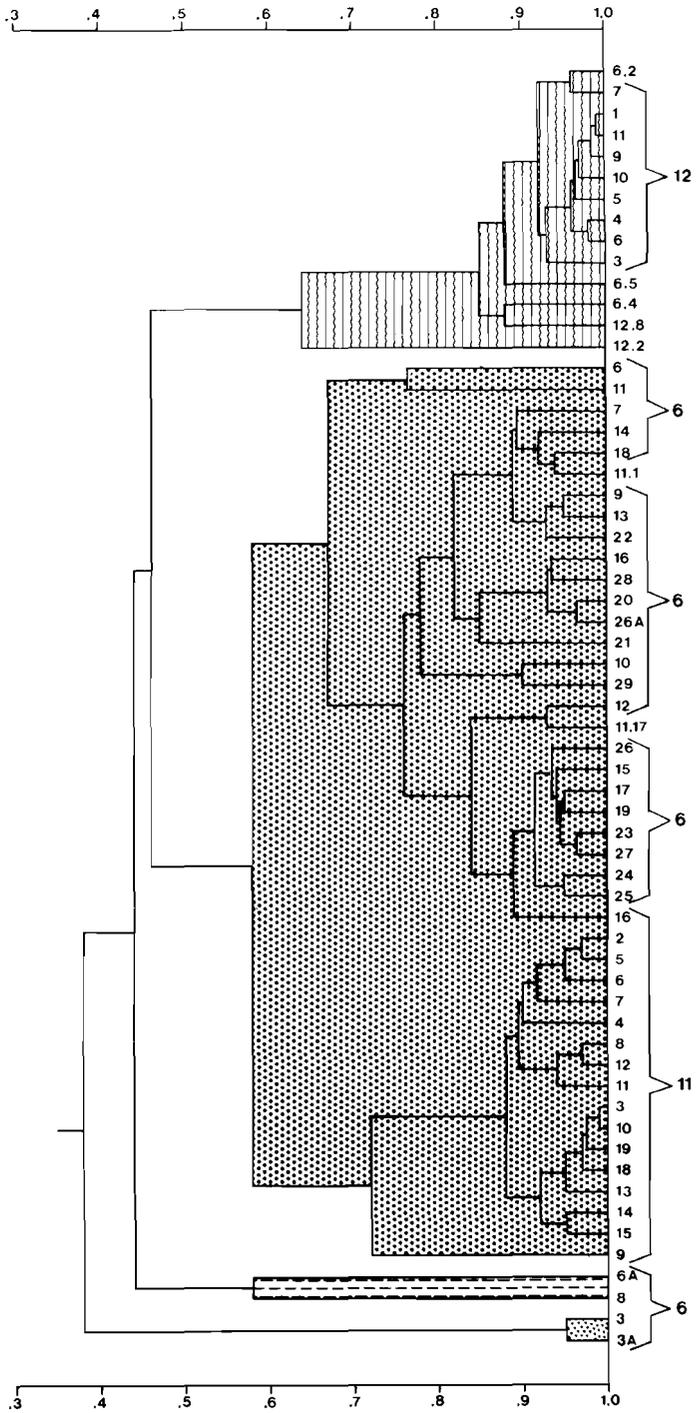


Fig. 29. Q-mode dendrogram of the samples from both Tojeira sections.

The results are given in figs. 27 and 28. As expected, these figures most closely resemble the equivalent figures of the Tojeira 1 section. The P/B-ratio is correlated with all deep water species, as was the case in the Tojeira 2 section.

The Q-mode analysis (fig. 29) shows two main groups. One group formed by all "12" samples, and samples 6.2, 6.4, and 6.5 (the *S. tenuissima* cluster). The second large group is formed by all "11" samples and most "6" samples (the *E. mosquensis* cluster). The two small clusters, 6.6A + 6.8 and 6.3 + 6.3A are formed because of high factor scores of respectively *O. carinatum* and *L. muensteri*.

In a second Q-mode analysis, several additional samples have been entered. These samples are 14.1, 14.2, and 5.7 from the Montejunto Formation, and 7.4 and 7.7 from the Tojeira Formation. Samples 14.1 and 14.2 have been taken (fig. 15) in the vicinity of bioclastic to oolitic limestone beds, which, if the particles have not been transported from their original site, represent no more than a few tens of metres of water depth (M.R. Gibling, pers. comm.). The very high percentage of *S. tenuissima* in those samples once more stresses this species' preference for shallow water. In the Q-mode dendrogram of fig. 29, 14.1, 14.2 and 5.7 have to be placed among the "12" samples, 7.4 and 7.7 among the "6" and "11" samples. This shows again that based on the foraminiferal microfauna, it is possible to distinguish between samples from the Montejunto Formation and the Tojeira Formation, and hence to use the microfauna for regional correlation.

In conclusion it can be said that *E. mosquensis*, *P. rjasanensis*, *O. strumosum* and the agglutinants preferred relatively deep water (200–250 m). On basis of a study of seismic reflection profiles, Wilson (pers. comm.) interpreted the Tojeira and Abadia Formations to be part of a prograding slope system with an estimated paleowaterdepth of about 250 m. *Eoguttulina* spp., *O. carinatum*, the Restgroup and the three spirillinid species preferred shallow water. The ecological position of *L. muensteri* and the other Lenticulinids is somewhere in between. An ecological preference of *Nodosaria/Dentalina* spp., *E. ubligi* and *Epistomina* spp. is not clear.

2.4.8: The planktonic/benthonic ratio

The P/B-ratio, which is given in figs. 30 and 31, shows that planktonic foraminifera are relatively abundant throughout the Tojeira 1 section and the upper part of the Tojeira 2 section. Distinct peaks occur at several levels.

The planktonic microfauna encountered has a low diversity (probably only a few species) and consists entirely of simple globose forms, "similar" to the Recent genus *Globigerina*. The planktonic foraminifera from these and all other sections, plus the planktonics from the Grand Banks will be dealt with in a

separate chapter, and a comparison will be made with available hypotypic material from France (*G. oxfordiana*), topotypic material from Poland (*G. bathoniana*) and material from Switzerland. For the moment no generic and specific assignments will be given.

From Recent planktonic foraminifera (Emiliani, 1971; Be, 1977) it is known that diversified faunas occur in subtropical and tropical regions where there is a great difference between the temperature of the surface water and the temperature of deeper water. Emiliani (1971) showed that, in regions with a thermocline, species show a depth migration during their life-cycle, with more

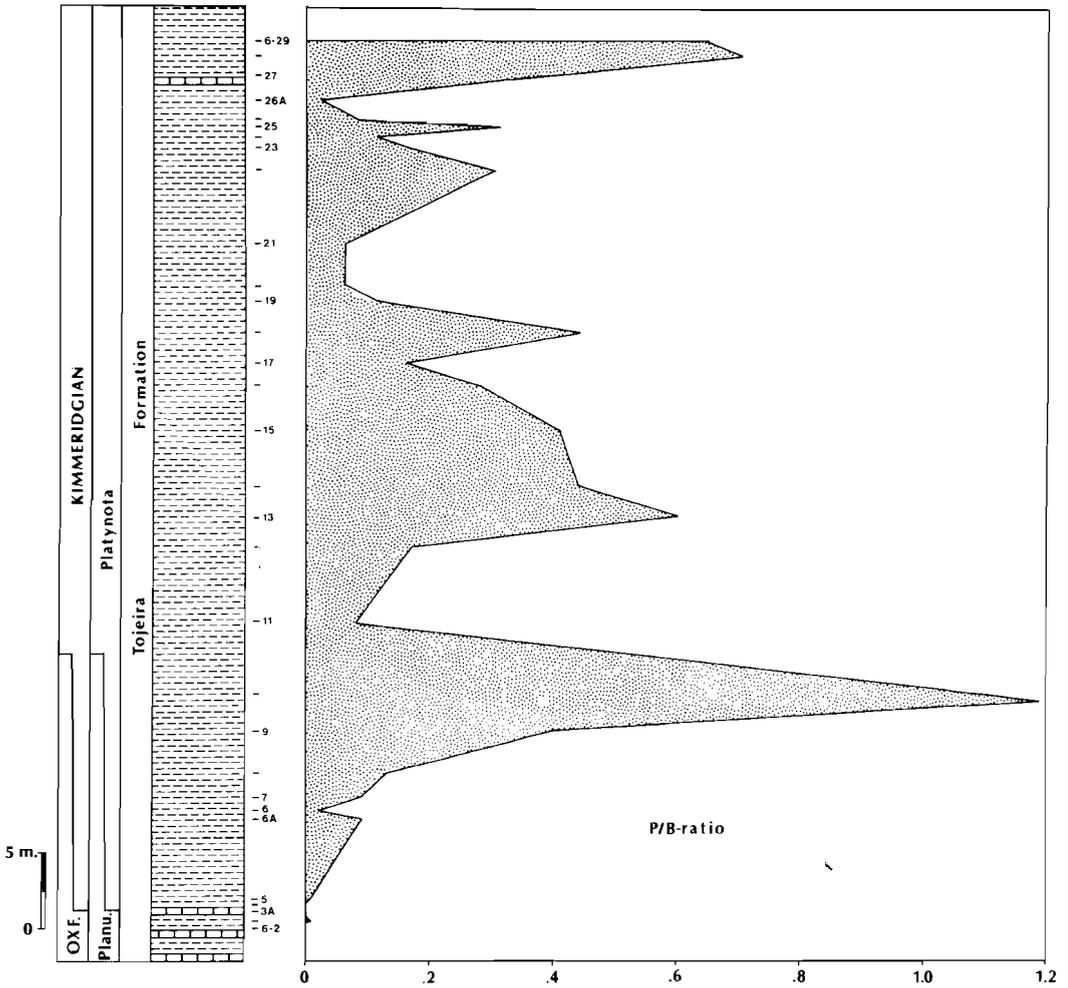


Fig. 30. P/B-ratio Tojeira 1 section.

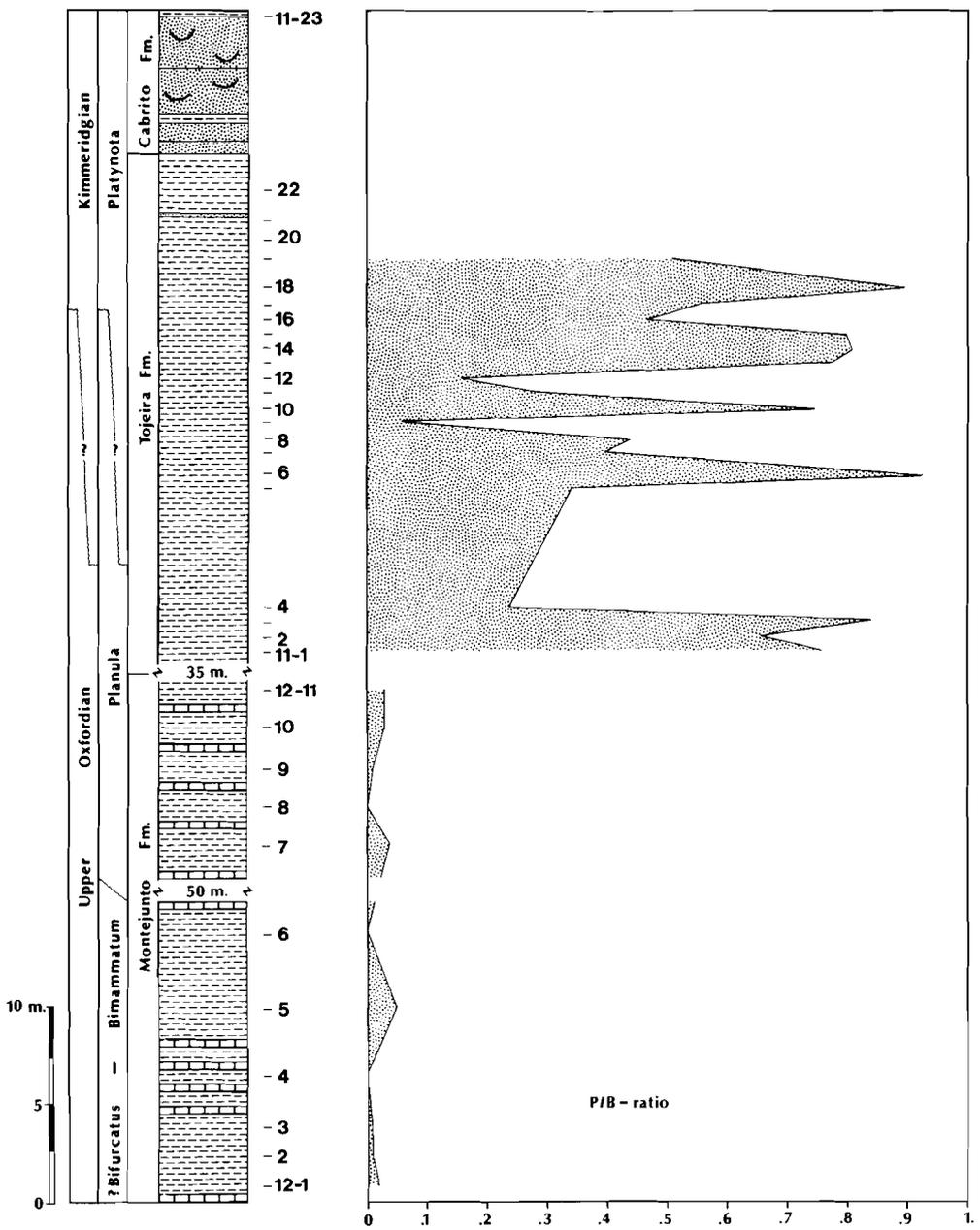


Fig. 31. P/B-ratio Tojeira 2 section.

complicated test morphologies (imperforate equatorial band, keel, double keel) occurring in progressively deeper water. Low diversity faunas composed of simple, non-keeled (e.g. globose) forms occur in the uppermost parts of the water column in relatively cold waters (Arctic, Antarctic), shallow seas, or even warm deep seas when there is no thermocline (Gulf of Elat-Aqaba; Reiss, 1977; Wonders, 1980).

This distribution model was used by Wonders (1980) to explain the occurrence and distribution of Middle and Late Cretaceous planktonic foraminifera and by Caron and Homewood (1983) for Mesozoic (Middle Jurassic through Upper Cretaceous) planktonics. Indeed, the model is attractive and it could account for several observations. No planktonics have been encountered that have a complicated test morphology (keel, double keel, raised sutures, etc.). In fact, such forms are not known from the Jurassic. According to the above described distribution model this would indicate either a boreal fauna, which is not likely in view of paleogeographic reconstructions and the Tethyan character of the ammonite fauna (Poulton, 1983, internal report Geological Survey of Canada, appendix), or more likely a more (sub)tropical fauna living in waters with no thermocline, which causes a thickening of the well-mixed upper water layer, or with restricted environmental conditions (Wonders, 1980).

No thermocline or restricted conditions or both means that the water circulation at least was reduced. This reduction in circulation is most likely to occur in the deeper parts of a basin, well below the wave base, and it could have an effect on the benthonic fauna. In terms of P/B-ratio it implies that during periods of reduced water circulation the abundance of simple globose planktonics, because of the increase of food and their high reproductive potential (Caron and Homewood, 1983), increases relative to the abundance of benthonic foraminifera. It also means that an increase in P/B-ratio is linked to an increase in water depth, which explains the positive correlation between the P/B-ratio and the deep water foraminifera such as for example *E. mosquensis* and *P. rjasanensis*.

What kind of stress, if any, the benthonic species experienced and how it influenced the occurrence and abundance of individual species is difficult to determine. The relatively diverse and rich benthonic microfauna and the absence of lamination indicate that bottom conditions were not aberrant.

SOUTHERN PORTUGAL

3.1: INTRODUCTION

Lower, Middle and Upper Jurassic sediments are exposed in southern Portugal, in the so-called Algarve Basin. This is an east-west elongated basin, bordered in the north by the Iberian Meseta, with an eastern limit near the Portuguese-Spanish border and a western limit near Cape St. Vicente (fig. 32). The biostratigraphic framework and paleogeographic setting (see introduction chapter 2) have been described by Pratsch (1958), Mouterde *et al.* (1972), Rocha (1977) and Rocha *et al.* (1979). The last two papers only deal with the western part of the Algarve Basin.

3.2: LATE TRIASSIC THROUGH LATE JURASSIC PALEO GEOGRAPHY OF THE ALGARVE BASIN

Like the Lusitanian Basin, the Algarve Basin originated in the Late Triassic as a result of movements along Hercynian basement faults. The first sediments deposited throughout the basin consist of conglomerates, red sandstones and shale, dolomites and multi-coloured shales, locally with gypsum. This non- to marginal marine Upper Triassic through Lower Jurassic (Sinemurian) sequence, usually referred to as "Gres de Silves" (Palain, 1978), unconformably overlies Paleozoic (Carboniferous) basement, as so well exposed at Telheiro Beach, north of Cape St. Vicente (fig. 32). Based on the distribution of Jurassic sediments, three areas can be recognized (Pratsch, 1958). These areas are (fig. 32) the western Algarve, west of Lagos (1), the central and eastern Algarve (2) and the north-central Algarve (3), between the Hercynian basement and the first strike-slip fault to the south.

In the western Algarve, the Gres de Silves is overlain by shallow marine, sometimes oolitic, limestones. In these limestones the first ammonites occur (Jamesoni and Ibex Zones, Mouterde *et al.*, 1972). This shallow water facies predominates from the Pliensbachian through the Bajocian after which there was a sudden change to a more shaly facies which persisted during the Bathonian and Early Callovian. In the Middle and Late Callovian the shale facies is gradually replaced by a carbonate facies as indicated by a steady increase in limestone deposits during this interval. The Callovian Lamberti Zone and most of the Oxfordian are missing as marked by Lower Kimmeridgian shallow water

limestones that unconformably overlie Upper Callovian (Athleta Zone) limestones (Rocha *et al.*, 1979). The shallow water character of the Lower Kimmeridgian limestones is stressed by the occurrence of the larger foraminifer *Alveosepta jaccardi* (Schrodt), Tunel Beach (fig. 33).

In the central and eastern Algarve the Gres de Silves is overlain by non-dated terrigenous clastics and gypsum (locally). The first known marine sediments deposited in this area are of Bathonian and Callovian age and are developed in the same facies as sediments of this timespan in the western Algarve. As in the western Algarve, there is a Late Callovian hiatus but the duration of it differs: well dated (Mouterde *et al.*, 1972) Middle and Upper Oxfordian limestones unconformably overlie the Upper Callovian sediments. In the Early Kimmeridgian this carbonate facies is replaced by a shale facies.

In the north-central Algarve most of the Jurassic is missing. The Gres de Silves is overlain by (Lower) Kimmeridgian dolomites.

The above described distribution of Jurassic sediments allows for several general conclusions relevant to the Jurassic paleogeography of the Algarve Basin. A local transgression and/or subsidence in the western Algarve resulted in the establishment of a shallow marine stable platform from Pliensbachian through Bajocian time. A possibly larger Bathonian transgression affected both

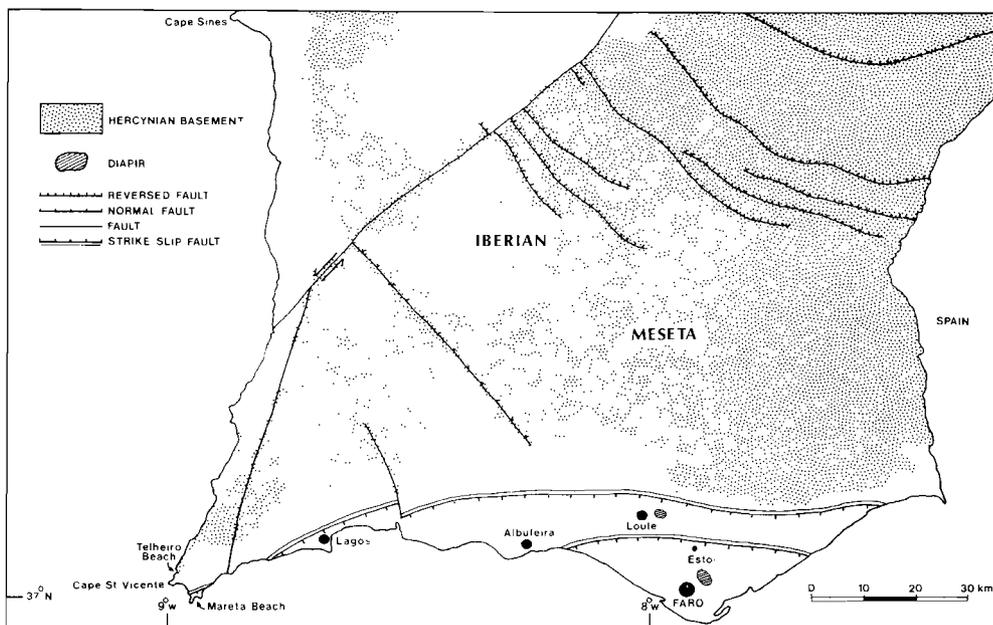


Fig. 32. Sketch map outlining the Algarve Basin, with some of the major faults (after Ribeiro *et al.*, 1972).

the western and the central and eastern Algarve, as did the Late Callovian regression and uplift. The first (Middle Oxfordian) sediments after this uplift occurred in the central and eastern Algarve, which was probably due to subsidence in this area caused by movements along strike-slip faults north of Loule. An Early Kimmeridgian transgression affected the entire Algarve Basin as indicated by shallow marine sediments in the western and north-central Algarve and a change from limestone to shale in the central and eastern Algarve. During the remainder of the Jurassic the sea gradually regressed, which eventually led to the deposition of shallow or non-marine Lower Cretaceous sandstones.

3.3: THE STRATIGRAPHIC SECTIONS

Two sections, the Mareta Beach section in the western Algarve and the Albufeira section in the central Algarve have been sampled in detail. Nine additional samples have been collected in the eastern Algarve, seven 3 km south of Loule, along the road to Faro and two north of Estoi (fig. 32). Only the samples from the Mareta Beach section have been used for quantitative foraminiferal analyses. The samples from the Albufeira section and from Loule and Estoi contained too few foraminifera to justify statistical treatment. These samples will be briefly discussed from a qualitative point of view.

3.4: THE MARETA BEACH SECTION

3.4.1: Introduction

The Mareta Beach section is exposed along the beach directly south of the town of Sagres (fig. 33). It ranges in age from (Late) Bajocian to Kimmeridgian (Rocha *et al.*, 1979). The lithostratigraphical column (fig. 34) is a composite of 4 subsections (numbers 1–4, figs. 33, 34). Based on field evidence, it is believed that subsections 1 and 2 belong to the same litho- and chronostratigraphic level (see also Pratsch, 1958, p. 35–36 and Rocha, 1977, p. 37, fig. 2.8). The possible gaps between 1–2, 3 and 4 are thought to be in the order of several metres or less.

3.4.2: Lithological description

The lower part of the section (subsections 1, 2) consists of bioclastic, oolitic and terrigeno-clastic limestone with minor shale and shaly limestone intercalations. The top of this lower part of the section is bounded by a ferruginous erosional surface (omission surface; Gibling and Stuart, in preparation). The basal part of both subsections is formed by a “reefal” limestone with abundant corals

and some gastropods. The upper surface of this “reefal” limestone is karstified and filled in with sandstone and overlain by a limestone breccia. Throughout this lower part of the section the trace fossil *Zoophycos* occurs on bedding planes, sometimes in large numbers.

The middle part of the section (subsection 3 and the lower part of 4) again starts with a “reefal” limestone, rich in corals and with some small ammonites. This is followed by some 55 m of bluish-grey to brown calcareous shale with at some levels thin (up to several cm) sandstone beds showing ripple marks, load- and flute casts. As already mentioned by Pratsch (1958), characteristic throughout this part of the section is the presence of abundant broken *Bositra buchii* (Roemer) parallel to the bedding plane (*Posidonia alpina* Gras, Pratsch, 1958 is synonymous with *B. buchii*). Small pyritized ammonites occur throughout this middle part of the section. At the top this shale unit is intersected by two basaltic dykes, 10–40 cm thick.

The upper part of the section consists of an alternation of bluish-grey shale and yellow-grey to bluish limestone. In general the limestone beds increase in thickness and become more predominant from base to top of this part of the section. Apart from the top 10–15 m, relatively small scale slumping occurs throughout this unit, with a major ca. 12 m thick large scale slumped section which occurs about 10–15 m below the top of the sampled composite section (fig. 34). Ammonites (few) have been observed throughout this upper part. The

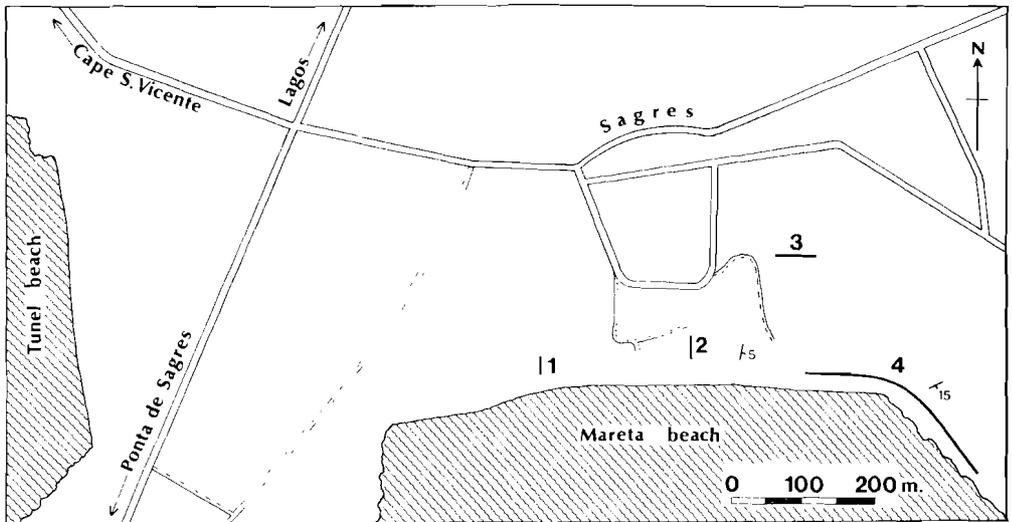


Fig. 33. Location map of the Mareta Beach section.

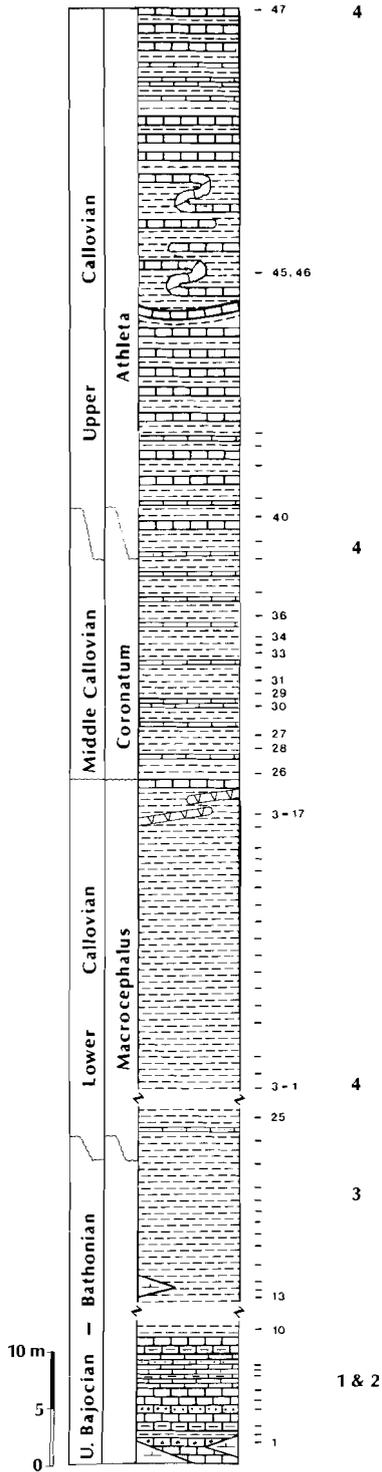


Fig. 34. Litho-, bio- and chronostratigraphic framework for the Mareta Beach section.

Table 8. Distribution chart (%) of the foraminifera from the Mareta section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------|------|------|-----|-----|------|------|------|-----|------|------|------|------|
| Sample number | | | | | | | | | | | | |
| 3 | 68.0 | 1.0 | 6.8 | .0 | .0 | 1.5 | 13.1 | .0 | .0 | 4.9 | 2.9 | 1.9 |
| 7 | 62.0 | 1.2 | 4.7 | 4.7 | 1.8 | 2.9 | 9.9 | .0 | .0 | 8.1 | 3.0 | 1.8 |
| 10 | 67.4 | 5.5 | 7.9 | .0 | 2.3 | .0 | 8.2 | 2.1 | 4.0 | .0 | 1.6 | 1.0 |
| 13 | 39.9 | 5.1 | 7.3 | 2.8 | 9.6 | 6.2 | 7.3 | .6 | 10.2 | 1.7 | 4.0 | 5.6 |
| 14 | 30.0 | 7.5 | 6.1 | 1.9 | 15.0 | 7.9 | 2.8 | 1.9 | 7.1 | 2.8 | 5.7 | 11.2 |
| 16 | 46.1 | 5.0 | 4.7 | 5.4 | 3.5 | 10.1 | 3.9 | 3.1 | 8.5 | .0 | 4.3 | 5.8 |
| 17 | 34.6 | 8.2 | 3.8 | 1.4 | 17.4 | 4.8 | 4.8 | .5 | 10.7 | .0 | 6.7 | 7.5 |
| 18 | 48.2 | 2.3 | 8.3 | .5 | 8.2 | 3.7 | 1.8 | 3.7 | 7.9 | .0 | 7.8 | 7.8 |
| 19 | 46.4 | 5.3 | 4.5 | 1.5 | 8.7 | 3.0 | 1.1 | .8 | 14.8 | .0 | 4.6 | 9.5 |
| 20 | 34.0 | 5.5 | 4.5 | 2.5 | 14.5 | 8.0 | .5 | 2.5 | 9.0 | .5 | 8.5 | 1.0 |
| 21 | 23.0 | 11.3 | 3.8 | 3.8 | 3.3 | 3.8 | .0 | .5 | 42.8 | .0 | 4.1 | 3.8 |
| 22 | 27.9 | 13.5 | 3.4 | 5.3 | 15.9 | 5.3 | .0 | .0 | 19.2 | .0 | 6.8 | 2.9 |
| 23 | 35.5 | 7.2 | 9.2 | 2.0 | 11.9 | 2.4 | 1.0 | 1.4 | 22.9 | .0 | 2.6 | 3.7 |
| 24 | 38.4 | 3.8 | 4.4 | .3 | 4.1 | 5.3 | .6 | 2.5 | 26.8 | .0 | 8.3 | 4.9 |
| 25 | 33.5 | 3.5 | 1.9 | .4 | 6.9 | 2.7 | 3.5 | 1.2 | 36.5 | 2.7 | 6.3 | 1.2 |
| 3.1 | 60.7 | 1.4 | 7.9 | 1.8 | 2.9 | 2.1 | 2.1 | 1.8 | 16.5 | .4 | 2.9 | .4 |
| 3.2 | 32.4 | 4.7 | 5.1 | 1.2 | 4.0 | 5.9 | 1.6 | 2.0 | 30.6 | 1.2 | 3.2 | 8.1 |
| 3.3 | 29.6 | 4.6 | 3.9 | 2.6 | 6.2 | 9.9 | .7 | 3.0 | 31.0 | .7 | 3.7 | 4.1 |
| 3.4 | 40.2 | 3.1 | 9.0 | 3.1 | 11.0 | 5.0 | 1.7 | .6 | 14.0 | 1.4 | 5.9 | 5.0 |
| 3.5 | 39.0 | 3.2 | 5.5 | 1.7 | 11.6 | 4.4 | 1.7 | 1.2 | 20.0 | 2.3 | 4.9 | 4.5 |
| 3.6 | 46.3 | .8 | 5.1 | 1.1 | 7.0 | 5.6 | 2.0 | 3.1 | 19.8 | 3.7 | 2.7 | 2.8 |
| 3.7 | 30.3 | 4.4 | 6.0 | 5.6 | 11.6 | 10.0 | .0 | 1.2 | 18.4 | .4 | 5.6 | 6.5 |
| 3.8 | 34.4 | 2.3 | 2.6 | 4.7 | 9.4 | 8.8 | .0 | 1.7 | 24.2 | 2.6 | 6.1 | 3.2 |
| 3.9 | 59.7 | 4.7 | 5.7 | 3.0 | 2.2 | 6.0 | 1.7 | .0 | 13.8 | .0 | 2.1 | 1.1 |
| 3.10 | 28.9 | 3.0 | 3.0 | 3.0 | 8.0 | 10.0 | 1.0 | 3.0 | 28.9 | 3.0 | 3.5 | 4.7 |
| 3.11 | 35.2 | 4.0 | 3.4 | 3.4 | 5.9 | 12.6 | .6 | .6 | 25.2 | .6 | 4.5 | 4.0 |
| 3.12 | 37.1 | 2.2 | 4.3 | 3.9 | 9.5 | 6.9 | 2.6 | .0 | 19.8 | .9 | 6.0 | 6.8 |
| 3.13 | 48.3 | 3.3 | 6.7 | 3.0 | 10.8 | 6.3 | 4.8 | .4 | 6.3 | 2.2 | 1.8 | 6.1 |
| 3.14 | 27.8 | 3.7 | 2.8 | 3.7 | 5.5 | 3.7 | 3.7 | 2.1 | 35.5 | 2.4 | 5.2 | 3.6 |
| 3.15 | 57.2 | .0 | 7.2 | 1.0 | 3.4 | 5.8 | 6.3 | .5 | 6.8 | .5 | 5.4 | 5.9 |
| 3.16 | 32.2 | 3.5 | 1.7 | 1.7 | 4.4 | 1.7 | 2.6 | .0 | 11.3 | 21.7 | 3.5 | 15.7 |
| 3.17 | 44.7 | 6.0 | 4.3 | 3.4 | 7.7 | 15.7 | 5.5 | .9 | 7.6 | .9 | .9 | 2.4 |
| 26 | 71.7 | 1.7 | 4.5 | 1.0 | .9 | 1.4 | 4.1 | 3.1 | 5.5 | .0 | 4.9 | .7 |
| 27 | 62.8 | 4.0 | 2.7 | 3.6 | 1.3 | 2.2 | 7.6 | 2.6 | 1.7 | .4 | 7.5 | 3.0 |
| 28 | 57.0 | 3.0 | 3.4 | 2.5 | 6.5 | .5 | 8.4 | 3.0 | 5.0 | .5 | 7.4 | 3.0 |
| 30 | 57.5 | 1.6 | 3.6 | 3.1 | 12.9 | 11.9 | 1.6 | .0 | 1.0 | .0 | 5.7 | 1.0 |
| 31 | 71.3 | .9 | 1.7 | 2.1 | 2.2 | .9 | 3.4 | 2.6 | 3.0 | .0 | 9.0 | 2.9 |
| 32 | 56.7 | 6.9 | 6.0 | 8.3 | .9 | 3.7 | .5 | 1.4 | 2.8 | 2.3 | 5.0 | 5.6 |
| 33 | 72.4 | 4.1 | 3.7 | 7.7 | 2.4 | 2.0 | .0 | 2.4 | 2.0 | .0 | 1.2 | 1.6 |
| 35 | 61.8 | 5.5 | 6.4 | 8.6 | 1.5 | 5.5 | .0 | 2.3 | .5 | .0 | 6.5 | 1.9 |
| 36 | 65.7 | 2.7 | 5.5 | 7.0 | 3.9 | 4.5 | .8 | 1.4 | 1.2 | .0 | 3.4 | 3.8 |
| 38 | 52.5 | 1.4 | 9.9 | 1.1 | 4.7 | 3.2 | 11.7 | 4.3 | 5.0 | .4 | 5.7 | .4 |
| 39 | 41.9 | 1.0 | 5.9 | 9.9 | 9.9 | 5.9 | 12.3 | 1.0 | .5 | .0 | 7.9 | 3.9 |
| 40 | 50.3 | 2.3 | 2.3 | 1.6 | 4.1 | 2.6 | 18.8 | 3.9 | 3.2 | 1.6 | 6.7 | 2.5 |
| 41 | 72.6 | 2.4 | 4.0 | 1.2 | 1.2 | 4.4 | 7.9 | .4 | .0 | 1.2 | 2.0 | 2.8 |
| 42 | 72.3 | 10.3 | 4.7 | .9 | .5 | 1.4 | .0 | .5 | 2.8 | .5 | 3.8 | 1.9 |
| 45 | 50.2 | .0 | 2.6 | .0 | 3.6 | 2.0 | 3.9 | 8.1 | 11.0 | .0 | 15.2 | 3.3 |

1 = *S. tenuissima*

4 = *L. muensteri*

7 = *P. feifeli*

10 = Miliolids

2 = *S. infima*

5 = *Nodosaria/Dentalina* spp.

8 = *Discorbis* spp.

11 = *Lenticulina* spp.

3 = *S. elongata*

6 = *Eoguttulina* spp.

9 = Agglutinants

12 = Restgroup

section is unconformably overlain by (not shown in fig. 34) ?Middle Oxfordian (Rocha, 1977) or Lower Kimmeridgian (Rocha *et al.*, 1979) dolomitic limestone.

3.4.3: Faunal analyses

Forty-seven samples (tables 8 and 9) were used for quantitative foraminiferal analyses, using the frequency patterns of thirteen categories, twelve of which concern species or species groups. These species/species groups are: *S. tenuissima*, *S. elongata*, *S. infima*, *L. muensteri*, all other *Lenticulina* species, *Nodosaria/Dentalina* spp., *Eoguttulina* spp., *Discorbis* spp., *Paalzowella feifeli*, the miliolids, the agglutinants and a Restgroup consisting of all other (rare) species. Epistominids occur in low numbers and usually as pyritized casts in the upper part of the section and have been included in the Restgroup.

Table 8 shows that *S. tenuissima* is common to abundant throughout the section and that the agglutinants form an important part of the benthonic microfauna in samples from subsection 3 and the lower part of subsection 4. The number of species (table 9) ranges from 10 to 29 with an average of about 21. Planktonic foraminifera do occur, but in such low numbers that the P/B-ratio has not been used in the analyses.

Table 9. Number of species (N) and P/B-ratio (P/B) for the Mareta section

| Sample number | N | P/B | Sample number | N | P/B |
|---------------|----|------|---------------|----|------|
| 3 | 10 | .000 | 3.10 | 22 | .000 |
| 7 | 14 | .006 | 3.11 | 28 | .009 |
| 10 | 16 | .003 | 3.12 | 26 | .000 |
| 13 | 24 | .011 | 3.13 | 20 | .000 |
| 14 | 23 | .000 | 3.14 | 25 | .000 |
| 16 | 22 | .000 | 3.15 | 20 | .000 |
| 17 | 24 | .005 | 3.16 | 18 | .000 |
| 18 | 22 | .005 | 3.17 | 21 | .029 |
| 19 | 24 | .000 | 26 | 22 | .000 |
| 20 | 27 | .000 | 27 | 23 | .004 |
| 21 | 23 | .033 | 28 | 22 | .000 |
| 22 | 22 | .005 | 30 | 15 | .000 |
| 23 | 24 | .027 | 31 | 21 | .009 |
| 24 | 24 | .000 | 32 | 20 | .046 |
| 25 | 25 | .012 | 33 | 18 | .004 |
| 3.1 | 21 | .014 | 35 | 21 | .014 |
| 3.2 | 28 | .001 | 36 | 23 | .072 |
| 3.3 | 25 | .019 | 38 | 22 | .007 |
| 3.4 | 29 | .003 | 39 | 18 | .034 |
| 3.5 | 27 | .005 | 40 | 19 | .029 |
| 3.6 | 25 | .000 | 41 | 18 | .048 |
| 3.7 | 21 | .000 | 42 | 16 | .000 |
| 3.8 | 24 | .003 | 45 | 23 | .000 |
| 3.9 | 17 | .000 | | | |

Table 10. Q-mode factor analysis Mareta section

| Sample number | Factor (U) | U1 | U2 | U3 | U4 |
|---------------|------------|-----|-----|------|-----|
| 3 | | .94 | .30 | -.04 | .12 |
| 7 | | .92 | .34 | -.09 | .16 |
| 10 | | .91 | .39 | -.07 | .05 |
| 13 | | .70 | .63 | -.30 | .11 |
| 14 | | .57 | .63 | -.49 | .18 |
| 16 | | .77 | .58 | -.22 | .07 |
| 17 | | .59 | .67 | -.42 | .10 |
| 18 | | .78 | .56 | -.24 | .09 |
| 19 | | .70 | .66 | -.20 | .11 |
| 20 | | .60 | .67 | -.42 | .02 |
| 21 | | .19 | .97 | .05 | .02 |
| 22 | | .43 | .81 | -.35 | .01 |
| 23 | | .53 | .81 | -.20 | .04 |
| 24 | | .54 | .83 | -.07 | .05 |
| 25 | | .40 | .91 | -.00 | .07 |
| 3.1 | | .81 | .58 | -.04 | .03 |
| 3.2 | | .42 | .90 | -.08 | .11 |
| 3.3 | | .38 | .91 | -.10 | .04 |
| 3.4 | | .64 | .70 | -.29 | .09 |
| 3.5 | | .59 | .77 | -.22 | .09 |
| 3.6 | | .68 | .71 | -.12 | .09 |
| 3.7 | | .51 | .80 | -.30 | .06 |
| 3.8 | | .51 | .83 | -.17 | .06 |
| 3.9 | | .83 | .55 | -.05 | .02 |
| 3.10 | | .40 | .90 | -.12 | .08 |
| 3.11 | | .50 | .84 | -.17 | .04 |
| 3.12 | | .57 | .78 | -.23 | .10 |
| 3.13 | | .80 | .53 | -.27 | .11 |
| 3.14 | | .33 | .94 | -.02 | .08 |
| 3.15 | | .85 | .49 | -.14 | .09 |
| 3.16 | | .56 | .58 | -.15 | .57 |
| 3.17 | | .75 | .56 | -.28 | .03 |
| 26 | | .90 | .43 | -.07 | .04 |
| 27 | | .89 | .42 | -.14 | .07 |
| 28 | | .85 | .47 | -.18 | .08 |
| 30 | | .86 | .41 | -.26 | .00 |
| 31 | | .90 | .40 | -.10 | .06 |
| 32 | | .86 | .44 | -.16 | .09 |
| 33 | | .91 | .38 | -.09 | .03 |
| 35 | | .89 | .41 | -.17 | .02 |
| 36 | | .89 | .42 | -.17 | .05 |
| 38 | | .84 | .47 | -.18 | .06 |
| 39 | | .80 | .43 | -.35 | .08 |
| 40 | | .85 | .42 | -.17 | .12 |
| 41 | | .93 | .35 | -.09 | .07 |
| 42 | | .91 | .38 | -.07 | .04 |
| 45 | | .77 | .57 | -.14 | .06 |

Rotated factor matrix

Table 10. (continued).

| Factor (U) | U1 | U2 | U3 | U4 |
|---------------------------------|-------|------|-------|-------|
| Species/speciesgroup | | | | |
| <i>S. tenuissima</i> | 74.4 | 5.6 | 37.1 | -16.2 |
| <i>S. infima</i> | .1 | 5.3 | -5.9 | -4.0 |
| <i>S. elongata</i> | 4.6 | 2.4 | -3.6 | -3.4 |
| <i>L. muensteri</i> | 2.3 | 1.2 | -5.1 | -4.1 |
| <i>Nodosaria/Dentalina</i> spp. | -4.0 | 6.5 | -31.8 | -3.6 |
| <i>Eoguttulina</i> spp. | -1 | 6.1 | -12.7 | -8.9 |
| <i>P. feifeli</i> | 7.2 | -3.3 | -.1 | 9.6 |
| <i>Discorbis</i> spp. | 1.8 | 1.4 | 1.3 | -2.4 |
| Agglutinants | -12.3 | 43.6 | 28.1 | -4.3 |
| Miliolids | -.9 | -.3 | 4.5 | 38.4 |
| <i>Lenticulina</i> spp. | 2.9 | 3.6 | -5.8 | -1.9 |
| Restgroup | -1.6 | 3.0 | -7.5 | 26.1 |
| no. of species | 9.4 | 23.1 | -8.1 | -2.7 |
| P/B-ratio | .0 | .0 | .0 | -.0 |

Varimax factor scores

Significant positive and negative correlations are given in fig. 35. Significant positive trends are shown by *S. tenuissima*, *L. muensteri* and *Lenticulina* spp., whereas the agglutinants show a negative trend. An R-mode cluster analysis on the matrix of correlation coefficients shows five groups (fig. 36): group 1 consists of *L. muensteri* and *S. infima*; group 2 consists of *S. tenuissima*, *P. feifeli* and *S. elongata*; group 3 consists of *Lenticulina* spp. and *Discorbis* spp.; group 4 is formed by the miliolids and the restgroup; and group 5 consists of the agglutinants, *Nodosaria/Dentalina* spp. and *Eoguttulina* spp. A Q-mode analysis (fig. 37 and table 10) shows two groups of samples, one group formed by samples 21, 25, 3.2, 3.3, 3.10 and 3.14 and another group consisting of all other samples.

Table 11. Trend analyses Mareta Beach benthonic foraminifera.

| | | |
|---------------------------------|---|---|
| <i>S. tenuissima</i> | - | + |
| <i>S. infima</i> | | |
| <i>S. elongata</i> | | |
| <i>L. muensteri</i> | | |
| <i>Nodosaria/Dentalina</i> spp. | | - |
| <i>Eoguttulina</i> spp. | + | - |
| <i>P. feifeli</i> | - | + |
| <i>Discorbis</i> spp. | | |
| Agglutinants | + | - |
| Miliolids | | |
| <i>Lenticulina</i> spp. | | + |
| Restgroup | | |

Left +/- column deepening lower part of the section, right +/- column shallowing upper part of the section.

Munk (1980) the occurrence of *Paalzowella* is strongly facies controlled, with greater abundances within shallow water reef biotopes. In this respect it is interesting to note that *P. feiffeli* is most abundant in samples 3 and 7, close to the "reefal" limestone, and in a few samples in the shallow water upper part of the section (table 8). The "reefal" limestone masses could be allochthonous blocks (rock falls) that have been transported downslope (Gibling and Stuart, in

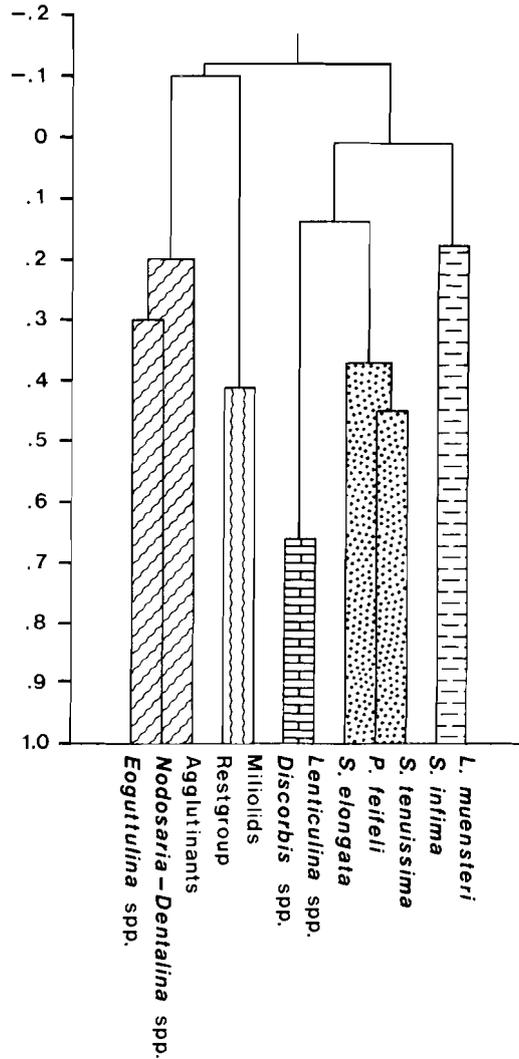


Fig. 36. R-mode dendrogram of the benthonic foraminifera from the Mareta Beach section.

preparation). The abundance of *P. feifeli* in beds overlying the “reefal” limestone would suggest that transport, if any, was minimal.

In view of the results of the other sections, it was expected that *S. infima* would be grouped together with the other spirillinids. It is not really clear why this species shows a different behaviour in case of the Mareta Beach section. Possibly local transport (abundant broken *Bositra buchii*) caused some mixing.

As mentioned earlier, *S. tenuissima*, *L. muensteri* and *Lenticulina* spp. show a significant positive trend and the agglutinants a significant negative trend. This is based on an analysis that included all 47 samples that contained enough foraminifera (usually 200–300). However, as outlined in the paleogeographic reconstruction which is well reflected in the lithologies present in the Mareta Beach section, a transgression and a regression occurred during the timespan that the entire section was laid down. This could mean that in an analysis of all samples trends are “averaged out”. For example a species preferring deeper water could show a positive trend in the lower part of the section (transgression) and a negative trend in the upper part of the section (regression), the net result possibly being no trend at all. To avoid this the section has been “cut” in half for trend analysis, half meaning in two parts with comparable amounts of samples. The two parts used for trend analysis are a lower part up to approximately the level of the dikes and an upper part from sample 3.1 towards the top. The results obtained (Table 11) clearly confirm the shallow water preference of *S. tenuissima* and *P. feifeli* and the deeper water preference of *Eoguttulina* spp., *Nodosaria/Dentalina* spp. and the agglutinants. *S. infima* and

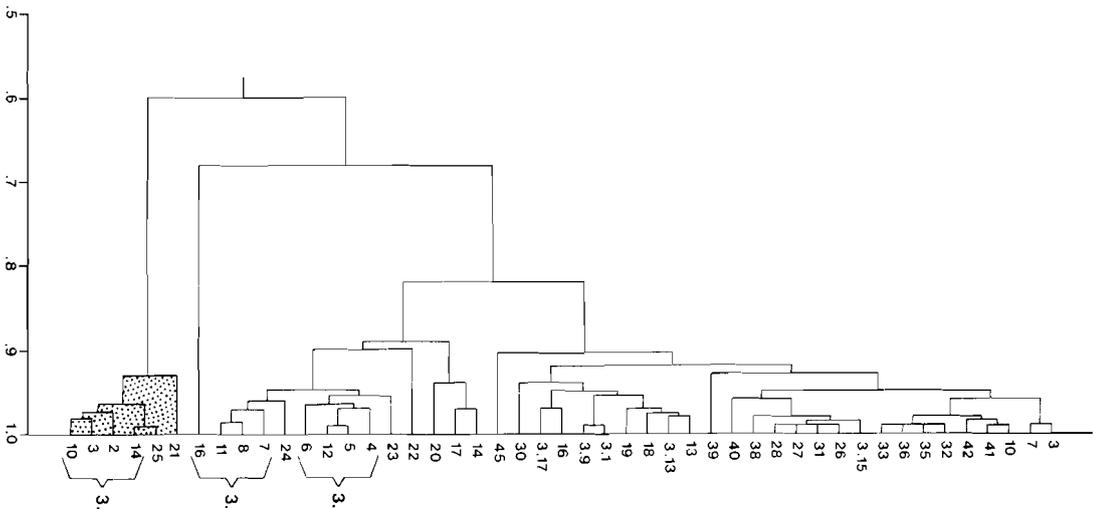


Fig. 37. Q-mode dendrogram of the samples from the Mareta Beach section.

S. elongata show a high but not quite significant negative trend in the lower part of the section.

The number of species, as in the analyses of the Tojeira 1 section, is negatively correlated with two shallow water species and positively correlated with two deeper water species (fig. 35). A possible meaning of this was discussed in section 2.4.5.

The Q-mode analyses (fig. 37 and table 10) are confusing. A few samples, for example nrs. 3, 7 and 10 in the lowest part of the section, load heavily on the first factor which has high factor scores of *S. tenuissima*. Several other samples, shown as dotted cluster, load heavily on the second factor which has high factor scores of the agglutinants. Most other samples have no unique loading. They usually have high loadings on the first and the second factor, sometimes even on more than two factors (sample 3.26).

It is almost contradictory to have high loadings on the first two factors, because these factors have high factor scores of species with an opposing ecological preference. The "trouble" starts with sample 13 (beginning of the calcareous shale above the third "reefal" limestone) and continues with only a few exceptions (like the samples of the dotted cluster) until sample 45. A possible explanation is that the Q-mode analyses are affected by the closed-sum effect. An R-mode analysis using DISTUR indicated that *S. tenuissima* may disturb. Therefore *S. tenuissima* was deleted in a second Q-mode factor analysis, and somewhat better results were obtained. Samples 13 through 25 and 3.1 through 3.17 and sample 30 are grouped together because of high factor scores of *Nodosaria/Dentalina* spp. and the agglutinants. All other samples are grouped in clusters with high factor scores of *P. feifeli* or *S. infima* and *L. muensteri*. Thus, even though a large part (table 8) of the microfauna has been deleted, the second Q-mode factor analysis is essentially in accordance with the R-mode analysis.

The trace fossil *Zoophycos*, which is common to abundant in the lowest part of the section, was used by Hallam (1978) for bathymetric interpretation and interpreted as being characteristic for a relatively deeper water calcareous facies. Plicka (1970) and Ekdale *et al.* (1984) report this trace fossil to be common in very shallow to very deep water, which indicates that *Zoophycos* is not a good bathymetric indicator. In the case that Hallam's interpretation is accepted, it would mean that a marine transgression (whether global or not) occurred directly after the deposition of the lowest "reefal" limestone. However, as discussed above, based on sedimentology and micropaleontology a transgression occurred after the deposition of the uppermost "reefal" limestone rather than the lowest "reefal" limestone.

3.5: ALBUFEIRA, LOULE AND ESTOI

Outcrops in the vicinity of Albufeira, Loule and Estoi have been sampled because of the occurrence of marine (pelagic) Oxfordian and Kimmeridgian strata in these areas (Mouterde *et al.*, 1972), even though no exact localities were known. An examination of the microfauna from these samples could facilitate a comparison with the microfauna from Oxfordian-Kimmeridgian strata in the Lusitanian Basin, with special reference to planktonic foraminifera.

The Albufeira section (figs. 38, 39) consists of bluish-grey shale and blue (silty) shale rich in black plant remains at the top. At some levels intercalations of silty/sandy shale and seemingly discontinuous sandstone occur. Belemnites and badly preserved ammonites are common in the lower part of the section.

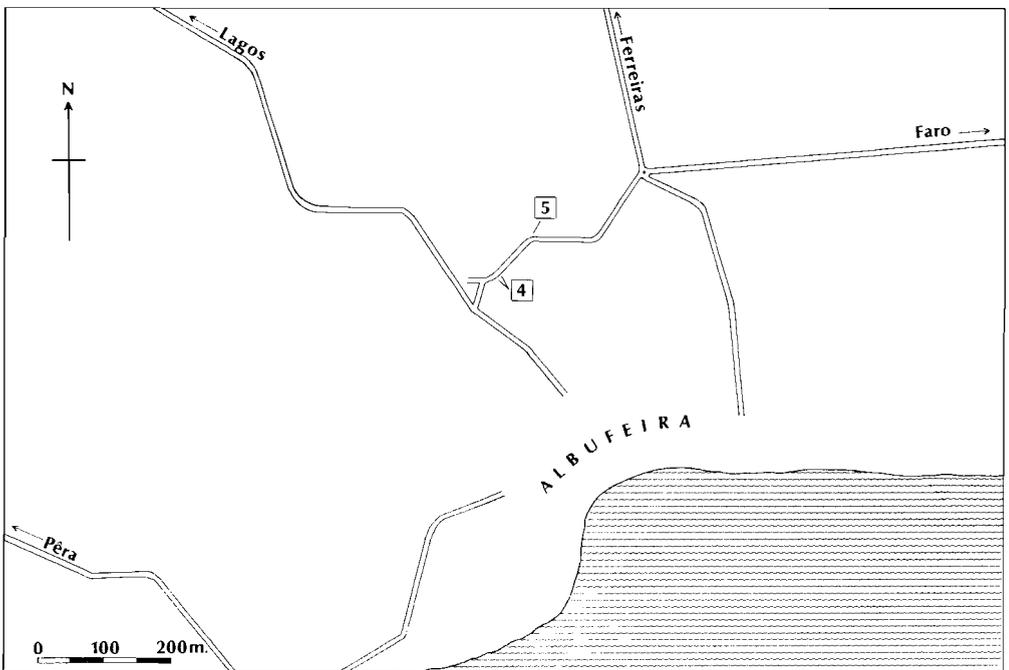


Fig. 38. Sample locations near Albufeira. Location 4: samples 4.1–4.17; location 5: samples 5.1–5.2.

The age of the section is thought to be Oxfordian-Kimmeridgian (Rocha, pers. comm.), however, as yet no ammonite data are available to support this age determination. Pratsch (1958, p. 47) reported that the ammonite species (3 in total) that he found in the Albufeira shale, even though not diagnostic for particular ammonite zones, are the same as those that occur in the *Bimammatum* plus *Planula* Zones (Late Oxfordian) and *Acanthicum* Zone (Middle Kim-

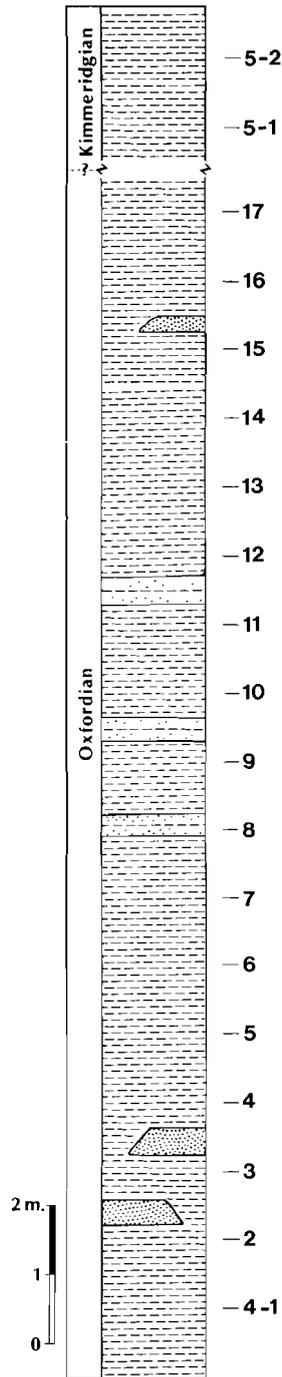


Fig. 39. Lithological column of the Albufeira section with tentative age assignments (see text).

meridgian) of the Lusitanian Basin (Montejunto-Abadia Formations). Worth noting is that the top of the Albufeira section is lithologically somewhat similar to the Abadia Formation: blue in colour, many black plant remains.

Although, because of the scarcity of benthonic foraminifera, no quantitative analyses have been attempted, a tentative conclusion would be that the shale has been deposited under similar (depth) conditions as the Callovian shale part of the Mareta Beach section. *S. tenuissima* together with a few agglutinated species such as *Dorothia hechti* and *Verneuilinoides minuta* occur in most samples. Very rare *E. ubligi* (sample 4.5) and *Epistomina*-like casts (sample 4.9) have been encountered. A pyritized cast of a planktonic foraminiferid has been found in sample 4.6. Pratsch (1958, p. 46) noted that the "Albufeira shale" is petrographically very similar to the Callovian shale of the Algarve Basin.

The occurrence of abundant plant fragments and a marked increase in quartz grains in the upper part of the section (samples 5.1 and 5.2), plus the fact that the section is overlain by limestone with abundant corals followed by well sorted red sandstones indicates a shallowing.

Less is known concerning the age of the outcrops in the Loule and Estoi areas, as an updated geological map was still (1984) unavailable. According to a geological map of Pratsch (1958, fig. 14), the outcrops in these two areas are of Kimmeridgian-Portlandian age. The outcrop 3 km south of Loule, just before entering the small village of Alfarrobeira (not shown in fig. 32) consists of an alteration of hard white limestones and grey calcareous shale, whereas the outcrop north of Estoi consists of brownish to grey shale. The scarce microfauna encountered is virtually the same as in the case of the Albufeira section, with the exception of the rare occurrences of *E. mosquensis* and the lack of any planktonics. *S. tenuissima* seems to be more abundant, possibly indicating a shallower depth of deposition if compared with the Albufeira section.

3.6: THE ALGARVE AND LUSITANIAN BASINS, A COMPARISON

If the, to a large degree consistent, results of the quantitative foraminiferal analyses of all five sections are compared, the following conclusions can be made (see also fig. 40).

The three *Spirillina* species, most notably *S. tenuissima* which is always the most abundant of the three, together with *O. carinatum* and *P. feifeli* preferred relatively shallow water. A tentative depth estimate would be 50 metres or less.

The agglutinants, *E. mosquensis*, *P. rjasanensis* and *O. strumosum* preferred deeper water, ranging from about 200 to 250 metres or possibly more.

L. muensteri, *Lenticulina* spp., *Discorbis* spp., *Eoguttulina* spp. and *Nodosaria/Dentalina* spp. filled the depth niche in between, from ca. 50 to ? 150 m.

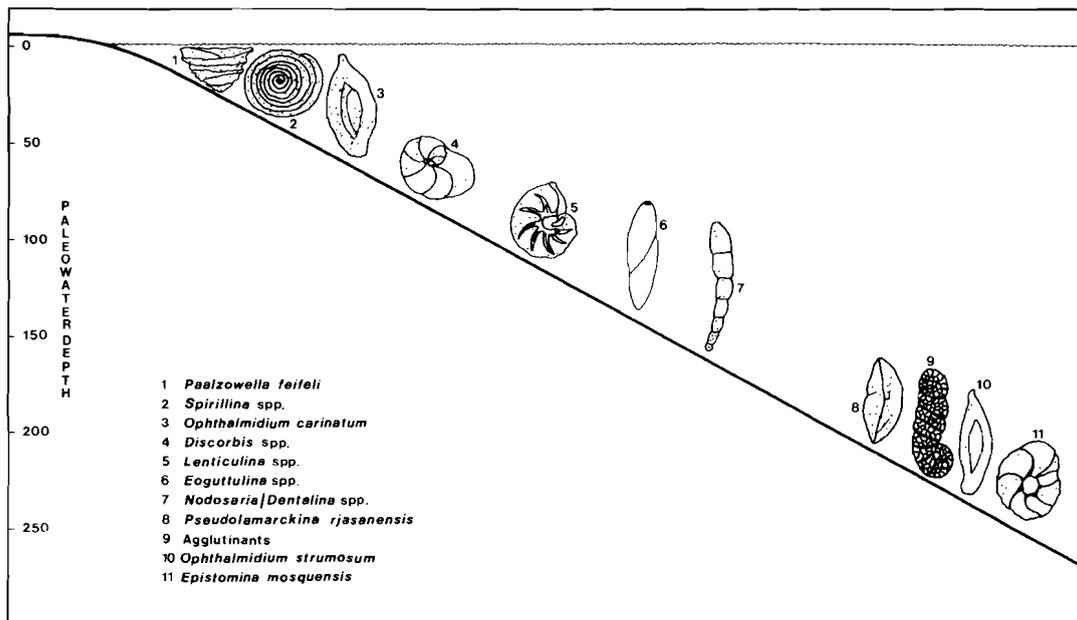


Fig. 40. Cartoon showing the preferred paleowaterdepth of several Jurassic benthonic foraminifera.

The latter two categories tentatively preferred somewhat deeper water than the former three, based on the Q-mode analyses of the Murtinheira and Brenha sections, and their association with the agglutinants in the Mareta Beach section. In the case of the Tojeira sections, *Eoguttulina* spp. were associated with the shallow water group whereas the ecological position of *Nodosaria*/*Dentalina* spp. was not clear. It should be noted however that the Q-mode analyses of the Tojeira sections showed that an intermediate assemblage (between deep and shallow) was virtually lacking.

The ecological preference of *E. ubligi* and *Epistomina* spp. is not really clear from any of the analyses. This species and species group are common in both Tojeira sections whereas they are rare to absent in the other sections. *E. ubligi* and *Epistomina* spp. are therefore probably closer to the foraminifera that preferred deeper water than to the foraminifera that preferred shallower water.

Chapter 4

THE GRAND BANKS OF NEWFOUNDLAND

4.1: INTRODUCTION

The Grand Banks are located off the coast of Newfoundland. More than 6,000 m of Jurassic sedimentary strata accumulated in several grabens and half-grabens (from east to west the Carson, Jeanne d'Arc, Horseshoe, Whale and South Whale Subbasins, fig. 41) created by block faulting (Amoco Canada Petroleum Company Ltd. and Imperial Oil Ltd., 1973, fig. 7; Kent, 1976). A general lithostratigraphic and tectonic framework of the Grand Banks has been described by, amongst others, Bartlett and Smith (1971), Amoco Canada Petroleum Company Ltd. and Imperial Oil Ltd. (1973), Jansa and Wade (1975a, b) and Benteau and Sheppard (1982). Papers dealing with Jurassic biostratigraphy of the Grand Banks have been published by Gradstein (1977, 1978), Barss *et al.* (1979), Jansa *et al.* (1980) and Ascoli (1981).

In chapter 1 it was suggested that, in view of paleogeographic reconstructions, the Algarve and Lusitanian Basins and the Grand Banks Basin(s) should have a comparable sedimentary, tectonic and faunal history during the Jurassic. Wilson (1975b) described a close similarity in facies distribution and structural control (grabens and half-grabens developed along Hercynian basement structures) between Iberia and the Grand Banks. In a detailed stratigraphic and micropaleontologic study of the Grand Banks and Portugal, Exton and Gradstein (1984) concluded that the Triassic – Lower Jurassic lithostratigraphy of the Grand Banks and the Lusitanian Basin are closely similar. Also, these authors showed that the Early Jurassic ostracode and foraminiferal assemblages of Portugal and the Grand Banks are comparable in composition: three zones could be recognized in both areas. This allowed for the indirect integration of Early Jurassic microfossil assemblages of the Grand Banks with the standard European ammonite zones.

In this chapter the results, in terms of foraminiferal paleoecology and biostratigraphy, obtained using the Portuguese samples will be applied to the Middle and Upper Jurassic of the Grand Banks. This, of course, can only be done if the foraminiferal microfauna of both regions is similar. The washed residues of all available sidewall cores and cuttings of eighteen wells in which Jurassic strata have been sampled were studied, and an overview of the foraminifera encountered will be given. Down-hole depths are as measured from the rotary table.

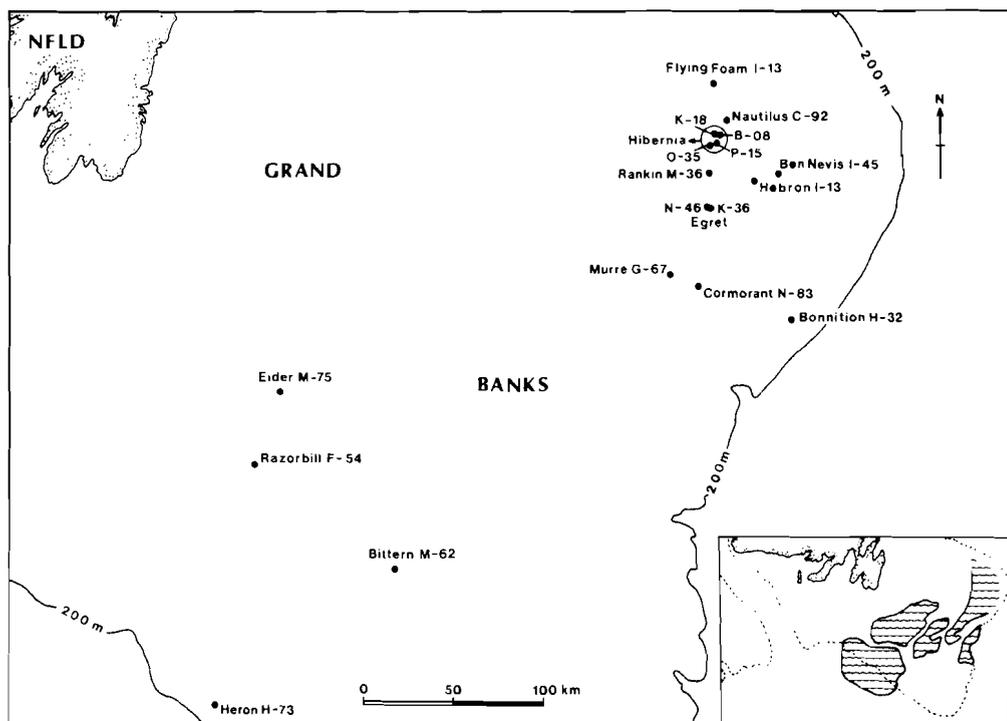


Fig. 41. Location map of the Grand Banks area. The subbasins, from east to west, are the Carson, Jeanne d'Arc, Horseshoe, Whale and South Whale.

4.2: THE WELLS

The eighteen Grand Banks wells that have been used are located in the five different subbasins mentioned above (fig. 41). The Heron H-73 well is located in the South Whale Subbasin, the Eider M-75 and Razorbill F-54 wells are located in the Whale Subbasin, the Bittern M-62 well is located in the Horseshoe Subbasin, and the Bonniton H-32 well is located in the Carson Subbasin. The remaining thirteen wells (see fig. 4.1) are all located in the Jeanne d'Arc Subbasin.

The Jurassic section present in each individual well (after Gradstein, 1977, 1978; Barss *et al.*, 1979) is given in fig. 42. From this figure it can be seen that in most wells only Upper Jurassic sediments have been drilled. Lower and Middle Jurassic sediments have been sampled from the Eider M-75, Heron H-73, Bittern M-62, Cormorant N-83 and Murre G-67 wells. In most wells Upper Jurassic or Lower Cretaceous strata are unconformably overlain by Upper

Cretaceous or younger sediments. This so-called Avalon unconformity relates to continental blocks, tilting during break-up between the Grand Banks and Portugal in Albian time.

| JURASSIC | | GRAND BANKS | | | | | | | | | | | | | | | | | |
|----------|---------------|-------------|----------------|------------|--------------|---------------|----------------|------------|------------|------------|-------------|----------------|-------------|---------------|---------------|---------------|---------------|---------------|------------------|
| | | Eider M-75 | Razorbill F-54 | Heron H-73 | Bittern M-62 | Bonneton H-32 | Cormorant N-83 | Murre G-67 | Egret K-36 | Egret N-46 | Hebron I-13 | Ben Nevis I-45 | Rankin M-36 | Hibernia P-15 | Hibernia O-35 | Hibernia B-08 | Hibernia K-18 | Nautilus C-92 | Flying Foam I-13 |
| Malm | Tithonian | | | | | | | | | | | | | | | | | | |
| | Kimmeridgian | | | | | | | | | | | | | | | | | | |
| | Oxfordian | | | | | | | | | | | | | | | | | | |
| Dogger | Callovian | | | | | | | | | | | | | | | | | | |
| | Bathonian | | | | | | | | | | | | | | | | | | |
| | Bajocian | | | | | | | | | | | | | | | | | | |
| | Aalenian | | | | | | | | | | | | | | | | | | |
| Lias | Toarcian | | | | | | | | | | | | | | | | | | |
| | Pliensbachian | | | | | | | | | | | | | | | | | | |
| | Sinemurian | | | | | | | | | | | | | | | | | | |
| | Hettangian | | | | | | | | | | | | | | | | | | |

Fig. 42. Jurassic section recovered from the various Grand Banks wells.

4.3: MIDDLE AND LATE JURASSIC FORAMINIFERA FROM THE GRAND BANKS

To allow for an easy comparison between the Jurassic microfauna from Portugal and the Grand Banks, the foraminifera that have been recognized in the wells on the Grand Banks are presented in two tables.

In table 12 all those species are listed that are important for the quantitative analyses of the Portuguese sections and are important from a stratigraphical point of view. This table clearly shows that many of the Portuguese Jurassic foraminifera are also present in the Jurassic of the Grand Banks. Species groups such as the agglutinants also have many species in common with Portugal: *A. coprolithiformis*, *D. hechti*, *B. jurassica*, *V. minuta*, *T. jurassica*, *Trochammina* spp. have all been recognized. The same holds for *Lenticulina* spp.: *L. tricarinella*, *L. subalata*, *L. anceps* etc. are all present. Simple, globose planktonic foraminifera, as those found in Portugal, have been encountered in five Grand Banks wells.

In table 13 only those species are listed that do occur in the Jurassic of the Grand Banks, but that have not been recognized in any of the Portuguese sec-

Table 12. Distribution chart of Middle and Late Jurassic foraminifera from 18 Grand Banks wells. Only those species are listed that occur in the Portuguese sections studied.

| | Wells | | | | | | | | | | | | | | | | | |
|---------------------------------|-------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| <i>D. parapsis</i> | | | | | x | | | | | x | | | x | x | | | | |
| <i>D. scutiliformis</i> | | | | | | | | | | | | | | x | | | | |
| <i>E. bilocularis</i> | | | | x | | | | | | | | | | | | | | |
| <i>E. metensis</i> | x | | | | | | | | | | | | x | | | | | |
| <i>E. oolithica</i> | x | | | x | x | | | | | | | | | | | | | |
| <i>E. mosquensis</i> | x | | | x | x | x | x | | | x | x | x | x | x | x | x | x | x |
| <i>E. ominoreticulata</i> | | | | | | | x | | | x | | | x | | | | x | |
| <i>E. ubligi</i> | x | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| <i>E. volgensis intermedia</i> | | | | | x | | | | | | | | x | | | | | |
| <i>E. volgensis volgensis</i> | | | | | x | x | | | | | | x | | | | | | |
| <i>Epistomina</i> sp. 1 | | | | | | | | | | | | | | | | | | |
| <i>Epistomina</i> sp. 2 | | | | | | x | | | | | | | | | | | | |
| <i>L. muensteri</i> | x | | x | | x | x | x | | x | | x | x | x | x | x | x | x | x |
| <i>L. dorbignyi</i> | | | | | | x | x | | | | | | | | | | | |
| <i>L. quenstedti</i> | x | | | x | x | x | x | x | | x | x | x | x | x | | | | |
| <i>Lenticulina</i> spp. | | | | | x | x | | | x | x | | x | x | x | x | | x | x |
| <i>Nodosaria/Dentalina</i> spp. | | | | x | | x | x | | | | | | x | | | | | |
| <i>O. carinatum</i> | x | | x | x | | x | x | | | | | | | | x | | | |
| <i>O. concentricum</i> | | | | | | x | | | | | | | | | | | | |
| <i>O. strumosum</i> | | | | | | | | | | | | | | | | | | |
| <i>P. feifeli</i> | x | | | x | x | | x | | | | | x | x | x | x | | x | x |
| <i>P. rjasanensis</i> | | | | | x | x | x | | | | x | x | | | x | | | x |
| <i>S. elongata</i> | | | | x | x | | | | | | | | x | | | | | |
| <i>S. infima</i> | | | | | x | | | | | | | | x | | | | | |
| <i>S. tenuissima</i> | x | | x | x | x | x | x | x | | x | x | x | | x | x | | | x |
| Agglutinants | x | | | x | x | x | x | x | | x | x | x | x | x | x | x | x | x |
| Planktonics | x | x | | x | | x | x | | | | | | | | | | | |

1 = Eider M-75
 2 = Razorbill F-54
 3 = Heron H-73
 4 = Bittern M-62
 5 = Bonniton H-32
 6 = Cormorant N-83

7 = Murre G-67
 8 = Egret K-36
 9 = Egret N-46
 10 = Hebron I-13
 11 = Ben Nevis I-45
 12 = Rankin M-36

13 = Hibernia P-15
 14 = Hibernia O-35
 15 = Hibernia B-08
 16 = Hibernia K-18
 17 = Nautilus C-92
 18 = Flying Foam I-13

Table 13. Distribution chart of Middle and Late Jurassic foraminifera from 18 Grand Banks wells. Species listed do not occur in any of the Portuguese sections studied.

| | Wells | | | | | | | | | | | | | | | | | |
|-------------------------------------|-------|---|---|---|---|---|----|---|---|----|----|----|----|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| <i>Alveosepta jaccardi</i> | | | | | x | | | x | x | | | | x | | | | | |
| <i>Anchispirocyclina lusitanica</i> | | | | | x | | | x | | | | | | x | | | | |
| ? <i>Eoguttulina</i> sp. | | | | | | | | x | x | x | | | | | | | | |
| <i>Epistomina regularis</i> | x | | | x | | x | x | | | x | | | | | | | | |
| <i>Epistomina stellicostata</i> | | x | | | | | ?x | | | x | x | x | x | x | x | x | x | x |
| <i>Epistomina</i> sp. 3 | | | | | x | x | | | | | x | x | | | | | | |
| <i>Garantella ampasindavaensis</i> | x | | | | | x | x | | | | | | | | | | | |
| <i>Garantella ornata</i> | x | | | | | | x | | | | | | | | | | | |
| <i>Garantella</i> aff. <i>rudia</i> | x | | | | | x | x | | | | | | | | | | | |
| <i>Garantella sera</i> | x | | | | | x | x | | | | | | | | | | | |
| <i>Garantella stellata</i> | x | | | | | | | | | | | | | | | | | |
| <i>Reinholdella cebra</i> s.s. | x | | | | | | x | | | | | | | | | | | |
| <i>Reinholdella cebra</i> var. | x | | | | | | x | | | | x? | | | | | | | |
| <i>Reinholdella epistominoides</i> | x | | | | | | | | | | | | | | | | | |
| <i>Reinholdella media</i> | x | | | | | x | x | | | | | | | | | | | |

1 = Eider M-75
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 5 = Bonniton H-32
 6 = Cormorant N-83

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 8 = Egret K-36
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 10 = Hebron I-13
 11 = Ben Nevis I-45
 12 = Rankin M-36

13 = Hibernia P-15
 14 = Hibernia O-35
 15 = Hibernia B-08
 16 = Hibernia K-18
 17 = Nautilus C-92
 18 = Flying Foam I-13

tions studied. This does not necessarily mean that these species are not known from Portugal. For example, the type locality of the Grand Banks Tithonian marker *Anchispirocyclus lusitanica* is Cape Espichel, south of Lisbon (fig. 2).

The largest differences in foraminiferal content between the Grand Banks and Portuguese Jurassic occur in the Eider M-75, Murre M-62 and Cormorant N-83 wells. In these wells many species of the genera *Garantella* and *Reinholdella* occur that have not been found in any of the coeval Portuguese sections. *Garantella* and *Reinholdella* essentially are Middle Jurassic genera (Espitalié and Sigal, 1963; Loeblich and Tappan, 1964; Ohm, 1967; Pazdro, 1969). On the other hand, no *Garantella* and *Reinholdella* species have been recognized in two other Grand Banks wells, Heron H-73 and Bittern M-62, from which Middle Jurassic sediments have been sampled (fig. 42). For this reason it is postulated that these differences in Middle Jurassic foraminifera are more likely the result of local differences in depositional environment within the Grand Banks region rather than a result of the presence of physical barriers between the Grand Banks and Portugal.

Eider M-75

In the Eider M-75 well Middle and Upper Jurassic sediments are present in the interval between ca. 2,700 and 11,000 feet. Gradstein (1975) described the biostratigraphy and depositional environment of this well. Of particular interest are the sidewall cores and cuttings in the interval between 6,230 and 10,600 feet: they contain a relatively diversified microfauna with abundant *Garantella*, *Reinholdella* and *Epistomina*, together with many planktonic foraminifera. The age of this interval has been determined as Bajocian-Bathonian (Gradstein, 1978; Barss *et al.*, 1979). The sediments from 5,960 to 8,612 feet, mainly consist of grey and dark grey shales and were assigned to the Verrill Canyon Formation by Jansa and Wade (1975b). These authors suggested a deep neritic to epibathyal depositional environment for this formation, which is in agreement with the interpretation by Gradstein (1975).

From 7,340 to approx. 6,560 feet (Upper Bathonian; Gradstein, 1978) the samples contain less foraminifera, epistominids are still present, but planktonic foraminifera are very rare, indicating a shallowing waterdepth. This shallowing continues into the earliest Oxfordian, after the top occurrence of *E. regularis* at 5,560 feet, as indicated by the occurrence of *Chara* sporangia. Later, above 4,060 feet, during the Oxfordian and Kimmeridgian a deepening occurred, indicated by the common occurrence of *E. mosquensis* and *E. ubligi*, together with such species as *Eoguttulina metensis*, *L. muensteri*, *L. tricarinnella*, *A. coprolithiformis* and *V. minuta*. No Tithonian sediments are known from this well (Gradstein, 1978; Barss *et al.*, 1979).

Murre G-67 and Cormorant N-83

Middle and Upper Jurassic sediments occur in the Murre G-67 well in the interval between ca. 3,000 and 6,770 feet. A detailed account of the litho- and biostratigraphy of this well is given by Jansa *et al.* (1976). The Verrill Canyon Formation, which is equivalent with the upper half of the Whale Unit of Jansa *et al.* (1976), was recognized between 3,740 and 5,960 feet (Jansa and Wade, 1975).

The Bajocian through Callovian (from 6,770 to 4,419 feet; Gradstein, 1978) contains a relatively rich and diversified microfauna with *Garantella*, *Reinholdella* and *Epistomina*, together with planktonic foraminifera (Bathonian-Callovian). The paleowaterdepth during this interval is thought to be in the same order of magnitude as for the Bajocian-Bathonian of the Eider well. The presence between 5,960 and 6,588 feet, of the so-called Whale limestone of Bajocian age may be indicative of locally and temporally shallower marine conditions. Microfossil cavings obscure a possible shallow marine microfauna at these depths.

The paleowaterdepth during the Oxfordian-Tithonian, even though not shallow, was probably less than during the Bathonian-Callovian: the samples generally contain few foraminifera, only a few *E. mosquensis*, *E. ubligi* and *E. stelicostata* together with *L. quenstedti* and *P. feifeli* have been recognized.

The Middle and Upper Jurassic of the Cormorant N-83 well (present from ca. 2,700 to 5,100 feet) is closely similar to that of the Murre well (see also section on biostratigraphy).

Heron H-73

In the case of the Heron H-73 well, the Pliensbachian-Toarcian and the Bathonian through Kimmeridgian have been recognized by means of palynological determinations (Barss *et al.*, 1979). The Pliensbachian was also recognized by means of foraminifera, but sidewall cores from younger carbonates contained few and non-diagnostic foraminifera (Gradstein, 1978). Cutting samples from a large part of the Middle and Upper Jurassic section are absent. In fact, only a few spirillinids, *L. muensteri* and *O. carinatum* have been recognized, indicating a possibly relatively shallow water rather than a deep water origin for these carbonates.

Bittern M-62

The Middle-Upper Jurassic section in Bittern M-62 is present from approx. 3,850 to 9,000 feet. Sidewall cores from the upper part of this section contain a relatively rich and diversified microfauna. Epistominids are abundant, with

E. mosquensis and *E. ubligi* occurring throughout, whereas *E. regularis* is present in the lower part. The accompanying microfauna consists mainly of *L. muensteri*, *L. quenstedti*, agglutinants such as *V. minuta* and *D. hechti*, and *O. carinatum*. *S. tenuissima* is relatively abundant at the very top of this upper part, but rarely occurs below. Also present, sometimes in large numbers (sidewall core at 5,000'; Callovian-Oxfordian), are planktonic foraminifera. The Callovian-Oxfordian microfauna indicates a relatively deep water origin for the sediments. A shallowing occurred during the (Late Oxfordian) Kimmeridgian, indicated by the disappearance of planktonic foraminifera and the relative abundance of *S. tenuissima*. The Tithonian is missing (Gradstein, 1978; Barss *et al.*, 1979).

Samples from the lower part of the Jurassic section, below 6,540 feet (Early Callovian in age; Barss *et al.*, 1979), are relatively poor and contain mainly *S. tenuissima*, occasionally together with *L. muensteri* and/or *P. feifeli*, indicating relatively shallow waterdepths during the Bajocian and Bathonian.

Grand Banks paleobathymetry

So far paleowaterdepths have only been referred to as being relatively shallow or relatively deep. A comparison of Grand Banks Middle and Late Jurassic foraminiferal assemblages with those of Portugal may allow a more precise estimate.

Diversified assemblages rich in Epistominidae and planktonic foraminifera, as encountered in the Bajocian and Bathonian of the Eider (Whale Subbasin) and the Murre and Cormorant wells (Jeanne d'Arc Subbasin) are also present in the Oxfordian-Kimmeridgian Tojeira Formation of Portugal. Of course, such genera as *Reinholdella* and *Garantella*, which have their stratigraphic range restricted to the Bajocian-Bathonian, are not present in samples from the Tojeira Formation. This however does not invalidate the comparison. The Middle Jurassic Mareta Beach section (or for that matter the coeval part of the Brenha section) may serve as an example. From this section Bajocian through Callovian samples were analyzed and the results clearly showed the presence of a species group (*Eoguttulina* spp. and *Nodosaria/Dentalina* spp.) that preferred deeper water. The optimum waterdepth for this species group was estimated to be between 50 and ?150 m, probably closer to 150 than to 50 m (see chapter 3, section 3.6). This paleowaterdepth is much less than the estimated depth of deposition (250 m) of the Tojeira Formation with its rich epistominid and planktonic fauna. Pyritized casts of epistominids, not allowing for a generic/specific assignment, and pyritized casts of planktonic foraminifera were present in various samples from the Mareta Beach section but they always occurred in very low

numbers. This indicates that assemblages rich in epistominids and planktonics, as present in the Bajocian-Bathonian of the Eider, Murre and Cormorant wells, are most likely to be found in sediments with a depth of deposition similar to or perhaps even more than that of the Tojeira Formation (250 m). This view is supported when looking at the Bittern well (Horseshoe Subbasin). The sidewall cores from the Bajocian-Bathonian of the Bittern well contained, if any foraminifera at all, almost exclusively *S. tenuissima*, indicating a very shallow (up to 50 m) paleowaterdepth and therewith explaining the absence of epistominids and planktonics.

The paleowaterdepth from Callovian through Tithonian was less than 250 m (100–200 m) for most wells: epistominids are still present, but planktonic foraminifera are virtually absent. Exceptions are the Callovian and Callovian-Oxfordian of the Murre and Bittern wells respectively which still contains epistominids together with planktonics.

As mentioned earlier, from the remaining thirteen wells only Upper Jurassic sediments have been sampled, an exception being the Hebron I-13 well in which the occurrence of *E. regularis* at 4,085 feet indicates the presence of at least some Callovian sediments.

The Late Jurassic (Oxfordian-Kimmeridgian) foraminiferal content of these remaining wells, with the exception of the Egret K-36 and N-46 wells, is closely similar to that of the Murre G-67 well, indicating relatively deep (100–200 m) water. The occurrence of the shallow water larger arenaceous foraminifer *Alveosepta jaccardi* (Late Oxfordian-Early Kimmeridgian; Gradstein, 1978) in the Hibernia P-15 and Bonniton H32 wells may be due to local transport: both wells contain a relatively rich and diverse epistominid fauna, which would indicate a rather deep paleowaterdepth during that time interval. The same (transport) may account for the co-occurrence of *A. lusitanica* (Tithonian; Gradstein, 1978), *E. stelicostata* and *E. ubligi* in the Hibernia O-35 well.

Both the Egret K-36 (Gradstein *et al.*, 1976) and the Egret N-46 wells only contain shallow water Upper Jurassic sediments, as indicated by the virtual absence of epistominids and the relative abundance of *A. jaccardi* (Late Oxfordian-Early Kimmeridgian), an unknown ?*Eoguttulina* species, smooth ostracodes and *Chara* sporangia in both wells and the occurrence of *A. lusitanica* (Tithonian; Gradstein, 1978) in Egret K-36. Shallow water Tithonian sediments with *A. lusitanica* and *Chara* sporangia are also present in the Bonniton H-32 well.

Jurassic planktonic foraminifera were recognized in the Razorbill F-54 well, however the interval in which they occur cannot be determined with any degree of certainty due to much contamination.

Generally speaking a regression towards the Kimmeridgian-Tithonian can be recognized in all wells: samples contain less species and specimens stratigraphically upward and are sometimes dominated by larger foraminifera, indicating very shallow (50 m or less) water.

The shallowing trend during the Late Jurassic is about the only trend that can be recognized over the whole Grand Banks region. Older trends which may be recognized in individual wells do not run parallel. For example a shallowing occurred in the Eider well from the Bathonian to the Callovian, but at the same time a deepening occurred in the Bittern well. Most likely these changes in paleowaterdepth were caused by local vertical movements affecting only sub-basins or parts thereof rather than the entire Grand Banks.

| AGE | GRADSTEIN (1977 - 78) | This study |
|--------------|------------------------------------|-------------------------------------|
| | ZONES | |
| TITHONIAN | | <i>Epistomina stellicostata</i> |
| KIMMERIDGIAN | <i>Epistomina mosquensis</i> | <i>Epistomina mosquensis</i> |
| OXFORDIAN | | |
| CALLOVIAN | <i>Reinholdella cebra var.</i> | <i>Epistomina regularis</i> |
| BATHONIAN | <i>Globigerina bathoniana</i> | <i>Reinholdella spp.</i> |
| BAJOCIAN | <i>Garantella spp.</i> | <i>Garantella spp.</i> |

Fig. 43. Middle and Late Jurassic biozonation of the Grand Banks.

4.4: GRAND BANKS BIOSTRATIGRAPHY

Gradstein (1977, 1978) recognized six informal foraminiferal zones in the Middle and Upper Jurassic sediments of the Grand Banks. Two zones were based on the occurrences of the larger foraminifera *A. jaccardi* and *A. lusitanica*, whereas the other four (fig. 43) were based on the stratigraphic highest occurrences of several smaller foraminifera.

Here a somewhat different zonation is proposed (fig. 43): a zone of Tithonian age based on smaller foraminifera can be recognized in many of the 18 wells studied; the names and definitions of two Middle Jurassic zones have been changed, the age however remains the same. These changes and their implications will be discussed. Definitions of the unaltered zones such as for example the *Anchispirocyclina lusitanica* Zone are in Gradstein (1977, 1978). The definition of the *Epistomina stelicostata* Zone is in Ascoli (1981, his *Epistomina stelicostata* – *Epistomina uhligi* Zone, p. 11). The definitions of the two “new” zones are given below.

Reinholdella spp. Zone

Definition: The top is at the stratigraphically highest occurrence of the *Reinholdella* species *R. media* (Kaptarenko) and *R. cebra* s.s. Pazdro. *Globuligerina balakhmatovae* (Morozova) has its highest occurrence within this zone. The lower limit of this zone is the top of the underlying *Garantella* spp. Zone.

Age: Late Bathonian.

Occurrence: Eider M-75, cuttings 7,560–6,560'; Cormorant, cts. 4,410–3,690'; Murre G-67, cts. 5,700–5,260'.

Epistomina regularis Zone

Definition: Top at the stratigraphically highest occurrence of *Epistomina regularis* Terquem. The lower limit is the top of the underlying *Reinholdella* spp. Zone

Age: Callovian.

Occurrence: Bittern M-62, below sidewall core at 5,110'; Cormorant N-83, cts. 3,150–3,690'; Eider M-75, cts. ?6,650–5,560'; Hebron I-13, cts. below 4,085'; Murre G-67, cts. 5,260-sidewall core (swc.) 4419'.

The *E. stelicostata* Zone (Tithonian), based on the highest stratigraphical occurrence of this species, could not have been recognized by Gradstein (1977, 1978) simply because this species does not occur in any of the wells (apart from perhaps the Murre G-67 well; table 13) he studied.

The *R. cebra* var. Zone (Callovian in age; Gradstein, 1977, 1978) was based on the stratigraphically highest occurrence of *R. cebra* Pazdro var. and *E. regularis* Terquem. As far as the latter species is concerned there are no problems. *E. regularis* has a known stratigraphical range from Upper Bajocian through Callovian (see for example Ohm, 1967) and in those wells where this species is present, its top occurs always well below the top of *E. mosquensis*. The assignment of Grand Banks specimens to *R. cebra* var. however is problematical. In the literature no *Reinholdella* species is known from Callovian sediments. The stratigraphic range of this genus is from Toarcian through Bathonian (Loeblich and Tappan, 1964; Ohm, 1969; Pazdro, 1969). In a description of this genus Ohm (1967) reports it to range into the Oxfordian, which is due to the fact that he regards *Pseudolamarckina* to be synonymous with *Reinholdella*; all the *Reinholdella* species he describes are older than Callovian. It is the similarity between *Reinholdella* and *Pseudolamarckina* that could have caused the problem.

The taxon named *Reinholdella cebra* var. by Gradstein (and those listed as such in table 13) should be referred to as *Pseudolamarckina* species. An examination of cuttings and sidewall cores from the Eider, Murre and Cormorant wells and Gradstein's type-collection revealed that the specimens present lack the for *Reinholdella* characteristic arched interiomarginal aperture near the periphery. All specimens have an interiomarginal umbilical aperture with a small incision upface the chamber, which is a *Pseudolamarckina* characteristic (Loeblich and Tappan, 1964; see also taxonomic notes, chapter 6). The small incisions of the aperture, especially when visible on all chambers on the umbilical side, may look similar to the "pattern" of secondary apertures in *Reinholdella*. The *Pseudolamarckina* specimens recognized, even though higher trochoid, are similar to *P. rjasanensis* from the Oxfordian-Kimmeridgian of the Portuguese Tojeira Formation. Since the stratigraphic range of *E. regularis* is well documented, it is better to use this species to define the zone.

The "*Globigerina*" *bathoniana* Zone (Late Bathonian in age; Gradstein, 1977, 1978) was based on the stratigraphically highest occurrence of the planktonic foraminifera "*G*". *bathoniana* Pazdro. In practice this zone was essentially recognized by the highest stratigraphical occurrence of high spired planktonic foraminifera. An examination of ?Bajocian through Kimmeridgian planktonic foraminifera from Portugal, and available Middle and Upper Jurassic material from other localities plus a study of the relevant literature (chapter 5), showed that high spired planktonics can occur throughout the Middle and Late Jurassic. This is illustrated in fig. 44. In this figure specimen number 1 (see also plate 12, fig. 9) is the same specimen as figured by Gradstein (1977, pl. 3, fig. 1; 1978, pl. 2, figs. 3, 5), and was found in the Eider M-75 well, in the cuttings at 7,760

feet. Specimen number 2 (also on plate 10, fig. 12) comes from the Tojeira 1 section of Portugal, sample 6.20, Platynota Zone, Lower Kimmeridgian. Planktonic foraminifera closely similar to what could be called "typical" *G. bathoniana*, such as the one figured by Gradstein (1978, pl. 3, figs. 1a, b), are present throughout the Bathonian and Callovian of the Mareta Beach section, and in the Oxfordian-Kimmeridgian of both Tojeira sections. For these reasons the "*Globuligerina*" *bathoniana* Zone is not recognized here.

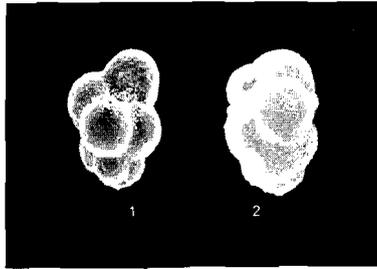


Fig. 44. *Globuligerina bathoniana*: 1-Grand Banks (Bathonian), 2-Kimmeridgian of Portugal.

Applying the zonal scheme as used here has two implications with respect to the zonation and correlation of Gradstein (1977, fig. 3; 1978, fig. 2).

First of all the *Reinholdella* spp. Zone and thus the Late Bathonian cannot be recognized in the Bittern M-62 well, because no *Reinholdella* species are known from this well.

The second implication concerns the Cormorant N-83 well (fig. 45). Oxfordian-Kimmeridgian (*Epistomina mosquensis* Zone) was not recognized in this well due to the top occurrence of *R. cebra* var. at 3,030 feet. The specimen found is illustrated by Gradstein (1977, pl. 3, fig. 7; note umbilical aperture). For reasons outlined above, this is a *Pseudolamarckina* species, that cannot be used to define the top of the Callovian. Cuttings between ca. 3,000 and 3,150' contained Oxfordian-Kimmeridgian species such as *L. quenstedti* and *E. mosquensis*. The top occurrence of *E. regularis* and therewith the top of the Callovian was recognized at 3,150 feet. This indicates the presence of at least some Oxfordian-Kimmeridgian sediments between 3,150 and 3,030' or higher, as also postulated by Barss *et al.* (1979). The sediments above the *Epistomina mosquensis* Zone are non-marine and probably of Tithonian age (Portlandian; Barss *et al.*, 1979).

A comparison between the observed occurrences of selected Jurassic foraminifera from the Grand Banks and Portugal is given in fig. 46.

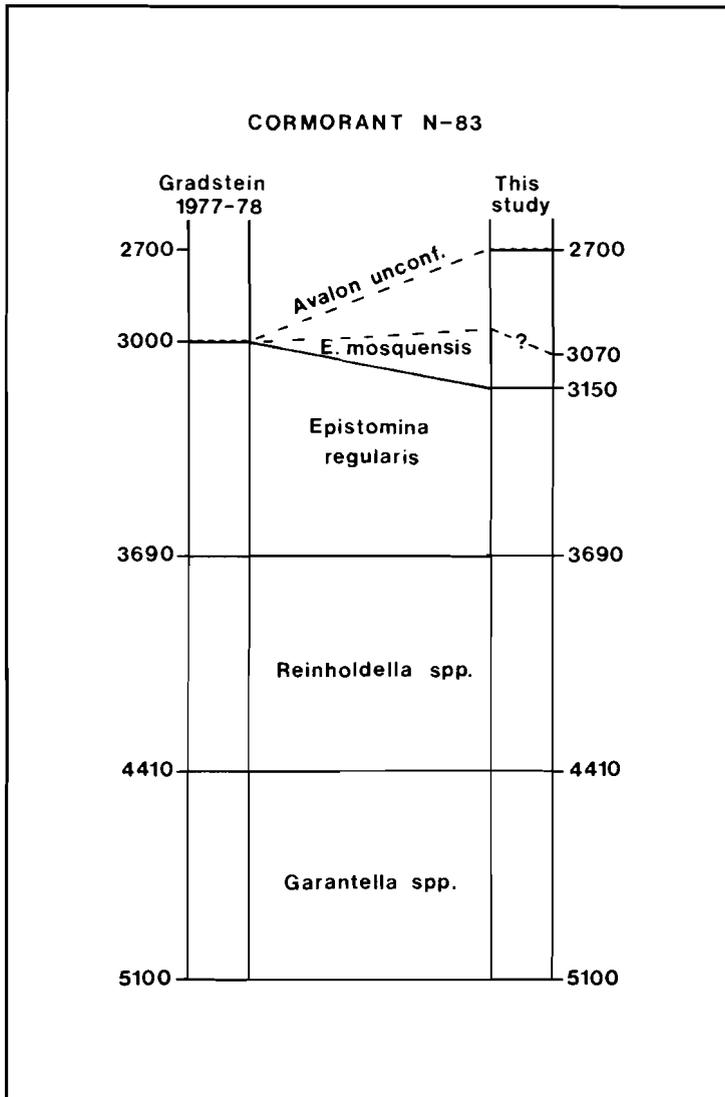


Fig. 45. Biozonation of the Cormorant N-83 well.

4.5: BURIAL, SUBSIDENCE AND SEDIMENTATION HISTORY

During the last 10 years, much work has been done on the burial history of Atlantic-type continental margins (Van Hinte, 1978; Steckler and Watts, 1978; Keen, 1979; Watts and Steckler, 1981; Chenet *et al.*, 1982). In essence, burial history analysis involves the integration of biostratigraphic and paleobathymetry.

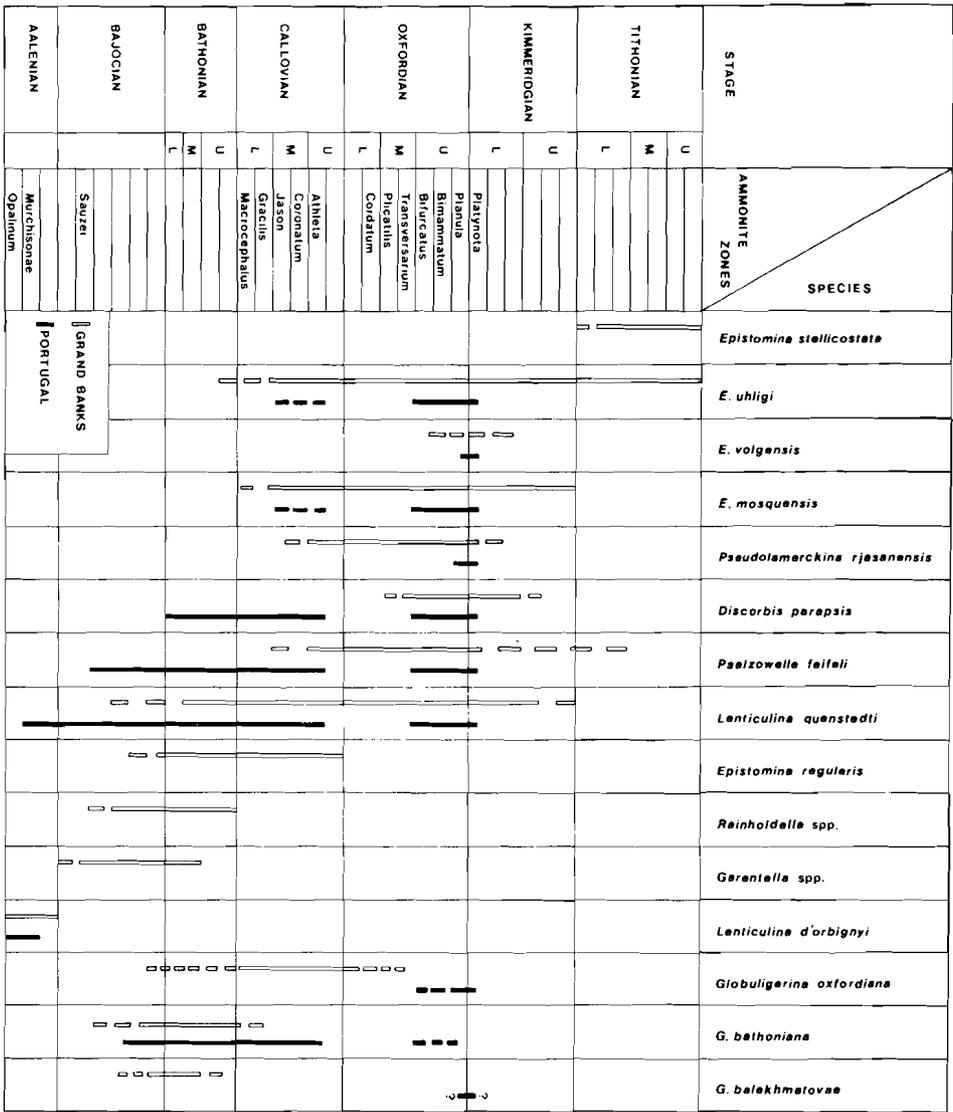


Fig. 46. Range chart showing the observed occurrences of selected Jurassic foraminifera.

metric data in a time-depth framework. Corrections can be made for the effects of compaction and sediment loading, changes in paleowaterdepth and global sea-level in order to obtain decompacted burial and tectonic subsidence information. Especially when displayed graphically, burial history analyses afford rapid insight into (de)compacted burial and tectonic subsidence of sedimentary basins.

Table 14. Decompacted sedimentation, burial, and subsidence rates in cm per 1000 years for the Cormorant N-83, Egret K-36, Eider M-75, Hibernia O-35 and Murre G-67 wells.

| <i>Cormorant N-83</i> | | | |
|-------------------------------------|-----------------------|----------------|--------------------|
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| .0 - 38.0 | .74 | .30 | .13 |
| 38.0 - 50.5 | .09 | .20 | .22 |
| 50.5 - 60.2 | .31 | .09 | .05 |
| 60.2 - 73.0 | .93 | .62 | .43 |
| 73.0 - 83.0 | .37 | -.64 | -.70 |
| 83.0 - 87.5 | 5.80 | 2.23 | .78 |
| 87.5 - 88.5 | 21.93 | .68 | -4.78 |
| 91.0 - 95.0 | 1.96 | 6.87 | 6.43 |
| 95.0 - 144.0 | .00 | .20 | .20 |
| 144.0 - 163.0 | 1.12 | -.76 | -1.06 |
| 163.0 - 169.0 | 2.54 | .90 | .27 |
| 169.0 - 181.0 | 6.03 | 4.26 | 2.06 |
| 181.0 - 194.0 | 6.65 | 5.15 | 2.59 |
| 194.0 - 206.0 | 6.17 | 6.59 | 4.32 |

| <i>Egret K-36</i> | | | |
|-------------------------------------|-----------------------|----------------|--------------------|
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| .0 - 10.0 | 1.64 | .74 | .38 |
| 10.0 - 12.0 | 2.62 | -1.88 | -2.33 |
| 12.0 - 20.0 | 1.41 | .44 | .14 |
| 20.0 - 30.0 | .02 | .75 | .80 |
| 30.0 - 37.0 | 3.73 | .29 | -.66 |
| 37.0 - 40.0 | 8.78 | 3.23 | .98 |
| 40.0 - 43.0 | 3.62 | -.54 | -1.30 |
| 43.0 - 72.0 | .00 | .52 | .54 |
| 72.0 - 80.0 | 1.37 | -.01 | -.30 |
| 80.0 - 88.0 | 7.16 | 3.36 | 1.01 |
| 88.0 - 91.0 | 11.76 | -4.07 | -7.39 |
| 91.0 - 97.0 | .00 | 5.00 | 4.98 |
| 97.0 - 105.0 | 2.60 | .92 | .27 |
| 105.0 - 113.0 | .00 | .00 | -.11 |
| 113.0 - 119.0 | 2.66 | .61 | -.07 |
| 119.0 - 124.0 | 8.88 | 3.93 | 1.22 |
| 124.0 - 131.0 | 7.32 | 3.63 | 1.31 |
| 131.0 - 144.0 | 4.24 | 2.11 | .77 |
| 144.0 - 152.0 | 7.35 | 3.76 | 1.33 |
| 152.0 - 156.0 | 25.69 | 19.37 | 8.89 |
| 156.0 - 160.0 | 13.44 | 12.31 | 8.01 |

| <i>Eider M-75</i> | | | |
|-------------------------------------|-----------------------|----------------|--------------------|
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| .0 - 73.0 | .23 | .20 | .14 |
| 73.0 - 83.0 | 1.77 | .62 | -.10 |

Table 14. (continued).

| <i>Eider M-75</i> | | | |
|-------------------------------------|-----------------------|----------------|--------------------|
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| 83.0 – 87.5 | 4.95 | 1.38 | -.68 |
| 87.5 – 91.0 | 4.68 | 1.79 | -.13 |
| 91.0 – 97.5 | 1.09 | 3.26 | 2.81 |
| 97.5 – 150.0 | .00 | .03 | .02 |
| 150.0 – 163.0 | 7.88 | 4.13 | .33 |
| 163.0 – 169.0 | 7.23 | 5.09 | 1.90 |
| 169.0 – 172.0 | 14.88 | 13.44 | 6.87 |
| 172.0 – 181.0 | 13.74 | 15.13 | 8.26 |
| <i>Hibernia O-35</i> | | | |
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| .0 – 17.5 | 2.53 | 1.59 | .51 |
| 17.5 – 23.0 | 1.96 | -2.06 | -2.83 |
| 23.0 – 37.0 | 3.06 | .81 | -.48 |
| 37.0 – 40.0 | 12.94 | 7.96 | 2.41 |
| 40.0 – 76.0 | .40 | 1.30 | 1.17 |
| 76.0 – 88.0 | 3.66 | .34 | -1.25 |
| 88.0 – 91.0 | 3.55 | 5.40 | 3.97 |
| 91.0 – 97.0 | 2.78 | 1.65 | .49 |
| 97.0 – 105.0 | 2.84 | 2.65 | 1.46 |
| 105.0 – 119.0 | 2.66 | 2.00 | .77 |
| 119.0 – 124.0 | 11.71 | 7.83 | 2.52 |
| 124.0 – 131.0 | 3.87 | 2.64 | 1.01 |
| 131.0 – 135.0 | 12.56 | 8.62 | 3.02 |
| 135.0 – 144.0 | 8.72 | 6.54 | 2.53 |
| 144.0 – 156.0 | 7.89 | 5.86 | 2.11 |
| 156.0 – 160.0 | 16.11 | 16.11 | 8.79 |
| <i>Murre G-67</i> | | | |
| Time interval, MA before present | Sedimentation rate | Burial rate | Subsidence rate |
| .0 – 24.6 | .73 | .27 | .08 |
| 24.6 – 38.0 | 1.42 | .70 | .31 |
| 38.0 – 52.0 | 1.63 | .95 | .50 |
| 52.0 – 73.0 | .00 | .14 | .17 |
| 73.0 – 87.5 | 1.51 | .17 | -.26 |
| 87.5 – 91.0 | 2.74 | -6.64 | -7.42 |
| 91.0 – 97.5 | .44 | 4.81 | 4.67 |
| 97.5 – 100.0 | 3.01 | 3.15 | 2.25 |
| 100.0 – 144.0 | .00 | .01 | .00 |
| 144.0 – 163.0 | 2.92 | 1.34 | .38 |
| 163.0 – 169.0 | 6.92 | .80 | -1.40 |
| 169.0 – 176.0 | 3.68 | 2.79 | 1.64 |
| 176.0 – 183.0 | 8.47 | 7.66 | 4.87 |
| 183.0 – 194.0 | 5.94 | 4.06 | 2.09 |
| 194.0 – 206.0 | 4.58 | 5.32 | 3.78 |

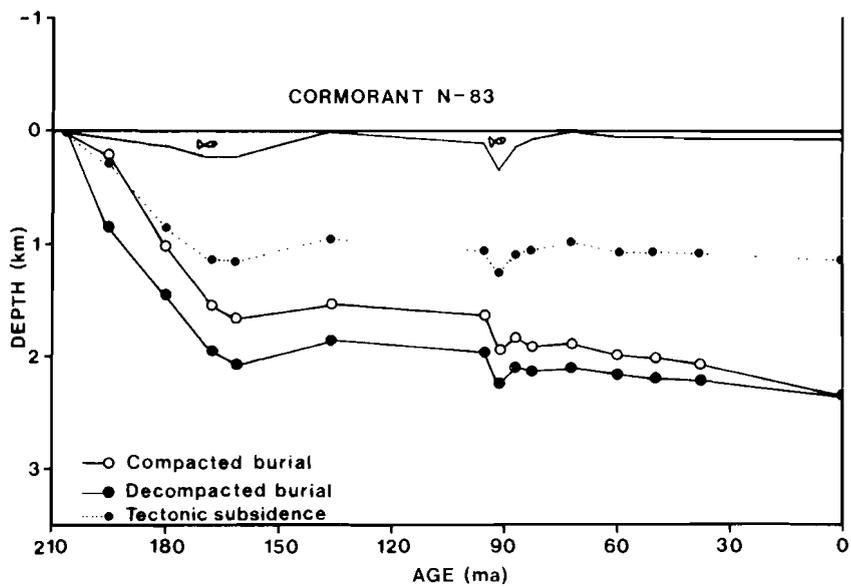
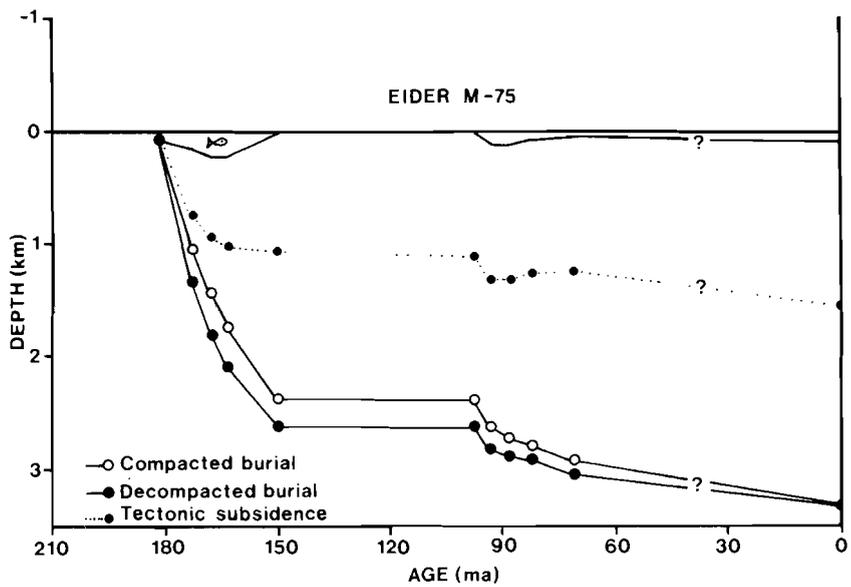


Fig. 47. Burial and subsidence history of the Cormorant N-83 and Eider M-75 wells.

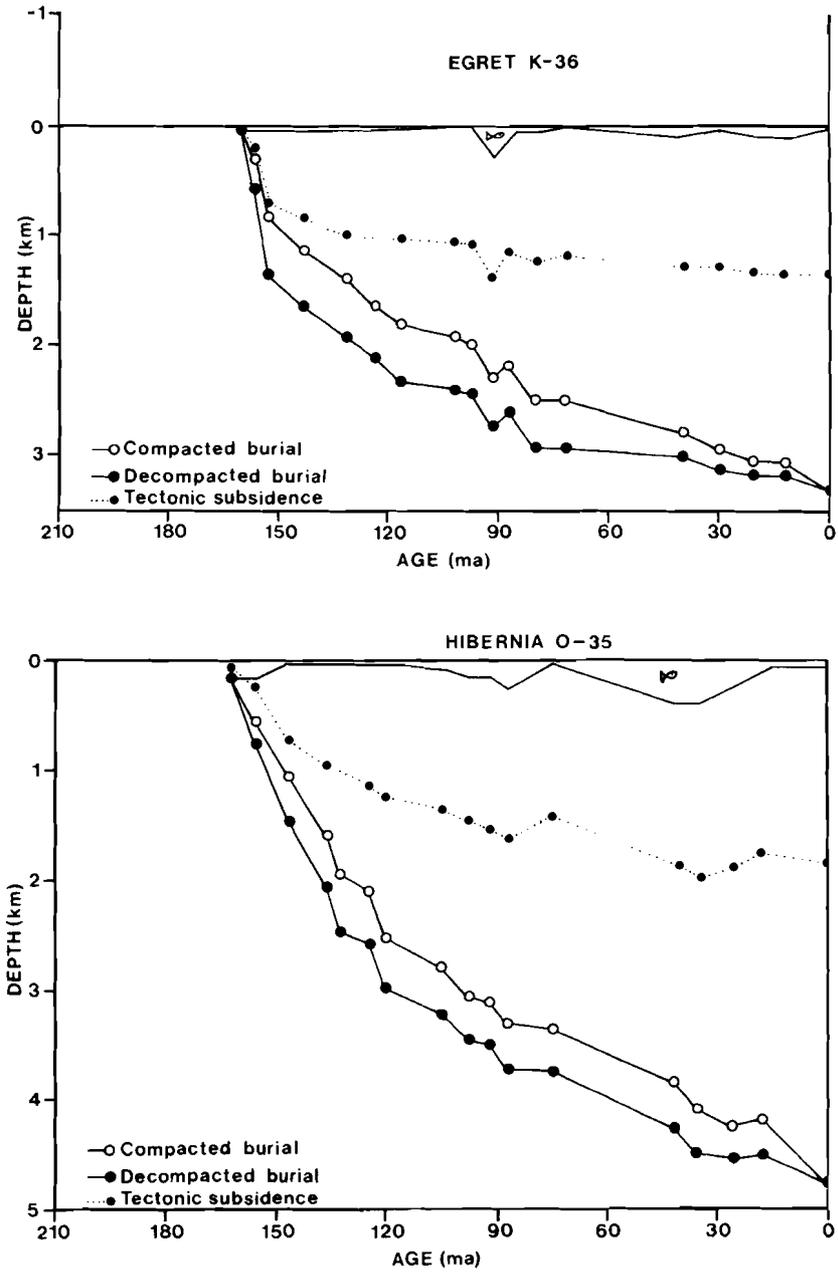


Fig. 48. Burial and subsidence history of the Egret K-36 and Hibernia 0-35 wells.

However, age and paleowaterdepth estimates are the weak spots in any such analysis and can seriously influence the timing and the order of magnitude of (de)compacted burial, subsidence and sedimentation rates. Therefore the improved knowledge concerning the Jurassic foraminiferal biostratigraphy and paleobathymetry is likely to provide a better approximation of these rates. The burial, subsidence and sedimentation histories of five wells (Egret K-36, Hibernia O-35, Eider M-75, Cormorant N-83 and Murre G-67) have been calculated, using the microcomputer programs BURSUB and DEPOR (Stam *et al.*, in prep.). Data on the post-Jurassic sections of these five wells are from Gradstein *et al.* (1985) and Gradstein (unpublished data).

The actual geohistory analysis is calculated by program BURSUB. The program, amongst other things, calculates the compacted and decompactied burial rates, the tectonic subsidence (that is the subsidence corrected for the effects of sediment load, paleowaterdepth and eustatic sea-level changes) and the decompactied sedimentation rate. Decompactied is achieved by means of backstripping: sediments in each age-depth interval are assigned to a specific lithology and these lithological units are progressively stripped off and the older, underlying units expanded (by sliding them up their respective porosity-depth curve) to previous thicknesses in time. The formula used for backstripping is from Watts and Steckler (1981).

For correct backstripping, the porosity (F) at zero depth and the amount (C) by which it decreases per metre burial have to be known, either for each lithology or for the well section as a whole. These two parameters define the porosity-depth curves, which may be linear or exponential. Using lithological information from well history reports and the digitized sonic logs, program DEPOR (written by P. Lloyd, Dept. of Geology, Dalhousie Univ., Halifax) calculates porosity depth points and calculates F and C for the best linear and exponential fit through these points. It also determines which of these two fits is the best. For each well, C and F for the best fit, whether linear or exponential, are used in program BURSUB.

The results obtained are presented in figs. 47, 48 and table 14. The burial and subsidence history of the Murre G-67 well is closely similar to that of the Cormorant N-83 well (fig. 47). In case of the Cormorant and Eider well, more than 80% of the total cumulative decompactied burial and tectonic subsidence occurred during the Early through Middle and Middle through Late Jurassic respectively. During the Oxfordian-Tithonian an uplift occurred at the site of the Cormorant well. For the Egret and Hibernia wells, 40–55% of the total cumulative decompactied burial and tectonic subsidence occurred during the Late Jurassic.

After initial rapid subsidence and burial during the Jurassic, subsidence

almost ceased (except for the Hibernia well), and burial rates (table 14) decreased during the remainder of the Mesozoic and Cenozoic. Tectonic subsidence followed by uplift during the Cenomanian – Turonian – Coniacian can be recognized in all four wells. The increase in paleowaterdepth during this time interval is more likely related to that tectonic subsidence than to a rise in eustatic sea-level (Jansa and Wade, 1975b).

The decompacted sedimentation rates (table 14) during the Early and Middle Jurassic are generally speaking somewhat higher than the decompacted burial rates. In all wells a tendency can be recognized for this difference between sedimentation and burial rates to increase towards the Late Jurassic, which eventually led to shallow marine (Hibernia and Egret) and non-marine (Cormorant, Murre and Eider) conditions at the end of the Jurassic and during the Early Cretaceous.

An examination of the tectonic subsidence of Atlantic-type continental margins is beyond the scope of this study. However, on the basis of figs. 47 and 48 it is possible to draw some generalized conclusions. It can be seen that, after correcting for the effects of sediment and water loads, the tectonic subsidence accounts for up to 50% of the (de)compacted burial. The tectonic subsidence curves of all four wells show an exponential decrease with time: early rapid subsidence gave way to lesser rates. Such exponential subsidence curves were explained by Steckler and Watts (1978) and Watts and Steckler (1981) to be a response to the thermal contraction of the basement as it cools following initial rifting. The time at which subsidence began cannot be determined from figs. 47 and 48: the (de)compacted burial and tectonic subsidence curves are plotted relative to the oldest age-depth point; none of the wells for which burial and subsidence curves are shown penetrated basement.

Chapter 5

JURASSIC PLANKTONIC FORAMINIFERA

5.1: INTRODUCTION

The first four presumably planktonic foraminiferal species from Jurassic strata were described in the second half of the last century: *Globigerina liasina* from the Middle Lias of France (Terquem and Berthelin, 1875), *G. helveto-jurassica* from the Early Oxfordian of Switzerland (Haeusler, 1881, 1890) and *G. oolithica* and *G. lobata* from the Bajocian of France (Terquem, 1883). It was not until after the description in 1958 of *G. oxfordiana* and *G. jurassica* by Grigelis and Hofman respectively, that more attention was focused on the occurrences of early planktonic foraminifera (for a literature review see Fuchs, 1973).

The oldest "planktonic" foraminifera were described from the Triassic of Austria (Oberhauser, 1960; Fuchs, 1973, 1975), but as pointed out by Masters (1977), these forms are more likely some kind of discorbids rather than early globigerinids. Based on morphological characteristics the discorbids have been suggested as possibly being the ancestor of the early globigerinids. Unfortunately, there is controversy as to whether the discorbids have a monolamellar wall structure (Loeblich and Tappan, 1964) or a bilamellar wall structure (Reiss, 1963) as the globigerinids have (Premoli-Silva, 1966; Pazdrowa, 1969). In their revised classification, Loeblich and Tappan (1984) unfortunately do not give any information concerning wall structures.

"True" planktonic foraminifera, with such typical features as a low to high trochospire, umbilical to extraumbilical aperture, finely perforate bilamellar wall, possibly occasionally an imperforate equatorial band and kummerform or bulla-like structures, are known from the Bajocian onward. To date two dozen or more species have been described, but due to the lack of comparative studies and the lack of distinct differential diagnoses, the taxonomical status and therewith the possible stratigraphic value of these species is not clear, and neither is their evolutionary relationship through time. In this chapter the author undertakes a critical review of the literature in which the planktonics are described and examines topotypic material from Poland, hypotypic material from France and material from Switzerland. As a result the number of useful species is dramatically reduced. This, together with the study of Atlantic globigerinid assemblages, relatively rich in specimens, from the well dated Portuguese sections and Grand Banks wells is expected to stabilize the

systematics and allows for a more realistic evaluation of the time-stratigraphic importance and the evolution of these planktonics.

5.2: SYSTEMATICS

Generic assignments

One of the first systematical classifications of Jurassic planktonics was given by Fuchs (1973), who introduced six new genera (*Polskanella*, *Tectoglobigerina*, *Woletzina*, *Mariannenina*, *Eoheterobelix* and *Jurassorotalia*) and a variety of new species. His classification was based on a study of glauconite moulds from Ogrodzieniec (Poland, type-locality of *Globigerina bathoniana* Pazdrowa). None of the genera (and species) erected by Fuchs are accepted here; partly because of obvious violations of the International Code of Zoological Nomenclature (see Grigelis and Gorbachik, 1980); and partly because the glauconite moulds (some of which are aberrant or deformed forms) do not show any characteristic features such as wall-structure and aperture.

Furthermore, an examination of material from the same locality and the same beds (which O. Pazdrowa kindly provided to F.M. Gradstein, who made it available for this study) clearly revealed, as already expected, that *Mariannenina* and *Jurassorotalia* are not planktonic; they are moulds of epistominids that do not justify a generic assignment, as do any of the other moulds present.

In other, more recent classifications by Grigelis and Gorbachik (1980) and Gorbachik and Kuznetsova (1983), the Jurassic planktonics are split in two genera: *Conoglobigerina* Morozova (in Morozova and Moskalenko, 1961) and *Globuligerina* Bignot and Guyader (1971). The latter genus differs from the former because of somewhat irregular trochoid coiling and because some representatives (*but not all*, see Grigelis and Gorbachik, 1980, p. 188) have a reticulate sculpture. According to the original descriptions and figures, *Globuligerina* is not irregularly trochoid nor is any of the species assigned to this genus, a possible exception being *G. jurassica*.

Loeblich and Tappan (1964) considered *Conoglobigerina* to be a junior synonym of *Gubkinella* Suleymanov, 1955. It is not clear if *Gubkinella* really is a planktonic foraminifera (Loeblich and Tappan, 1964, p. C652). The same holds for *C. dagestanica* Morozova (in Morozova and Moskalenko, 1961), the type species of *Conoglobigerina* and neither generic name is accepted here.

Globuligerina Bignot and Guyader (1971) was established as a subgenus of *Globigerina* because of its not entirely umbilical aperture, a loop-shaped arch bordered with a lip. In this study, *Globuligerina* is given generic rank (as in Grigelis, 1977; Grigelis and Gorbachik, 1980; Gorbachik and Kuznetsova, 1983) and its diagnosis is emended.

Family GLOBIGERINIDAE Carpenter, Parker and Jones, 1862

Genus *Globuligerina* Bignot and Guyader, 1971 emend. Stam, 1986

Type species: Globuligerina oxfordiana (Grigelis, 1958).

Diagnosis: Test free, chambers coiled in a trochospiral, the height of which may vary from low to high; chambers spherical to ovate; wall calcareous, perforate, radial, bilamellar. Chamber surface may be pitted, cancellated or hispid; Aperture umbilical-extraumbilical, and may vary from semicircular to a looped arch either narrow and high to broad and low, bordered with a lip. Previous apertures, when visible, are usually open to the umbilicus.

Stratigraphic range: Middle Jurassic (Late Bajocian) – Early Cretaceous (Early Valanginian).

All Jurassic planktonic foraminifera described to date fit within the above given emended description of *Globuligerina* and may therefore be classified under this genus. Splitting of the genus in two or more (sub)genera is unwarranted and both morphologically and stratigraphically misleading. As will be shown, a distinction at species level is difficult and often impossible, let alone a distinction on a higher level.

Table 15. Listing of 14 Jurassic and 2 Early Cretaceous planktonic foraminiferal species, with their type locality and age (after original descriptions).

| <i>Species</i> | <i>Type-locality</i> | <i>Age</i> |
|-----------------------------|----------------------------|------------------------------------|
| <i>G. caucasica</i> | Azerbaydzhiana (USSR) | early Berriasian-early Valanginian |
| <i>G. gulekbensis</i> | Azerbaydzhiana (USSR) | early Berriasian-early Valanginian |
| <i>G. conica</i> | Stubel (NW Bulgaria) | Tithonian |
| <i>G. terquemi</i> | Stubel (NW Bulgaria) | Tithonian |
| <i>G. stellapolaris</i> | Pechora River Basin (USSR) | Kimmeridgian-Tithonian |
| <i>G. oxfordiana</i> | Lithuania (USSR) | early Oxfordian |
| <i>G. helveto jurassica</i> | Aargau (Switzerland) | middle Oxfordian |
| <i>G. calloviensis</i> | Eastern Crimea (USSR) | early Callovian |
| <i>G. meganomica</i> | Eastern Crimea (USSR) | early-middle Callovian |
| <i>G. jurassica</i> | Southeast Crimea (USSR) | Bathonian-early Callovian |
| <i>G. bathoniana</i> | Ogrodzieniec (Poland) | middle Bathonian |
| <i>G. dagestanica</i> | Central Dagestan (USSR) | Bathonian |
| <i>G. avarica</i> | Central Dagestan (USSR) | early Bathonian |
| <i>G. balakhmatovae</i> | Dagestan (USSR) | early Bathonian |
| <i>G. spuriensis</i> | Rochetta (N Italy) | late Bajocian-early Bathonian |
| <i>G. gaurdakensis</i> | Turkmenia (USSR) | late Bajocian |

| PLANKTONIC SPECIES | DIAMETER mm. | HEIGHT mm. | H/D - RATIO | N. OF WHORLS | AGE | STRATIGRAPHIC RANGE |
|-------------------------------|--------------|------------|-------------|--------------|-----|---------------------|
| <i>G. caucasica</i> 16 | - | - | - | - | - | - |
| <i>G. gulekhensis</i> 15 | - | - | - | - | Vlg | - |
| <i>G. conica</i> 14 | — | — | — | — | - | — |
| <i>G. terquemii</i> 13 | — | - | - | - | - | — |
| <i>G. stellapolaris</i> 12 | - | - | - | - | Ber | — |
| C | - | - | - | - | - | - |
| <i>G. oxfordiana</i> 11 | B — | - | — | - | - | — |
| A | — | - | — | - | Tth | — 15 16 |
| B | — | - | — | - | - | - |
| <i>G. helvetojurassica</i> 10 | A — | - | — | - | Kim | — 13 14 |
| <i>G. calloviensis</i> 9 | - | — | — | - | - | - |
| <i>G. meganomica</i> 8 | - | — | — | - | - | - |
| <i>G. jurassica</i> 7 | - | - | - | - | - | — 12 |
| B | - | — | — | - | Oxf | — |
| <i>G. bathoniana</i> 6 | A — | — | — | — | - | — |
| <i>G. dagestanica</i> 5 | - | — | — | - | - | — 10 11 |
| B | — | — | — | - | Clv | — |
| <i>G. avarica</i> 4 | A — | - | — | — | - | — 8 9 |
| C | - | - | — | - | Bth | — |
| <i>G. balakhmatovae</i> 3 | B — | — | — | — | - | — 6 |
| A | — | - | — | - | Baj | — 1 2 3 |
| <i>G. spurriensis</i> 2 | — | — | — | - | - | — 4 5 7 |
| <i>G. gaurdakensis</i> 1 | - | - | — | - | - | - |

Specific assignments

The descriptions and figures of the planktonic foraminifera by Terquem and Berthelin (1875) and Terquem (1883) are inadequate for a positive identification of these forms; they have not been recognized by later students of Jurassic planktonic foraminifera. As mentioned earlier, none of the species erected by Fuchs (1973) are accepted here. That leaves 14 Jurassic species (table 15), which, with the exception of *G. helvetojurassica* (Haeusler), have all been described between 1958 and 1980. Two opposing views have been published (Masters, 1977 versus Grigelis and Gorbachik, 1980 and Gorbachik and Kuznetsova, 1983) concerning the preservation of these taxonomical units.

Masters (1977) lumps most Jurassic planktonics in two morphotypes: a low spired one, called *G. hoterivica* Subbotina, 1953, which evolved from a high spired one, called *G. jurassica*. The reported stratigraphic range of the latter species is from Bathonian through Tithonian, whereas the former one ranges from Middle Bathonian through Middle Aptian.

Grigelis and Gorbachik (1980) and Gorbachik and Kuznetsova (1983) preserved most species of the literature. Grigelis and Gorbachik (1980) also noted several evolutionary trends, which include (a) a decrease of the spire height, (b) more regular coiling, (c) an increase of surface reticulation and (d) an increase in size from Middle Jurassic through Early Cretaceous time.

The fact that these two views are so very different reflects upon the fact that the original descriptions and figures of most Jurassic planktonic species are too vague and that differences with other species are not adequately indicated, leaving too much room for subjectivity. In spite of that, both views recognize a decrease in the height of the spire through time.

As described and figured by Pazdrowa (1969), and accepted here, differences in shape and position of the aperture can be attributed to intraspecific variation. A typical aperture of *G. bathoniana* (Pazdrowa) is high, semicircular, umbilical-extraumbilical, bordered with a narrow lip, but forms with a high and narrow aperture or a low and broad aperture fall within the variation of this species.

Fig. 49. Height (H), Diameter (D), Height/Diameter-ratio (H/D-ratio) and the stratigraphic distribution after Grigelis and Gorbachik (1981) of the 14 Jurassic and two Early Cretaceous planktonic foraminifera.

1 = Balakhmatovae, in Morozova and Moskalenko (1961), 2 = Bars and Ohm (1968), 3A, 4A, 5 = Morozova, in Morozova and Moskalenko (1961), 3B, 4B = Broennimann and Wernli (1971), 3C, 6B = Gradstein (1977), 6A = Pazdrowa (1969), 7 = Hofman (1958), 8, 9 = Kuznetsova, in Kuznetsova and Uspenskaya (1980), 10A = Oesterle (1968), 10B = Seibold and Seibold (1960), 11A = Grigelis (1958), 11B = Bignot and Guyader (1966), 11C = Gradstein (1983), 12 = Grigelis (1977), 13, 14 = Jovcheva and Trifonova (1961), 15, 16 = Gorbachik and Poroshina (1979).

Because the height of the spire, or even better the height/diameter (H/D)-ratio, is often mentioned as being most characteristic, these parameters together with the number of whorls have been studied in some detail. Topotypic and hypotypic material for some key taxa was available for this purpose, but most of the values of these parameters were obtained from the literature, either directly from the descriptions, or from the provided figures, or if possible from both.

The diameter, height and H/D-ratio of the 14 published Jurassic species and 2 Early Cretaceous species are given in fig. 49. In this figure the stratigraphic range of the various species is after Grigelis and Gorbachik (1980). First of all, it is interesting to note that the size (diameter, height) of the species is by no means small (generally larger than 100 microns) and should not have hampered detailed observations (preservation might have). Secondly, fig. 49 clearly shows that, on basis of the height or the H/D-ratio, there is little ground for so many species.

The heights of two species, *G. spuriensis* (Bars and Ohm) and *G. conica* (Jovcheva and Trifonova), are extreme when compared with the other species. In the case of *G. conica* this extreme height is most likely an expression of the ontogenetic stage of development: the diameter is also fairly large, the number of whorls is 3–3.5; the H/D-ratio is comparable to that of several other species. *G. spuriensis* reaches extreme dimensions in 1.5–2 whorls; this species will be dealt with later.

On the basis of the H/D-ratio, which is a better parameter than height alone since it is independent of the ontogenetic stage, two groups can be recognized: a low and a high spired group. Based on topotypic (*G. bathoniana*) and hypotypic (*G. oxfordiana*) material, original descriptions and figures and fig. 49, the following species are recognized: *G. bathoniana*, *G. oxfordiana* and *G. balakhmatovae*.

***Globuligerina bathoniana* (Pazdrowa)**

Plate 9, figs. 6–13; plate 10, figs. 1–12; plate 11, figs. 1–10; plate 12, figs. 9–12; plate 13, figs. 1–12; plate 14, figs. 1–2, 5–7

Globuligerina bathoniana Pazdrowa, 1969, Ann. Soc. Geol. Pologne, vol. 39, fasc. 1–3, pp. 45–52, text figs. 1–16, pl. 2–4.

“*Globuligerina*” *helvetojurassica* Haeusler, Oesterle, 1968, Eclog. geol. Helv., vol. 61/2, pp. 774–778, text fig. 50.

Globuligerina hoterivica Subbotina, Masters, 1977, Oceanic Micropal., vol. 1, p. 460, pl. 22, figs. 1–3.

“*Globuligerina*” *bathoniana* Pazdrowa, Gradstein, 1978, Journ. Foram. Res., vol. 8, no. 2, pl. 2, figs. 3, 5, pl. 3, figs. 1a, b.

Globuligerina gulekhensis Gorbachik and Poroshina, 1979, Paleont. Journ., vol. 13, no. 3, pp. 286–288, text fig. 1, pl. 1, figs. 1, 2.

Diagnosis: Relatively high trochospiral, with an H/D-ratio ranging from 0.6–1.3, spherical chambers, four in the last whorl. Aperture semicircular, looped arch, umbilical-extraumbilical, bordered with a narrow lip. Aperture can vary from high and narrow to low and broad. Bulla-like structure may be present (only observed in specimens from the Grand Banks, plate 12, figs. 9–12; plate 13, figs. 1–4).

Remarks: *G. conica* (Jovcheva and Trifonova, 1961) was described from the Tithonian of Bulgaria. Although Pazdrowa (1969) mentioned *G. conica* to be higher than *G. bathoniana*, the H/D-ratios of both species fall within the same range (fig. 49). Because *G. conica* was created on the basis of glauconite moulds which may or may not show characteristic features, and because *G. bathoniana* is far better described and illustrated (including scanning electron microscope photographs), Pazdrowa's species has been given priority. Furthermore, the name *G. conica* (Jovcheva and Trifonova) does not satisfy the criteria of availability (International Code of Zoological Nomenclature, art. 13 a).

Masters (1977) splits *G. bathoniana* in a low spired morphotype (*G. hoterivica*) and a high spired morphotype (*G. jurassica*). Because the height of the Polish species forms an intergradational series (Pazdrowa, 1969), Masters' view on this species is not followed here.

Forms assigned to *G. helvetojurassica* (Haeusler) by Oesterle (1968) have H/D-ratios that fall within the range of *G. bathoniana* and are therefore included in the latter species (see also remarks on *G. oxfordiana*).

Also, the H/D-ratio of *G. gulekhensis* Gorbachik and Poroshina falls within the range of *G. bathoniana*. The height given by Gorbachik and Poroshina (1979, p. 287) does not match with that of the holotype as figured in their text fig. 1. The dimensions of *G. gulekhensis* in fig. 49 are as measured from the holotype. No differences with *G. bathoniana* are apparent from the original description and figures.

Stratigraphical range: ?Late Bajocian – Early Valanginian, based on original description, occurrences in Portugal and the Grand Banks (fig. 46), and synonymy list above (see fig. 49).

Occurrence: Grand Banks (Bittern M-62, Eider M-75, Cormorant N-83 and Murre G-67), Portugal (Brenha, Mareta Beach and both Tojeira sections), Central Poland, NW Switzerland, NW Bulgaria, USSR (Azerbaijdzhanian; Crimea).

Globuligerina oxfordiana (Grigelis)

Plate 7, figs. 1–12; plate 8, figs. 1–12; plate 9, figs. 1–5; plate 14, figs. 3–4, 8–15

- Globuligerina oxfordiana* Grigelis, 1958, Nauch. Dokl. Vyss. Shk., Geol.-Geogr. Nauki, no. 3, pp. 110–111, text fig. 1.
- Globuligerina helvetojurassica* Haeusler [nomen oblitum], 1881, Diss. Univ. Zuerich, p. 36, pl. 2, figs. 44, 44a.
- Globuligerina bulloides* d'Orbigny var. *helveto-jurassica* Haeusler, 1890, Abh. schweiz. geol. Ges., vol. 17, p. 118, pl. 15, fig. 46.
- Globuligerina* ? *helveto-jurassica* Haeusler, Seibold and Seibold, 1959, N. Jb. Geol. Palaeont., Abh., Vol. 109, no. 3, pl. 8, figs. m, o, r, Table 1, fig. 18.
- Globuligerina terquemi* Jovcheva and Trifonova, 1961, Proc. Geol. Sci. Bulgaria, Paleont. Ser., no. 3, p. 347, pl. 2, figs. 9–14.
- Globuligerina oxfordiana* Grigelis, Bignot and Guyader, 1966, Rev. Micropal., vol. 9, no. 2, pp. 105–107, pl. 1, figs. 1–11.
- Globuligerina oxfordiana* (Grigelis), Bignot and Guyader, 1971, Proc. II Plankt. Conf. Roma, pl. 1, figs. 1–4.
- Globuligerina stellapolaris* Grigelis, 1977, Doklady Earth Sci. Sect., vol. 233, p. 96, text fig. 1.
- Globuligerina caucasica* Gorbachik and Poroshina, 1979, Paleont. Journ., vol. 13, no. 3, p. 288, text figs. 2, 3.
- Globuligerina caucasica* Gorbachik and Poroshina, Grigelis and Gorbachik, 1980, Journ. Foram. Res., vol. 10, no. 3, pl. 1, fig. 6.
- Globuligerina oxfordiana* (Grigelis), Grigelis and Gorbachik, 1980, Journ. Foram. Res., vol. 10, no. 3, pl. 1, fig. 4.
- Globuligerina stellapolaris* Grigelis, Grigelis and Gorbachik, 1980, Journ. Foram. Res., vol. 10, no. 3, pl. 1, fig. 5.
- Globuligerina meganomica* Kuznetsova and Uspenskaya, 1980, Doklady Earth Sci. Sect., vol. 254, p. 246, pl. 2, figs. 5–8.
- Globuligerina calloviensis* Kuznetsova and Uspenskaya, 1980, Doklady Earth Sci. Sect., vol. 254, p. 244, pl. 2, figs. 1–4.
- Globuligerina* aff. *oxfordiana* (Grigelis), Gradstein, 1983, Init. Repts. Deep Sea Drill. Proj., vol. 76, pl. 2, figs. 1–10, 14, 15, 18, 19.
- Globuligerina oxfordiana* (Grigelis), Gorbachik, 1983, Akad. Nauk USSR, vol. 26, pl. 6, figs. 1–4, pl. 7, figs. 1–3, pl. 8, figs. 1, 2, pl. 9, figs. 1–3, pl. 10, figs. 1–3, pl. 11, figs. 1, 2.
- Globuligerina oxfordiana* (Grigelis), Bignot, 1984, C. R. Acad. Sci. Paris, tome 298, ser. 2, no. 17, pl. 1, figs. 2, 3, 5–8.

Diagnosis: Relatively low trochospiral, with an H/D-ratio from about 0.37 to 0.77, spherical chambers, four in the last whorl. Last whorl only slightly elevated above previous whorl. Aperture varies from a relatively high looped-arch to a low and broad slit, bordered by a lip, umbilical-extraumbilical.

Remarks: Although described some 70 years earlier, *G. helvetojurassica* is included in the synonymy of *G. oxfordiana*. Haeusler's (1881, 1890) figures are reminiscent of planktonic foraminifera, but his descriptions are inadequate. Also, no type locality and no holotype were designated. Because the name *G. helvetojurassica* has remained unused for more than fifty (69 to be exact) years after Haeusler's (1890) publication, it is to be considered a nomen oblitum (forgotten name; International Code of Zoological Nomenclature, art. 23 b), and should not be used (the name *G. helvetojurassica* Haeusler [nomen oblitum])

has been referred to the International Commission on Zoological Nomenclature, dd. 3 November, 1985). Also, all identifications of supposedly *G. helvetojurassica* (Seibold and Seibold, 1959; Oesterle 1968; Masters, 1977) are, as indicated by these authors, doubtful.

Haeusler mentioned his species to occur in the so-called Birmenstorfer Schichten. Gygi (1969) designated the "Eisengraben" section (ca. 30 km NW of Zuerich, Canton Aargau) as typelocality of the Birmenstorfer Schichten, and Oesterle (1968) selected the same section as typelocality for all foraminiferal species described by Haeusler from the Birmenstorfer Schichten. However, Oesterle (1969), in his revision of the work of Haeusler and a description of the foraminifera from the Eisengraben section, only found recrystallized and badly preserved specimens of presumably *G. helvetojurassica*. His description of this species was based on pyrite moulds from the so-called Renggeri Tonen from Liesberg (75 km west of the Eisengraben section, SW of Basel).

In 1984 the author resampled the Eisengraben section (for location and lithological column, see Oesterle, 1968, figs. 2, 3). Planktonic foraminifera were found in one sample from the same layer as Oesterle's sample number 4. Even though they are rare and small in size, this sample contained well preserved planktonics (plate 7, figs. 6–12, plate 8, figs. 1–3). Specimens have a low trochospire, and have an aperture that varies from semicircular to low and elongated, bordered with a lip, umbilical-extraumbilical. Based on the original description and figures, and hypotypic material from France (plate 7, figs. 1–5), these forms do not differ from the by now well established *G. oxfordiana* (Grigelis). Therefore it was decided to include *G. helvetojurassica*, being a nomen oblitum, in the synonymy of *G. oxfordiana*. The forms described by Oesterle (1968), not coming from the (later) designated typelocality and being high spired, are included in *G. bathoniana* (Pazdrowa).

G.? *helvetojurassica* Haeusler, Seibold and Seibold (1959), also from Liesberg, are tentatively included in the synonymy of *G. oxfordiana*: the H/D-ratio falls within the range of Grigelis' species, but as indicated by Seibold and Seibold, it is not certain that that form is indeed a planktonic; no aperture is visible. It could well be an arenaceous benthonic form like *Trochammina* (Masters, 1977).

G. terquemi, *G. stellapolaris*, *G. caucasica*, *G. meganomica* and *G. calloviensis* are considered to be junior synonyms of *G. oxfordiana*, all for the same reason: the original descriptions and figures, and diagnostic differences (when given) do not warrant the recognition of any of these species. Their H/D-ratios fall within the range, and their apertures fit within the variation of *G. oxfordiana*. For example, Grigelis (1977) mentioned his *G. stellapolaris* to differ "... from the Oxfordian *Globuligerina oxfordiana* (Grigelis) in the round (and not oval)

shape of its test, in its greater size, and its more closely packed chambers". Grigelis (1958) in describing the variability of *G. oxfordiana*: "... degree of compactness with which the chambers of the last whorl join together (also) varies. The test is usually formed by loosely joined, adjacent chambers, and such specimens have an oval shape; tests with the chambers more tightly in the spiral are round." (translation from the Ellis and Messina Catalogue of Foraminifera). Since, in this study, the size of a specimen is not regarded to be a specific characteristic, one cannot but conclude that the Grigelis (1977) species is a junior synonym of his 1958 species.

Stratigraphic range: Middle Bajocian-Early Valanginian, based on original description, occurrences in Portugal and the Grand Banks (fig. 46), synonymy list above (see fig. 49), and Bignot (1984, Middle Bajocian).

Occurrence: Grand Banks (Bittern M-62 and Murre G-67), Portugal (Both Tojeira sections), USSR (Lithuania; Pechora River Basin; Azerbaydzhanian; Crimea), N Switzerland, SW Germany, NW Bulgaria, France (Normandy), western North Atlantic (Blake Bahama Basin, off the coast of Florida).

***Globuligerina balakhmatovae* (Morozova)**

Plate 11, figs. 11–12; plate 12, figs. 1–8

Globuligerina balakhmatovae Morozova, 1961, Vop. Micropaleont., vol. 5, p. 23, pl. 1, figs. 1–13, pl. 5, figs. 1–21.

"*Golbigerina*" *balakhmatovae* Morozova, Broennimann and Wernli, 1971, Proc. II Plant. Conf. Roma, p. 121, pl. 1, figs. 1–4, pl. 4, figs. 1–2.

"*Globigerina*" *balakhmatovae* Morozova, Gradstein, 1977, Maritime Sediments, Spec. Publ. 1, pl. 3, figs. 3, 4.

Diagnosis: Closely similar to *G. oxfordiana* (Grigelis), from which it differs in having less inflated chambers which have an ovate outline in side-view. Occasionally an imperforate equatorial band or even a weakly developed keel may be present (plate 12, figs. 2, 8).

Remarks: Masters (1977) considered the amount of flattening of the chambers to be negligible and included this species in his low spired morphotype. Nevertheless, the flattening is considerable in specimens from the Grand Banks, and in view of their preservation, this is not likely to be due to post-mortem processes.

Stratigraphic range: So far this species has only been reported from the Late Bajocian-Late Bathonian. Possibly it also occurs in the Oxfordian-Kimmeridgian of Portugal (fig. 46; plate 11, figs. 11–12).

Occurrence: Grand Banks (Eider M-75, Murre G-67), USSR (Dagestan; Turkmenia), France (Jura Meridional), ?Portugal (Tojeira 1 section).

Incertae sedis

The following species could not be positively identified as being planktonic foraminifera: *G. jurassica*, *G. gaurdakensis*, *G. dagestanica*, *G. avarica* and *G. spuriensis*. Only a re-examination of holo- and/or topotypes will allow for a determination as to whether these forms are indeed planktonic.

Described as being the most characteristic feature of *G. jurassica* (Hofman), 1958, pp. 125–126, is its (op cit.) “woolball shape” (=glomospiral, Morozova in Morozova and Moskalenko, 1961, p. 27). Glomospiral coiling is atypical for a planktonic.

G. dagestanica (Morozova, 1961), *G. gaurdakensis* (Balakhmatova and Morozova, 1961) and *G. avarica* (Morozova, 1961) are too poorly illustrated and the mentioned differences between these forms are either too vague or non-existent (compare H, H/D-ratio of *G. gaurdakensis* and *G. dagestanica*, fig. 49). The aperture of *G. avarica*, small, slit-like and marginal, is more typical for a benthonic.

G. spuriensis (Bars and Ohm, 1968) is well described and illustrated, but appears to have a closed umbilicus and a low and broad sutural aperture (described as being primary although sutural apertures are usually secondary), which makes a secondary chamber in the position as illustrated by Bars and Ohm (1968, fig. 1b) difficult to explain. Aberrant are the dimensions of this form and the size of its pores.

The recognition of only three planktonic species, two of which range from Bajocian through Valanginian, does not obscure any stratigraphic gaps: Grigelis and Gorbachik (1980) indicated two gaps in the Jurassic planktonic record (fig. 49), a Late Callovian and a Late Oxfordian one. Gorbachik and Kuznetsova (1983) believe these gaps to be due to a lack of material rather than a non-existence of planktonic foraminifera, which as this study showed is indeed the case. Planktonic foraminifera occur throughout the (Lower, Middle and Upper) Callovian of the Mareta Beach section, and they are also present in the upper Oxfordian-lower Kimmeridgian Montejunto and Tojeira Formations. This still leaves a gap with the well-known Hauterivian-Aptian species *G. hoterivica* Subbottina. To not ignore this gap, *G. hoterivica* is treated as a separate species.

5.3: EVOLUTIONARY TRENDS AND PALEOECOLOGY

As already mentioned, both Masters (1977) and Grigelis and Gorbachik (1980) recognized the decrease in the height of the spire as an evolutionary trend through time. In both cases however, it is not clear on what observation(s) this conclusion is based. For example, Masters' (1977) low spired *G.*

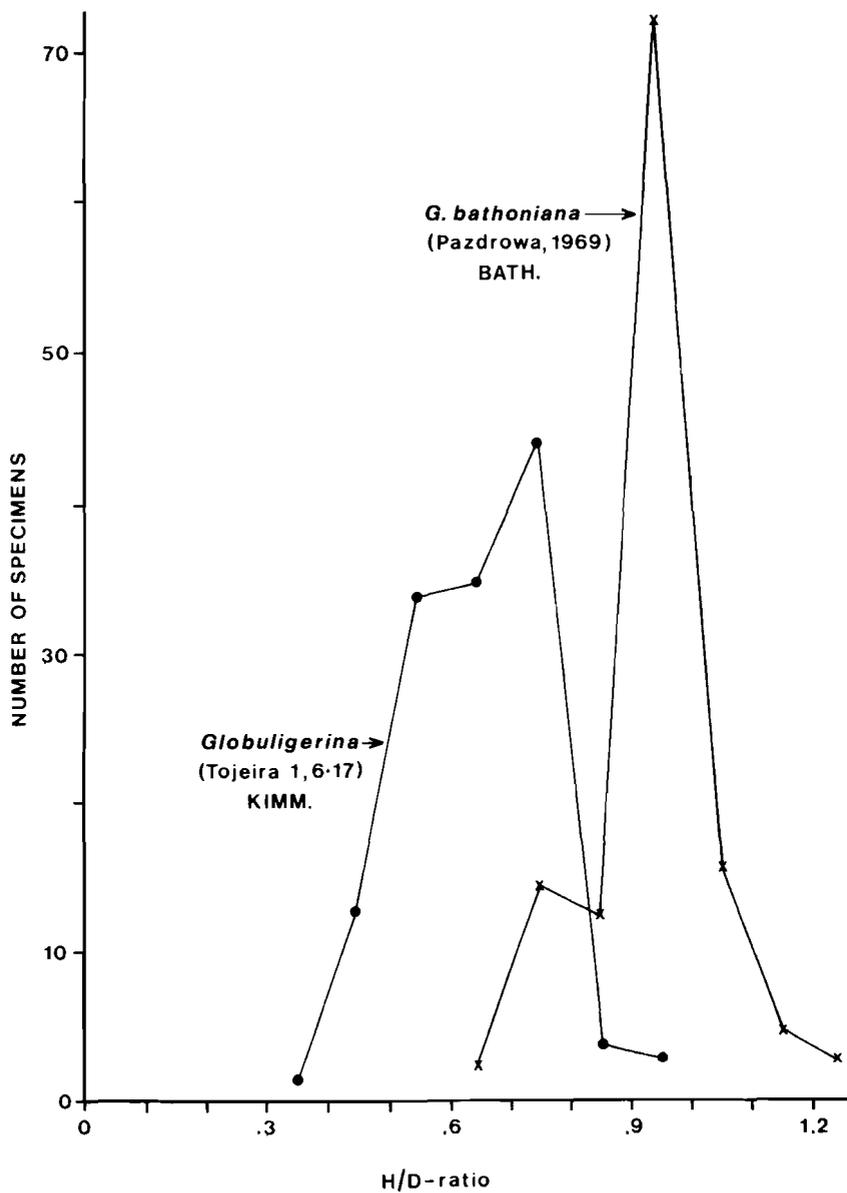


Fig. 50. Comparison of the H/D-ratio of *Globuligerina* spp. from the Oxfordian-Kimmeridgian of Portugal (Tojeira 1 section, sample 6.17) with the H/D-ratio of *G. bathoniana* from the Bathonian of Poland (after Pazdrowa, 1969).

hoterivica evolved from his high spired *G. jurassica*, but according to their stratigraphical range, both species co-existed from the Bathonian through the Tithonian.

From fig. 49 no decrease in the height of the spire (nor the H/D-ratio) is apparent. Neither is a general increase in size through time (Grigelis and Gorbachik, 1980). Also the development of a more complicated test sculpture could not be recognized despite the availability of rich and well preserved Middle and Upper Jurassic material from Portugal and the Grand Banks.

Fig. 49 was intended to illustrate whether or not reported differences between species were real. Since only a few values were available of the various parameters for each species, this figure has limited statistical value. In order to get a better insight in possible trends of the spire height through time, the height and the diameter of all 128 Globuligerinids from a split of sample 6.17, Tojeira 1 section (Kimmeridgian) were measured and the H/D-ratio calculated. The obtained H/D values are compared in fig. 50 with values of the same parameter measured from 120 Bathonian representatives of *G. bathoniana* (data from Pazdrowa, 1969, p. 51, fig. 16).

The mean H/D-ratio of the Kimmeridgian planktonics is 0.65, with a standard error of 0.01. For the Bathonian planktonics the mean H/D value lies between 0.90 and 0.95, and is therewith significantly higher. This indeed could reflect an evolutionary trend, however the overlap of both curves (partly due to the presence of both *G. oxfordiana* and *G. bathoniana* in sample 6.17) indicates that care has to be taken in drawing stratigraphical conclusions based on one or a few specimens, as was also illustrated in fig. 44.

On the other hand, instead of being an evolutionary trend, the occurrence of high and low spired species may be ecologically controlled. For example, *Guembilitria harrisi* Tappan, a stratigraphical (Albian) homeomorph of *G. bathoniana*, occurs in abundance in relatively shallow water deposits, whereas its abundance is always greatly reduced in deeper water (Price, 1977). Also abundant in relatively shallow water (for example inner Scotian Shelf) is *Globigerinita bradyi* (Wiesner), a Recent homeomorph of *G. bathoniana* (see plate 13, figs. 13–16).

The estimated paleowaterdepth for the sediments from which Pazdrowa (1969) described *G. bathoniana* is very shallow (Pazdrowa, 1967, 1969, p. 45; Gradstein, pers. comm.). Samples from the relatively shallow water Bajocian through Callovian of the Mareta Beach section contained exclusively high spired planktonics (*G. bathoniana*). In the samples from the relatively deep water Tojeira Formation the low spired *G. oxfordiana* predominates, but *G. bathoniana*, although in low numbers, is definitely present (plate 10, figs. 9–12).

If it is assumed that the occurrence of high and low spired planktonic foraminifera is ecologically controlled, then, in view of the distribution model for planktonic foraminifera as described in chapter 2 (2.4.8), *G. balakhmatovae* becomes of interest. This low spired species, together with *G. bathoniana*, *Garantella* spp. and *Reinholdella* spp., is common in the deep water Bajocian-Bathonian interval of the Murre G-67 and Eider M-75 wells. As mentioned in the diagnosis of *G. balakhmatovae*, this species has flattened chambers and occasionally an imperforate equatorial band or even a weakly developed keel. The existence of this morphology may be the first sign in the Jurassic towards the occurrences of “more” complicated test morphologies in progressively deeper water. This however needs further study. No accounts concerning the paleoecology of *G. balakhmatovae* are known from the literature.

Chapter 6

TAXONOMY

6.1: INTRODUCTION

In this chapter only those species are referred to that are of importance in the quantitative analyses, or are important from a stratigraphical point of view (e.g. *Lenticulina d'orbignyi*, all epistominids). All other species together with their occurrence are listed in table 16.

6.2: TAXONOMIC NOTES

***Discorbis parapsis* (Schwager, 1866)**

Plate 6, figs. 5–6

Rosalina parapsis Schwager, 1866, Geogn.-Pal. Beitr., Muenchen, Deutschland, Bd. 1, Heft 2, p. 310, fig. 16.

Discorbis parapsis (Schwager), Wernli, 1971, Arch. Sci. Genève, vol. 24, fasc. 2, p. 337, pl. 7, figs. 1–10.

Remarks: This non-ornamented species has a convex spiral side and a concave umbilical side, with a relatively wide umbilicus. Chambers increase gradually in size as added.

Occurrence: rare to common Mareta section, rare in both Tojeira sections.

***Discorbis scutiliformis* (Seibold and Seibold, 1960)**

Conorbina scutiliformis Seibold and Seibold, 1960, Neues Jb. Geol. Palaeont., Abh., Bd. 109, no. 3, p. 381, figs. 8c, 8d.

Discorbis scutiliformis (Seibold and Seibold), Wernli, 1971, Arch. Sci. Genève, vol. 24, fasc. 2, p. 338, pl. 7, figs. 11, 12, pl. 6, figs. 18, 21, 22, 24.

Remarks: *D. scutiliformis* differs from *D. parapsis* in having a last chamber which is broader than high.

Occurrence: Both Tojeira sections, rare.

***Eoguttulina?* cf. *bilocularis* (Terquem, 1864)**

Plate 5, fig. 4

Polymorphina bilocularis Terquem, 1864, Quatr. Mem. Foram. Lias, Metz:Lorette, p. 293, pl. 11, figs. 9–32.

Eoguttulina bilocularis (Terquem), Ruget, 1973, Rev. Facul. Cienc. Lisboa, 2nd Ser., C, vol. 17, fasc. 2, p. 537, pl. 8, figs. 8–10.

Remarks: The chamber arrangement is often not or difficult to see which makes a generic and specific assignment tentative. Differs from *E.?* cf. *metensis* and *E.?* cf. *oolithica* because two different parts (? chambers) are present.

Occurrence: Murtinheira and Mareta sections, rare in both.

***Eoguttulina?* cf. *metensis* (Terquem, 1864).**

Plate 5, fig. 1

Polymorphina metensis Terquem, 1864, Quatr. Mem. Foram. Lias, Metz: Lorette, p. 301, pl. 13, fig. 38.

Remarks: For remarks on generic and specific assignment see *E.?* cf. *bilocularis*. Most characteristic of this species is the elongated, sometimes flattened, fusiform shape.

Occurrence: Brenha and the Tojeira sections, rare in all three.

***Eoguttulina?* cf. *oolithica* (Terquem, 1874)**

Plate 5, figs. 2–3

Polymorphina oolithica Terquem, 1874, Quatr. Mem. Foram. Syst. Ool., p. 299, pl. 32, figs. 1–5, 8, 10.

Eoguttulina oolithica (Terquem), Lloyd, 1962, Micropal., vol. 8, no. 3, p. 373, pl. 1, figs. 5, 8, text-fig. 5.

Remarks: For remarks on generic and specific assignment see *E.?* cf. *bilocularis*. Test outline varies from ovoid to ellipsoidal. More elongated specimens differ from *E.?* cf. *metensis* in being relatively thick.

Occurrence: rare to common in all sections.

***Epistomina mosquensis* Uhlig, 1883.**

Plate 1, figs. 1–6

Epistomina mosquensis Uhlig, 1883, partim, Geol. Reichsanst., Jahrb., Wien, Bd. 33, p. 766, pl. 7, figs. 3a-c, not figs. 1, 2.

Epistomina mosquensis Uhlig, Ohm, 1967, partim, Palaeontographica, Abt. A, Bd. 127, Liefg. 3–6, p. 125, pl. 17, figs. 4, 11, not pl. 16, figs. 7–10, not pl. 17, figs. 1–12.

Epistomina sp. 3, Ohm, 1967, p. 132, fig. 28.

Epistomina mosquensis Uhlig, Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 49, text-fig. 7, pl. 2, fig. 3.

Remarks: The specimens included here in *E. mosquensis* vary from planoconvex to biconvex, in which case the ventral side is more convex than the dorsal side. All chambers are visible on the dorsal side and are separated by sharp, raised sutures. Most characteristic is the ornamentation on the ventral side: a high sharp ring surrounding a central depression, from which ridges run via the sutures towards the periphery. One keel, sometimes two separated by a very narrow keelband. Uhlig (1883) in her description of this species mentions that

a high sharp ring bordering a central depression is often present, but she also mentions that sometimes instead of a central depression, the centre of the ventral side is covered with "cells", small depressions bordered by ridges, in which case it often happens that this pattern of "cells" becomes so dense and widespread that it is not possible to recognize individual chambers of the last whorl. In the same year Terquem described *E. regularis*, and although his figures are less accurate than the ones given by Uhlig, he mentions in his description that this species is biconvex, with raised sutures on the dorsal side ("à loges régulières, quadrangulières et bordées") and a ventral side with no raised sutures but covered with an irregular pattern of ridges ("surface couverte de fines côtes irrégulièrement contournées"). It seems that *E. regularis* Terquem is very similar to those specimens assigned to *E. mosquensis* by Uhlig that have those above mentioned "cells", which is probably why Loeblich and Tappan (1964, p. C771) regarded *E. mosquensis* to be a junior synonym of *E. regularis* (Uhlig's paper was published shortly after the one by Terquem). It is agreed with Pazdro (1969) that only the relocation of the original collections of Terquem and Uhlig, or the establishment of neotypes could solve the question whether or not these two species are the same. For the moment however, because Terquem (1883) does not mention the presence of a central depression bordered by a high sharp ring, those specimens that do have these features should be assigned to *E. mosquensis*, whereas specimens that do not have these features should be assigned to *E. regularis*. This narrows down considerably the variation of *E. mosquensis* as described by Uhlig, and makes a distinction with *E. regularis* more easy (presence/absence criterium).

In view of the above and when examining the figures of *E. mosquensis* given by Ohm (1967), whose collection has been studied in Hannover (F.R.G.), only two figures can be assigned to *E. mosquensis* (pl. 17, figs. 4 and 11). Pl. 17, fig. 12 is a pyritized cast, which does not show any of the diagnostic features of *E. mosquensis*.

Epistomina ornata (Roemer, 1841), described from the Cretaceous of northern Germany, is similar to *E. mosquensis*. However, a distinct difference between the two species is the presence of relatively large and with ridges surrounded additional lateromarginal apertures in *E. ornata* (Ohm, 1969).

Occurrence: common to abundant in both Tojeira sections, rare *E. mosquensis* like pyritized casts occur in all other sections.

***Epistomina omninoreticulata* Espitalié and Sigal, 1963**

Epistomina omninoreticulata Espitalié and Sigal, 1963, Madagascar, Ann. Géol., Tananarive, fasc. 32, p. 67, pl. 31, fig. 7.

Remarks: This species is best described as being a biconvex epistominid with a pitted surface on the dorsal as well as on the ventral side.

Occurrence: Tojeira 1 section, rare.

Epistomina uhligi Mjatluk, 1953

Plate 1, figs. 7–14

Epistomina uhligi Mjatluk, 1953, Trudy VNIGRI, vol. 71, p. 219, pl. 2, fig. 5.

Brotzenia parastelligera Hofker, 1954, Palaeontographica, vol. 105, pt. A, fasc. 3–6, p. 180, text-figs. 4–6.

Epistomina uhligi Mjatluk, Ohm, 1967, Palaeontographica, Bd. 127, Abh. A, Liefg. 3–6, p. 128, text-figs. 22–24.

Epistomina parastelligera (Hofker), Wernli, 1971, Arch. Sci. Genève, vol. 24, fasc. 2, p. 345, pl. 3, figs. 13, 14, 16, 17.

Brotzenia sp. aff. *B. uhligi* (Mjatluk), Luterbacher, 1972, Init. Repts. Deep Sea Drill. Proj., vol. 11, p. 584, pl. 4, figs. 14–16.

Epistomina uhligi Mjatluk, Gradstein, 1978, Journ. Foram. Res., vol. 8, no. 2, pl. 1, fig. 2.

Remarks: The variability of this species is considerable. The dorsal side varies from flat to convex, the ventral side from convex to high convex. The umbilical disc varies from relatively small and thin to so large and thick that it becomes a dominating aspect of the ventral side. Additional slit like apertures usually only visible on the last (two) chambers. About seven chambers in the final whorl (see *Epistomina* sp. 2).

Epistomina parastelligera (Hofker, 1954), described from the Middle Jurassic of northwestern Germany can in general be described as being a non-ornamented epistominid, biconvex, with additional slit-like apertures and a small umbilical disk. Considering the original figures and description of *E. parastelligera* and comparing this with the variation of *E. uhligi* as described above, made me include *E. parastelligera* in the synonymy of *E. uhligi*.

The variation of *E. uhligi* as described by Ohm (1967) is very similar to the variation described above.

E. nuda Terquem, 1883, described from the Upper Bajocian of France differs from *E. uhligi* because it has a keeled (Terquem, 1883) or very sharp periphery (Pazdro, 1969).

E. caracolla (Roemer, 1841), described from the Cretaceous of northern Germany, is very similar to *E. uhligi*. According to M.A. Williamson (pers. comm.) *E. caracolla* is smaller and less biconvex than *E. uhligi*. Considering the variation of *E. uhligi* in our Portuguese material, it is clear that those differences are difficult to use. The question whether or not *E. uhligi* and *E. caracolla* are two distinct species remains as yet unanswered.

Occurrence: common in the Tojeira sections, rare *E. uhligi* like pyritized casts occur in the Mareta section.

Epistomina sp. 1
Plate 2, figs. 4–6

Trochospiral, biconvex, the dorsal side usually being more convex than the ventral side, 7–8 chambers in the last whorl. Ornamentation on the ventral side consists of a usually low ring, bordering a central depression, from which thick and raised sutures run radially towards the periphery. The ornamentation on the dorsal side is heavier and is characterized by sharp high raised outlines of the first two or three chambers. Sutures of subsequent chambers are thick but less raised than those of the first few chambers. Test-outline rounded to angular.

Remarks: *Epistomina* sp. 1 differs from *E. mosquensis* in having a more convex dorsal side, and in being much heavier ornamented on the dorsal side.

Occurrence: Both Tojeira sections, rare.

Epistomina sp. 2
Plate 3, figs. 3–4

Trochospiral, planoconvex, sometimes a slightly convex dorsal side, 13–14 chambers in the last whorl. Sutures on the dorsal side sometimes slightly raised. Ventral side smooth, with glassy umbilical disc.

Remarks: *Epistomina* sp. 2 can easily be distinguished from *E. ubligi* by the number of chambers in the last whorl, which is about seven for *E. ubligi*. This species has only been encountered in the size-fraction from 125–250 micron.

Occurrence: Tojeira 1 section, rare.

Epistomina aff. *E. volgensis* Mjatliuk var. **intermedia** Mjatliuk 1953
Plate 2, figs. 1–3

Epistomina volgensis Mjatliuk var. *intermedia* Mjatliuk, 1953, Trudy VNIGRI, vol. 71, p. 214, pl. 3, figs. 3a–c.

Remarks: Trochospiral, planoconvex, 7–8 chambers in the final whorl. The dorsal side high to extremely high (height occasionally larger than diameter). Ventral side is flat and smooth, no or only slightly raised sutures and no or a only very weakly developed central ring. Dorsal side is heavily ornamented: high ridges on the sutures. Test-outline round to angular, sometimes with weakly developed spines. No translation (from russian) of the description of this species was available. The specimen figured by Mjatliuk is more biconvex: dorsal side much higher. Dorsal side is, like in the case of our specimens, heavi-

ly ornamented, whereas the ventral side, in contrast to our specimens, is more convex and heavier ornamented.

This species differs from *Epistomina* sp. 1 in having a (almost) non ornamented ventral side and in being planoconvex.

Occurrence: Both Tojeira sections, rare.

***Epistomina* aff. *E. volgensis* Mjatliuk var. *volgensis* Mjatliuk, 1953.**

Plate 2, figs. 7–12

Epistomina volgensis Mjatliuk var. *volgensis* Mjatliuk, 1953, partim, Trudy VNIGRI, vol. 71, p. 214, pl. 4, figs. 1a–c, (not figs. 2a–c).

Remarks: Trochospiral, planoconvex to biconvex in which case the dorsal side is more convex than the ventral side, 8–10 chambers in the final whorl. Usually both sides are smooth, occasionally however sutures are slightly raised. Test-outline varies from round to angular with often short spines. Individuals with short spines dominate. No translation of the original description was available. Mjatliuk's figures of this species do not show any spines, but the angular outline which is common is well illustrated (fig. 1a).

This species has only been encountered in the size-fraction from 250 to 500 micron. Mjatliuk mentions the diameter of this species to range from 200 to 830 micron.

Occurrence: Tojeira 1 section, rare.

***Lenticulina muensteri* (Roemer, 1839)**

Plate 5, figs. 7–8

Robulina muensteri Roemer, 1839, Hannover, Deutschland, Hahn'schen Hofbuchhandlung, p. 48, pl. 20, fig. 29.

Cristellaria piriformis Schwager, 1865, Ver. Vaterl. Naturk., Wuerttemberg, Jahresh, vol. 21, p. 132, pl. 6, fig. 17.

Lenticulina (Lenticulina) muensteri (Roemer), Seibold and Seibold, 1956, Neues Jb. Geol. Palaeont., Abh., Bd. 103, no. 1/2, p. 109, pl. 4, figs. a, b, pl. 5, figs. q, r.

Lenticulina (Astacolus) piriformis (Schwager), Seibold and Seibold, 1956, Neues Jb. Geol. Palaeont., Abh., Bd. 103, no. 1/2, p. 120, pl. 5, fig. z, pl. 7, fig. 18.

Remarks: In their revision of C. Schwager's (1865) work, Seibold and Seibold (1956) state that the only difference between *L. muensteri* and *L. piriformis* is an uncoiling last part of the test of the latter species. However, a gradual variation can be observed between specimens with and without an uncoiling last part of the test.

Occurrence: rare to common Mareta section, common to abundant in all other sections.

Lenticulina d'orbignyi (Roemer, 1839)

Plate 6, figs. 1–2

Peneroplis d'orbignii Roemer, 1839, Hannover, Deutschland, Hahn'schen Hofbuchhandlung, p. 47, pl. 20, figs. 31a–b.

Lenticulina d'orbignyi (Roemer), Copestake and Johnson, 1981, British Micropal. Soc. Ser., p. 94, pl. 6.1.2, fig. 14.

Remarks: *L. algarviensis* Ruget, 1973, has a less regular ornamentation and is uncoiling.

Occurrence: Murtinheira and Brenha sections, rare to very rare in both.

Lenticulina quenstedti (Guembel, 1862)

Plate 5, figs. 9–11

Cristellaria quenstedti Guembel, 1862, Wuerttemberg naturw. Jahresh., Stuttgart, Deutschland, Jahrg. 18, p. 226, pl. 4, fig. 2.

Lenticulina quenstedti (Guembel), Shipp and Murray, 1981, British Micropal. Soc. Ser., p. 139, pl. 6.3.3, figs. 16, 17.

Remarks: This species is easily recognized by a raised ring on both sides from which raised and backwards curved sutures run towards the periphery.

Occurrence: In Mareta and Tojeira sections rare to very rare, common to abundant in Brenha and Murtinheira.

Ophthalmidium carinatum Kuebler and Zwingly, emend. Wood, 1947

Plate 4, figs. 11–12

Ophthalmidium carinatum Kuebler and Zwingly, 1870, Schweizer Jura, p. 16, pl. 2, figs. 11–12.

Ophthalmidium carinatum Kuebler and Zwingly, emend. Wood, 1947, Geol. Soc. London, Quart. Journ., vol. 102, pt. 4, p. 462, pl. 29, figs. c-h, pl. 30, figs. 2, 3.

Ophthalmidium carinatum Kuebler and Zwingly, Coleman, 1981, British Micropal. Soc. Ser., p. 115, p. 6.2.1, fig. 13.

Remarks: Wood (1947) noted a large variation of *O. carinatum*. The test-outline varies from oval with no or almost no keel to almost round with usually a sharp periphery. *O. strumosum* looks similar, but can be distinguished by the much more elongated test-outline with more or less parallel peripheries, being more tightly coiled and having an aperture on a long neck. The overall appearance of *O. strumosum* is more robust.

Occurrence: rare to common, occasionally abundant in Tojeira 1 section, usually rare in Brenha section.

Ophthalmidium concentricum (Terquem and Berthelin, 1875)
Plate 4, fig. 13

Spiroloculina concentrica Terquem and Berthelin, 1875, Soc. Géol. France, Mém., sér. 2, tome 10, no. 3, p. 80, pl. 7, figs. 1–4.

Spirophthalmidium concentricum (Terquem and Berthelin), Bartenstein and Brand, 1937, Abh. Senckenberg. naturf. Ges., Abh. 439, p. 181, pl. 2b, figs. 37, 38, pl. 4, fig. 16, pl. 5, figs. 71a–b, pl. 8, fig. 36, pl. 13, fig. 21, pl. 15a, figs. 39a–b.

Remarks: Differs from *O. carinatum* in having a thicker test, with a broadly rounded periphery.

Occurrence: Rare in Mareta section, usually rare in Brenha and Murtinheira sections.

Ophthalmidium strumosum (Guembel, 1862)
Plate 4, figs. 9–10

Guttulina strumosa Guembel, 1862, Jh. Ver. Vaterl. Naturk. Wuertt., Stuttgart, vol. 18, p. 227, pl. 4, figs. 13, 14.

Ophthalmidium strumosum (Guembel), Seibold and Seibold, 1955, Neues Jb. Geol. Palaeont., Abh., Bd. 101, no. 1, p. 102, pl. 3, figs. h, i.

Remarks: See *O. carinatum*.

Occurrence: Rare to common in the Tojeira sections.

Paalzowella feifeli (Paalzow, 1932)
Plate 6, figs. 7–8

Trocholina feifeli Paalzow, 1932, Jh. Ver. Vaterl. Naturk. Wuertt., Stuttgart, vol. 88, Abh. 3, p. 140, pl. 11, figs. 6, 7.

Paalzowella feifeli (Paalzow), Coleman, 1981, British Micropal. Soc. Ser., p. 114, pl. 6.2.1, fig. 6.

Occurrence: Brenha and Tojeira sections, rare; common to abundant Mareta section.

Pseudolamarckina rjasanensis (Uhlig, 1883)
Plate 3, figs. 7–9, 11–12

Pulvinulina rjasanensis Uhlig, 1883, Geol. Reichsanst., Jahrb., Wien, Bd. 33, p. 772, pl. 8, figs. 4–6.

Conorboides nuda (Terquem), Lutze, 1960, Geol. Jb., Hannover, Bd. 77, p. 492, pl. 33, fig. 8.

Pseudolamarckina rjasanensis (Uhlig), Loeblich and Tappan, 1964, Treatise, p. C769, fig. 632–1.

Reinholdella cebra Pazdro var., Gradstein, 1977, Maritime Sed. Spec. Publ., pl. 3, fig. 7.

Reinholdella cebra var. Pazdro, Gradstein, 1978, Journ. Foram. Res., vol. 8, no. 2, pl. 2, fig. 1

Remarks: This species has a convex spiral side and a flat umbilical side. The

sutures on the spiral side are relatively broad and slightly raised. The last chamber on the umbilical side extends to the centre, almost covering the umbilicus. The aperture is loop shaped and umbilical, with an incision upface. The specimens encountered closely resemble Uhlig's (1883) figures. The specimens found in cuttings and sidewall cores from wells on the Grand Banks (referred to as *Reinholdella cebra* var.) are somewhat higher trochoid than those from Portugal. The small incision of the aperture in *Pseudolamarckina*, especially when visible on all chambers on the umbilical side, looks similar to the pattern of secondary apertures in *Reinholdella*. The primary aperture of *Reinholdella* however is an interiomarginal arch near the periphery.

Occurrence: Tojeira 1 section, common to abundant; Tojeira 2 section rare to common.

***Spirillina elongata* Bielecka and Pozaryski, 1954**

Plate 6, fig. 11

Spirillina elongata Bielecka and Pozaryski, 1954, Poland, Inst. Geol., Prace, Warsaw, vol. 12, p. 67, pl. 10, fig. 53.

Spirillina elongata Bielecka and Pozaryski, Sliter, 1980, Init. Repts. Deep Sea Drill. Proj., vol. 50, p. 400, pl. 15, figs. 1, 2.

Remarks: The test-outline varies from almost subcircular to elongated with parallel peripheries. Also the degree in which the second whorl is involute varies.

Occurrence: Marena section common to abundant, common in the Tojeira sections, rare in Murtinheira section, rare to common Brenha section.

***Spirillina infima* (Strickland, 1846) emend. Barnard, 1952**

Plate 6, fig. 10

Orbis infimis Strickland, 1846, Quart. Journ. Geol. Soc. London, vol. 2, no. 31, p. 13, text-fig. a.

Spirillina infima (Strickland), Barnard, 1952, Geol. Assoc. Proc., vol. 63, pt. 4, p. 906, text-figs. 1-3.

Trisegmentina? sp. 1, Lutze, 1960, Geol. Jb., Hannover, Bd. 77, p. 493, pl. 33, fig. 4.

Remarks: *S. infima* is much thicker than individuals of the same size which in this study are assigned to *S. tenuissima*. The whorls of the second chamber are more involute, if compared with *S. tenuissima*, resulting in a very robust overall appearance.

Occurrence: very rare in Murtinheira section, rare to common in Brenha section, common to abundant lower part Tojeira 1 section, rare in the Tojeira 2 and upper part of the Tojeira 1 sections, common in Marena section.

Spirillina tenuissima Guembel, 1862

Plate 6, fig. 9

Spirillina tenuissima Guembel, 1862, Wuerttemberg naturw. Jahresh., Stuttgart, Deutschland, Jahrg. 18, p. 214, pl. 4, fig. 12.

Spirillina tenuissima Guembel, Barnard *et al.*, 1981, Rev. Esp. Micropal., vol 13, no. 3, p. 428, pl. 4, figs. 4, 8.

Remarks: This species varies from very thin and fragile forms with the whorls of the second chamber being evolute to somewhat thicker forms with the whorls of the second chamber being more or less involute; often the last whorl is more involute than the preceding ones. *S. minima* Schacko seems similar, but the coarser perforation as observed by Schacko has not been seen, but recrystallization might have obscured this difference.

Occurrence: common to abundant in all sections.

The following species have only been observed in cuttings and sidewall cores of wells on the Grand Banks (for occurrences see table 13).

Alveosepta jaccardi (Schrodt, 1894)

Cyclammia jaccardi Schrodt, 1894, Zeitschr. deutsch. geol. Ges. p. 733.

Pseudocyclammia jaccardi (Schrodt), Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 1, figs. 1, 2.

Anchispirocyclina lusitanica (Egger, 1902)

Dicylina lusitanica Egger, 1902, Akad. Wiss., Math.-Physik. Cl., Abh., vol. 21, pt. 3, p. 585, pl. 6, figs. 3–5.

Epistomina regularis Terquem, 1883

Plate 3, figs. 1–2

Epistomina regularis Terquem, 1883, Cinq. Mém. Foram. Syst. Ool., p. 379, pl. 44, figs. 1–3.

Epistomina regularis Terquem, Pazdro, 1969, Stud. Geol. Polonica, p. 44, pl. 1, figs. 1–5, pl. 2, figs. 1, 2, 4, pl. 13, figs. 1–4, pl. 14, fig. 1.

Epistomina regularis Terquem, Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 2, figs. 5, 6.

Remarks: see remarks on *E. mosquensis*.

Epistomina stelicostata Bielecka and Pozaryski, 1954

Plate 3, fig. 10

Epistomina stelicostata Bielecka and Pozaryski, 1954, Inst. Geol., Prace, p. 71, pl. 12, fig. 60.

Epistomina sp. 3

Plate 3, figs. 5–6

This species is somewhat similar to *E. ubligi*, from which it differs in always being biconvex, and having high raised, sharp sutures on the spiral side. The umbilical side is smooth.

Garantella aff. ampasindavaensis (Espitalié and Sigal, 1963)

Plate 3, figs. 13–14

Epistomina ampasindavaensis Espitalié and Sigal, 1963, Rev. Micropal., vol. 6, no. 2, p. 113, pl. 2, figs. 2–4.

Garantella ampasindavaensis (Espitalié and Sigal), Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 5, figs. 1, 2.

Garantella ornata (Hofker, 1952)

Reinholdella ornata Hofker, 1952, Palaeont. Zeitschr., vol. 26, no. 1–2, p. 24, figs. 12–16.

Garantella ornata (Hofker), Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 79, pl. 10, figs. 1–3, 6, pl. 11, fig. 2, pl. 15, figs. 3, 4.

Garantella ornata (Hofker), Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 4, figs. 1, 2.

Garantella rudia Kaptarenko, 1956

Garantella rudia Kaptarenko, 1959, Vopr. Mikropal., no. 1, p. 60, pl. 1, fig. 13.

Garantella rudia Kaptarenko, Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 81.

Garantella aff. rudia Kaptarenko, Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 5, figs. 4, 5.

Garantella sera Pazdro, 1969

Garantella sera Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 81, pl. 10, figs. 4, 5, 7.

Garantella stellata Kaptarenko, 1956

Garantella stellata Kaptarenko, 1956, Vopr. Mikropal., no. 1, p. 60, pl. 1, fig. 60.

Garantella aff. stellata Kaptarenko, Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 82, pl. 9, fig. 5.

Garantella stellata Kaptarenko, Gradstein, 1977, Maritime Sed., Spec. Publ., pl. 4, figs. 3, 4.

Reinholdella media (Kaptarenko, 1959)

Lamarckella media Kaptarenko, 1959, TRUDY Ak. Nauk. USSR, vol. 45, p. 94, pl. 12, figs. 1, 2.

Reinholdella media (Kaptarenko), Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 72, text fig. 14.

Reinholdella cebra Pazdro, 1969

Reinholdella cebra Pazdro, 1969, Stud. Geol. Polonica, vol. 27, p. 69, pl. 8, figs. 1–3, pl. 12, figs. 1, 2, pl. 14, figs. 7, 8, pl. 15, figs. 1, 2.

Table 16. Rare species and their occurrence, Portugal

| | Murtinheira | Brenha | Mareta | T ojeira 1 | T ojeira 2 |
|--|-------------|--------|--------|------------|------------|
| <i>Ammobaculites coprolithiformis</i> (Schwager, 1867) | | | x | x | x |
| <i>Ammobaculites suprajurassicus</i> (Schwager, 1865) | | | | x | x |
| <i>Astacolus gratus</i> (Reuss, 1863) | | | | x | x |
| <i>Bigenerina jurassica</i> (Haeusler, 1890) | | | x | x | x |
| <i>Dentalina communis</i> d'Orbigny, 1826 | x | x | x | x | x |
| <i>Dorothia bechti</i> Dieni and Massari, 1966 | | | x | x | x |
| <i>Dorothia</i> cf. <i>oxycona</i> (Reuss, 1860) | | | | x | x |
| <i>Lenticulina algarviensis</i> Ruget, 1973 | | | x | | |
| <i>Lenticulina anceps</i> (Terquem, 1870) | x | | x | x | x |
| <i>Lenticulina glabra</i> (d'Orbigny, 1826) | x | | x | x | x |
| <i>Lenticulina</i> cf. <i>subalata</i> (Reuss, 1854) | x | x | x | | |
| <i>Lenticulina tricarinnella</i> (Reuss, 1863) | | | x | | |
| <i>Lenticulina varians</i> (Bornemann, 1854) | x | x | x | x | x |
| <i>Lingulina dentaliniformis</i> Terquem, 1870 | | | x | | |
| <i>Lingulina nodosaria</i> (Terquem, 1862) | | | x | x | x |
| <i>Lingulina tenera</i> Bornemann, 1854 | | x | | x? | |
| <i>Marginulina oolithica</i> (Terquem, 1870) | | | x | | |
| <i>Neoflabellina deslonchampsii</i> (Terquem, 1864) | x | x | x | x | |
| <i>Nodophthalmidium pyriformis</i> (Tappan, 1940) | | | | x | x |
| <i>Nodosaria aspera</i> Reuss, 1845 | | | x | x | x |
| <i>Nodosaria hortensis</i> Terquem, 1866 | | x | x | x | x |
| <i>Planularia protracta</i> (Bornemann, 1854) | | x | | x | x |
| <i>Reophax horridus</i> (Schwager, 1865) | | x | x | x | x |
| <i>Reophax sterkii</i> Haeusler, 1890 | | x | x | x | x |
| <i>Saracenaria triquetra</i> (Guembel, 1862) | | | x | x | x |
| <i>Textularia agglutinans</i> d'Orbigny, 1839 | | x | | x | x |
| <i>Textularia dumortieri</i> (Schwager, 1866) | | | | x | x |
| <i>Textularia jurassica</i> Guembel, 1862 | | | x | x | x |
| <i>Tristix oolithica</i> (Terquem, 1886) | | | x | | |
| <i>Trochammina depressa</i> Lozo, 1944 | | | x | x | x |
| <i>Verneulinoides mauritii</i> (Terquem, 1866) | | x | x | | |
| <i>Verneulinoides minuta</i> Said and Barakat, 1958 | | x | x | x | x |

APPENDIX

Dr. T.P. Poulton's (1) report on the Jurassic ammonites collected in the Montejunto area, along cross-sections 1-2 of figs. 13-15 (this volume).

Report No. J-3-TTP-1983

Report on the 11 collections of Jurassic ammonites collected by T. Poulton in 1982 on the south side of Montejunto, Portugal, in a traverse working upsection to the south, in fieldwork organized by F. Gradstein (AGC).

The relevant parts of any manuscript prepared for publication that paraphrase or quote from this report should be referred to the Paleontology Subdivision, Calgary, for possible revision.

This report is written to assist with biostratigraphic control for correlation with microfossil and palynology samples collected by other participants in the project. The specimens collected by the writer are assigned to the sub-Mediterranean ammonite zones, based on comparisons with the European literature. Closest similarities are with the faunas of France, Bulgaria, southern Germany and southern Poland.

It is beyond the scope of this report to analyze the correlation of these zones with the stage stratotype areas of NW Europe, with which there are very few ammonite species in common. This can best be done by independent review of the literature, principally of southern Germany and Poland.

It is beyond the scope of this report to unravel the complex priorities, local synonymies, and generic assignments for the Upper Jurassic perisphinctids. It seems most useful to indicate which figured specimens are most likely those collected by the writer, without indicating which specific and generic names are favoured.

For the most part only small to medium sized specimens (ie: juvenile or inner whorls) were found. Because generic and subgeneric differentiation of the perisphinctids relies largely on knowledge of the size, apertural modifications, and ribbing modifications of the adult, the few subgeneric assignments given here are tentative at best.

GSC location number C-107860: Lower part of Kimmeridgian shale.

(1): Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, 3303-33 St. N.W., Calgary, Alberta.

Ammonites

Perisphinctes (Progeronia) (?) or *Lithacoceras* (?) sp. of the group including *P. unicomptus* Fontannes, *P. lictor* Quenstedt, “*Orthosphinctes polygyratus* Reinecke” of Atrops and Benest (1972), and “*O. (Ardescia) aff. desmoides*” of same authors. Locally known as *Perisphinctes abadiensis* Choffat, *P. ribeiro* Choffat, and *P. pseudolictor* Choffat (?).

Age and Correlation

Probably near the Planula-Platynota boundary (ie: Oxfordian-Kimmeridgian boundary) with closest resemblance to the higher zone. Probably Basal Kimmeridgian.

GSC location number C-107861: Tojeira shale (approx. sample 6.22, fig. 17).

Ammonites

“*Perisphinctes* sp. indet. aff. *P. vandellii* Choffat (?). *Phylloceras* (?) sp. indet.

Age and Correlation

The poorly preserved small fragments of perisphinctids are similar to *Progeronia triplex* (Quenstedt) of lower to (lower Middle) Kimmeridgian age, but are not positively determinable.

GSC location number C-107862: Tojeira shale (approx. sample 6.10/6.11, fig. 17).

Ammonites

Perisphinctes (Progeronia) (?) or *Lithacoceras* (?) *abadiensis* Choffat as in C-107860. *Perisphinctes (Orthosphinctes)* sp. aff. *virgulatus* Quenstedt and aff. *colubrinus* (Reinecke). Perisphinctid genus and sp. indet. with some resemblance to *Mirosphinctes*. *Taramelliceras* sp. aff. *T. pseudoflexuosa* (Favre). *Phylloceras* (?) spp. indet.

Age and Correlation

Probably Lower Kimmeridgian Platynota Zone, or possibly uppermost Oxfordian Planula Zone.

GSC location number C-107863: Tojeira shale (approx. sample 6.4, fig. 17).

Ammonites

“*Perisphinctes*” sp. of the group including *P. danubiensis* Schlosser, *P. breviceps* Quenstedt and *P. (Progeronia) triplex* Quenstedt. Locally known as *P. delgadoi* Choffat and with similarities to *P. fontanesi* Choffat. “*Perisphinctes*” *castroi* Choffat. *Perisphinctes (Progeronia)* sp. indet. *Sowerbyceras* sp. indet.

Age and Correlation

Probably near the Planula-Platynota boundary, with particular resemblance to the Planula Zone, uppermost Oxfordian, based on the *P. triplex* group of perisphinctids.

GSC location number C-107864: Upper few beds of Montejunto limestone, along small road (approx. sample 5.7, fig. 15).

Ammonites

Perisphinctes (*Orthosphinctes*) *tiziani* Oppel – *polygratus* Quenstedt, with similarities to *P. (O.) colubrinus* Reinecke and *P. planula* Hehl; locally known as *P. vandellii* Choffat, *P. mogosensis* Choffat. *Perisphinctes* (*Arisphinctes*) (?) sp. aff. *P. torresensis* Choffat, with similarities to *P. gigantoplex* Quenstedt. *Taramelliceras* sp. aff. *P. kobyi* Choffat.

Age and Correlation

Probably Planula Zone (Upper Oxfordian), although some specimens (i.e. *P. (Arisphinctes?)* sp.) have similarities with older (lower Bimammatum Zone) species elsewhere. The *P. (Arisphinctes?)* specimens identified here are not perfectly comparable with any published species, and the Planula age is based on the assemblage as a whole, the *P. (Orthosphinctes)* species in particular.

GSC location number C-107865: just below C-107864

Ammonites

“*Perisphinctes*” sp. indet. aff. *P. tiziani* Oppel and *P. janus* Choffat.

Age and Correlation

Undeterminable.

GSC location number C107866: Montejunto limestone.

Ammonites

“*Perisphinctes*” *monteiroi* Choffat.

Age and Correlation

Undeterminable.

GSC location number C-107867: Montejunto limestone (approx. sample 14.1–2, fig. 15).

Ammonites

Perisphinctes (*Orthosphinctes*) *tiziani* Oppel, including local synonyms *P. tizianiformis* Choffat and *P. fontanesi* Choffat; some specimens are very close to “*P. polygyratus*” Reinecke figured by Arkell. “*Perisphinctes*” sp. indet., *Perisphinctes* (*Arisphinctes*) (?) sp. aff. *P. torresensis* Choffat, with similarities to *P. gigantoplex* Quenstedt, *P. cyrilli* Neumann, *P. andelotensis* Enay, *P. cuneicostatus* Arkell, and *P. swidzinskii* Malinowska. *Ochetoceras* sp. aff. *O. canaliferum* (Oppel). *Sowerbyceras silenum* (Fontannes).

Age and Correlation

Probably Bimammatum Zone, Hypselum subzone. The *P. (Arisphinctes?)* has similarities to upper Plicatulus-Transversarium faunas, but are not perfectly comparable with any published species.

GSC location number C-107868: Base of Montejunto limestone.

Ammonites

"*Perisphinctes*" sp. of the group including *P. aeneas* Gemmelaro, *P. berlieri* deLoriol, *P. ultimus* Enay, *P. wortae* Bukowski, *P. elisabethae* de Riaz, *P. arussorium* Dacque, and *P. cautisnigrae* Arkell; with similarities to *P. danubien-sis* Schlosser, *P. dybowskii* Siemiradzki, *P. midowe* Siemiradzki, *P. laufenensis* Siemiradzki, *P. martelli* Oppel, and *P. elisabethaeformis* Burkhardt, known locally as *P. castroi* Choffat. *Perisphinctes (Dichotomoceras)* (?) sp. with similarities to *P. inconditus* Fontannes, *P. polyplycoides* Fontannes, *P. (Dichotomoceras) bifurcatus* Quenstedt of Sapunov. "*P. (D.) antecedens*" Salfeld of Arkell, known locally as *P. linki* Choffat. "*Perisphinctes*" sp. with similarities to *P. tiziani* Oppel. Perisphinctid gen. and sp. indet. with similarities to "*P.*" *andelotensis* Enay and *P. ingens* Young and Bird. *Euaspidoceras* sp. aff. *E. hypselum* (Oppel) and *E. paucituberculatum* Arkell. *Sowerbyceras silenum* (Fontannes).

Age and Correlation

The perisphinctids for the most part indicate the Transversarium Zone. However there are some species similar to those of the upper Plicatilis Zone, and a lesser number to those of the Bifurcatus or lower Bimammatum Zone. Probably Transversarium, or upper (ie. Antecedens Subzone) Plicatilis Zone.

GSC location number C-107869: Top Cabaco limestone.

Ammonites

Perisphinctes (Dichotomosphinctes) (?) spp. indet. with similarities to *P. (Dichotomosphinctes) elisabethae* de Riaz and *P. (D.) ouatius* Buckman. *P. (Orthosphinctes)* (?) sp. indet. with similarities to *P. parandiformis* Arkell, *P. rotoides* Ronchadze, and particularly *P. melmorei* Arkell. *Ochetoceras canaliculatum* (Muenster).

Age and Correlation

Probably Upper Plicatilis to Transversarium Zones, the lower zone favoured. Certain of the perisphinctids have similarities to those as high as the lower Bimammatum Zone but cannot be positively identified.

GSC location number C-107870: Upper part of Cabaco limestone.

Ammonites

Perisphinctes (Dichotomosphinctes) sp. of the group including *P. (D.) rotoides* Ronchadze, *P. (D.) auriculatus* Arkell, and *P. (D.) ouarius* Buckman. *Perisphinctes (Otosphinctes)* (?) sp. with similarities to *P. (O.) montfalconensis* deLoriol and *P. (O.) paturattensis* deLoriol. *Perisphinctes (Arisphinctes)* (?) sp. of the group including *P. parandiformis* Arkell, *P. vorda* Buckman, and *P. melmorei* Arkell.

Euaspidoceras sp. aff. *E. costatum* (Dorn), *E. crebricostis* Arkell, and *E. catena* (Sowerby).

Age and Correlation

Probably Antecedens subzone of Plicatilis Zone. Some specimens resemble those of the lower Plicatilis Zone or even some lower Oxfordian faunas, others are similar to faunas as young as the Planula Zone, but none of these are positively identifiable, and the overall assemblage indicates Plicatilis Zone.

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Plate 1

- Figs. 1–3. *Epistomina mosquensis* Uhlig, Tojeira 1 section, sample 6.10, Planula-Platynota Zones (Late Oxfordian-Early Kimmeridgian), X100 (figs. 1, 2), X110 (fig. 3).
- Fig. 4. *Epistomina mosquensis* Uhlig, Mareta Beach, sample 40, Athleta Zone (Late Callovian), X120.
- Figs. 5, 6. *Epistomina mosquensis* Uhlig, Bittern, swc. 5000' (fig. 5) and swc. 4432' (fig. 6), *Epistomina mosquensis* Zone, Oxfordian-Kimmeridgian, X115 (fig. 5), X150 (fig. 6).
- Figs. 7–10. *Epistomina uhligi* Mjatliuk, Tojeira 1 section, sample 6.25, Platynota Zone (Early Kimmeridgian), X70 (fig. 7), X100 (fig. 8), X50 (fig. 9), X65 (fig. 10).
- Figs. 11, 12. *Epistomina uhligi* Mjatliuk, Tojeira 1 section, sample 6.6, Planula-Platynota Zones (Late Oxfordian-Early Kimmeridgian), X130 (fig. 11), X115 (fig. 12).
- Figs. 13, 14. *Epistomina uhligi* Mjatliuk, Cormorant N-83, cts. 3150-3180', *Epistomina regularis* Zone (Callovian), X110.

Plate 1

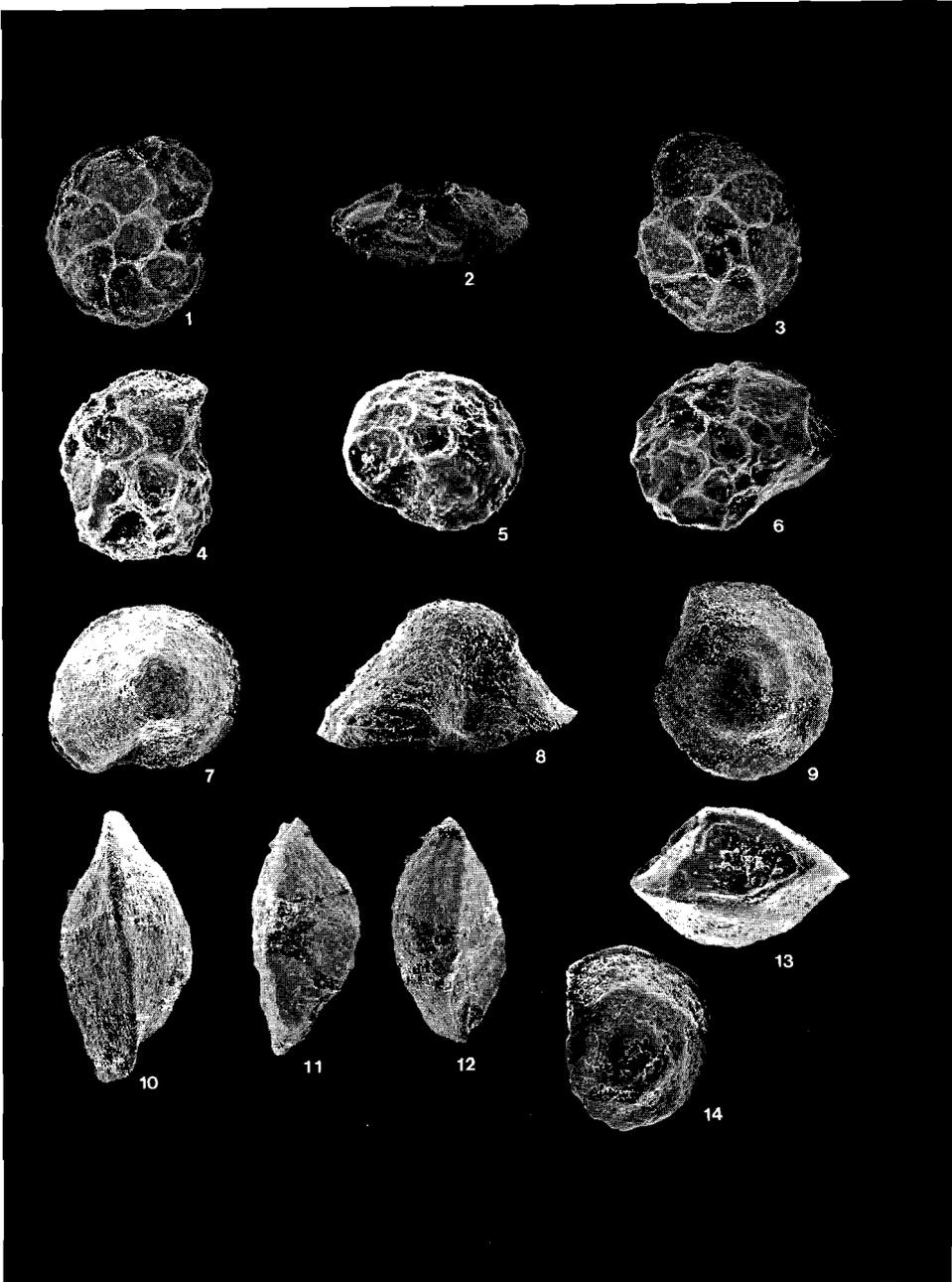


Plate 2

- Figs. 1–3. *Epistomina* aff. *volgensis* Mjatliuk var. *intermedia* Mjatliuk, Tojeira 1 section, sample 6.26A, Platynota Zone (Early Kimmeridgian), X65 (figs. 1, 2), X60 (fig. 3).
- Figs. 4–6. *Epistomina* sp. 1, Tojeira 1 section, sample 6.13, Platynota Zone (Early Kimmeridgian), X85.
- Figs. 7–9. *Epistomina* aff. *volgensis* Mjatliuk var. *volgensis* Mjatliuk, Tojeira 1 section, sample 6.26A (figs. 7, 8) and sample 6.14 (fig. 9), Platynota Zone (Early Kimmeridgian), X45 (fig. 7, 9), X50 (fig. 8).
- Figs. 10–12. *Epistomina* aff. *volgensis* Mjatliuk var. *volgensis* Mjatliuk, Bonniton H-32, cts. 8050–8080', *Epistomina regularis* Zone? (Oxfordian-Kimmeridgian), X65 (fig. 10), X75 (fig. 11), X55 (fig. 12).

Plate 2

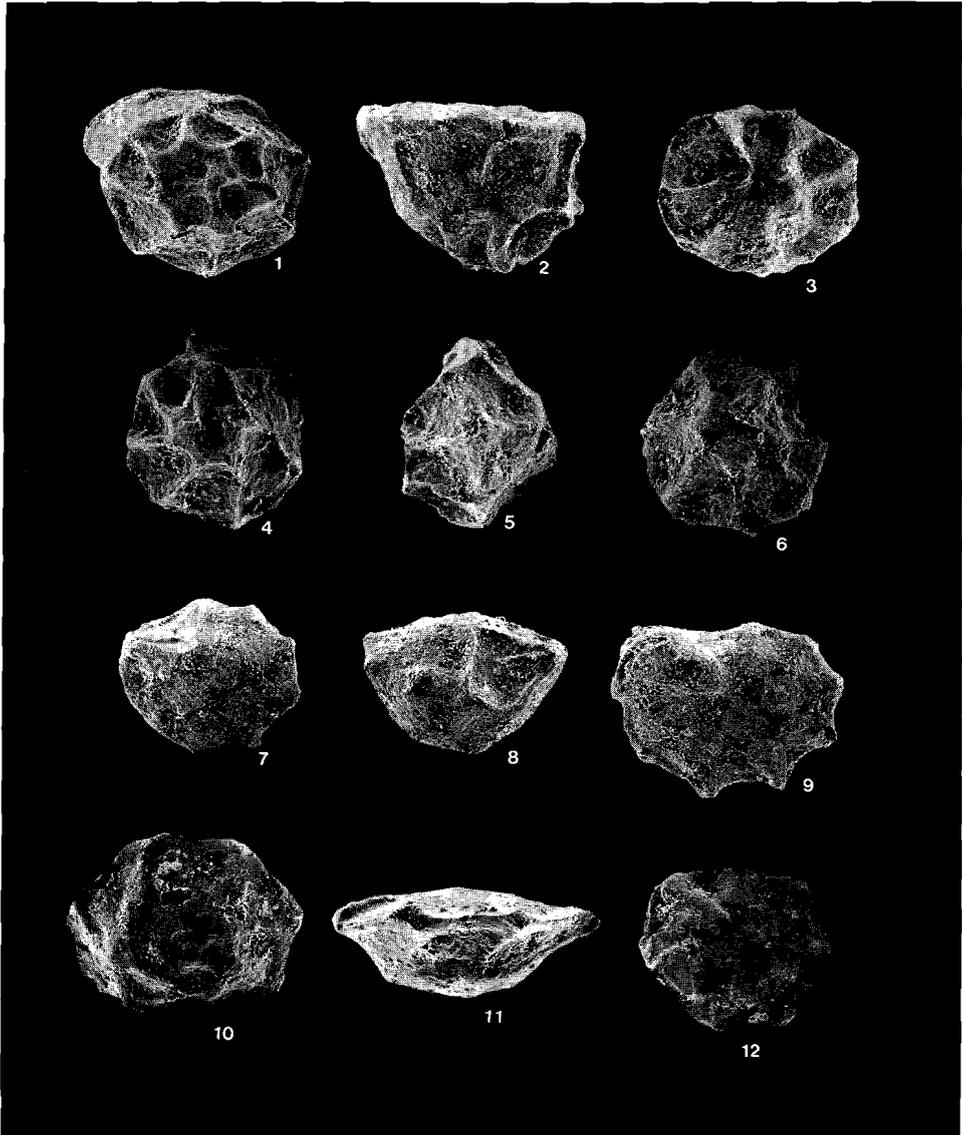


Plate 3

- Figs. 1, 2. *Epistomina regularis* Terquem, Cormorant N-83, cts. 3240–3270' (fig. 1) and cts. 3690–3720' (fig. 2), *Epistomina regularis* Zone, (Callovian), X100 (fig. 1), X115 (fig. 2).
- Figs. 3, 4. *Epistomina* sp. 2, Tojeira 1 section, sample 6.18, Platynota Zone (Early Kimmeridgian), X120.
- Figs. 5, 6. *Epistomina* sp. 3, Cormorant N-83, cts. 4770–4800', *Epistomina regularis* Zone (Callovian), X100.
- Figs. 7 - 9. *Pseudolamarckina rjasanensis* (Uhlig), Tojeira 1 section, sample 6.11 (figs. 7, 8) and 6.10 (fig. 9), Planula-Platynota Zones (Late Oxfordian-Early Kimmeridgian), X90 (fig. 7), X119 (fig. 8), X95 (fig. 9).
- Fig. 10. *Epistomina stelicostata* Bielecka and Pozaryski, Hibernia K-18, 3850 m, *Epistomina stelicostata* Zone (Tithonian), X65.
- Figs. 11, 12. *Pseudolamarckina* aff. *rjasanensis* (Uhlig), Cormorant N-83, cts. 3150–3180', *Epistomina regularis* Zone (Callovian), X115 (fig. 11), X150 (fig. 12).
- Figs. 13, 14. *Garantella* aff. *ampasindavaensis* Espitalié and Sigal, Cormorant N-83, cts. 6670–6700', *Involutina liassica* Zone (Pliensbachian; Gradstein, 1977, 1978; caved)

Plate 3

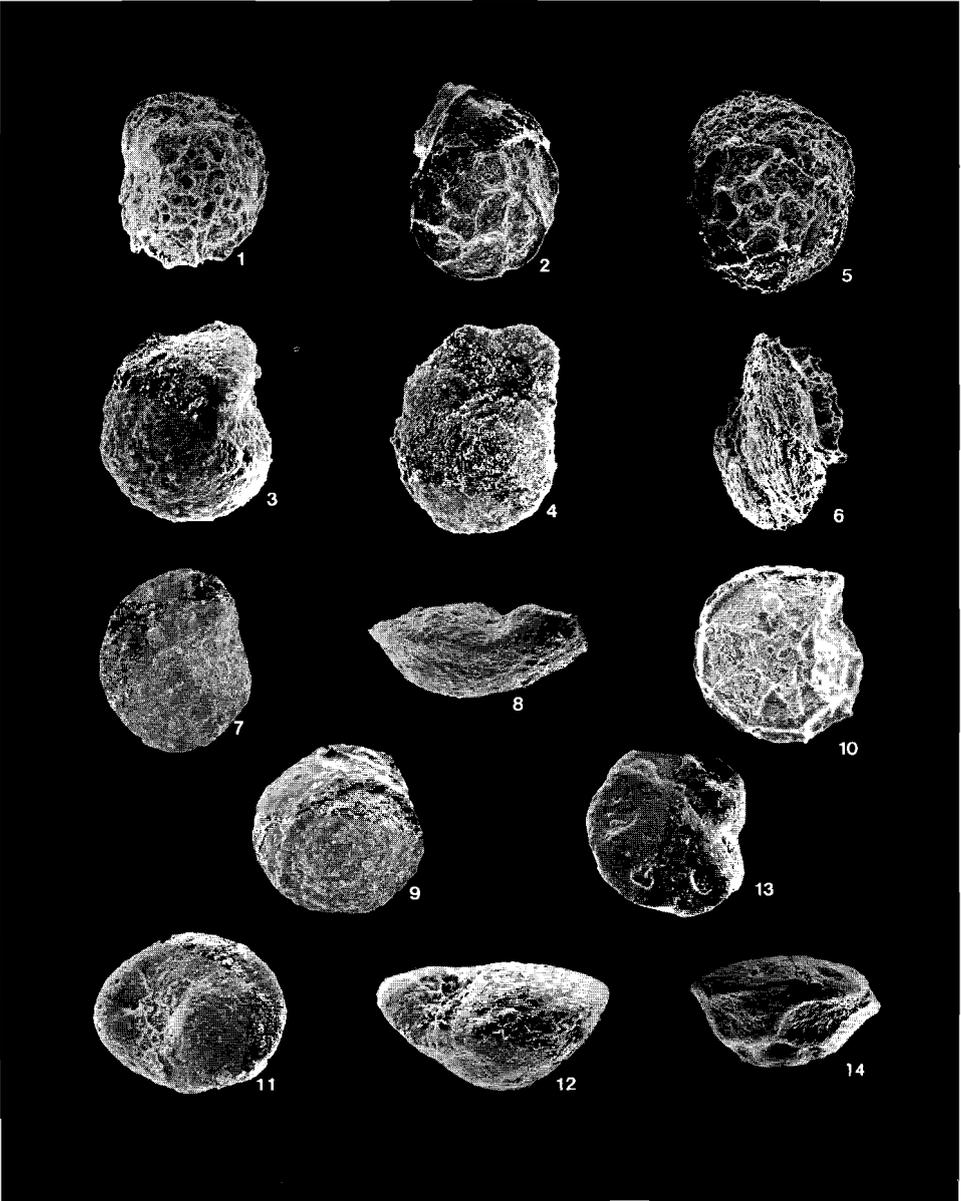


Plate 4

- Fig. 1. *Ammobaculites coprolithiformis* (Schwager), Ben Nevis I-45, cts. 4855–4865', *Epistomina mosquensis* Zone (Oxfordian-Kimmeridgian), X80.
- Fig. 2. *Ammobaculites coprolithiformis* (Schwager), Tojeira 1 section, sample 6.16, Platynota Zone (Early Kimmeridgian), X110.
- Fig. 3. *Reophax sterkii* Haeusler, Tojeira 1 section, sample 6.2, Planula Zone (Late Oxfordian), X70.
- Fig. 4. *Verneulinoides minuta* Said and Barakat, Tojeira 1 section, sample 6.2, Planula Zone (Late Oxfordian), X110.
- Fig. 5. *Trochammina* sp., Tojeira 1 section, sample 6.12, Planula-Platynota Zones (Late Oxfordian-Early Kimmeridgian), X120.
- Fig. 6. *Verneulinoides mauritii* (Terquem), Mareta Beach, sample 3.1, Macrocephalus Zone (Early Callovian), X145.
- Fig. 7. *Dorothia hechti* Dieni and Massari, Mareta Beach, sample 3.7, Macrocephalus Zone (Early Callovian), X145.
- Fig. 8. *Dorothia hechti* Dieni and Massari, Bonniton H-32, cts. 7850–7880', *Epistomina regularis* Zone? (Callovian), X150, triserial initial stage.
- Figs. 9, 10. *Ophthalmidium strumosum* (Guembel), Tojeira 1 section, sample 6.14 (fig. 9) and sample 6.18 (fig. 10), Platynota Zone (Early Kimmeridgian), X100.
- Figs. 11, 12. *Ophthalmidium carinatum* Kuebler and Zwingli, Tojeira 1 section, sample 6.6 (fig. 11) and sample 6.2 (fig. 12), Planula Zone (Late Oxfordian), X120 (fig. 11), X140 (fig. 12).
- Fig. 13. *Ophthalmidium concentricum* Terquem and Berthelin, Mareta Beach, sample 3.6, Macrocephalus Zone (Early Callovian), X140.

Plate 4

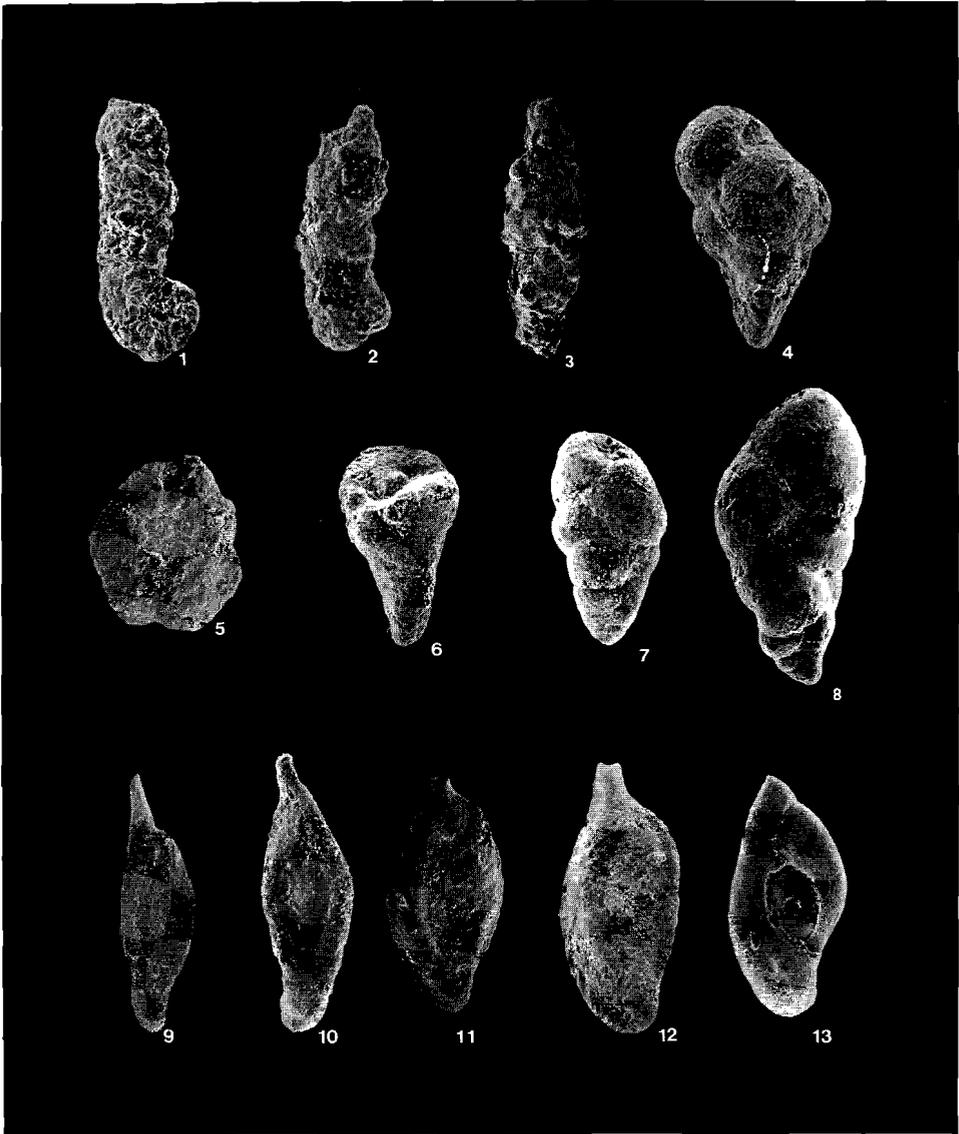


Plate 5

- Fig. 1. *Eoguttulina?* cf. *metensis* (Terquem), Tojeira 1 section, sample 6.5, Planula Zone (Late Oxfordian), X70.
- Fig. 2. *Eoguttulina?* cf. *oolithica* (Terquem), Tojeira 1 section, sample 6.6, Planula zone (Late Oxfordian), X140.
- Fig. 3. *Eoguttulina?* cf. *oolithica* (Terquem), Bonniton H-32, cts. 8050–8080', *Epistomina regularis* Zone? (Callovian), X110.
- Fig. 4. *Eoguttulina?* cf. *bilocularis* (Terquem), Mareta Beach, sample 3.7, Macrocephalus Zone (Early Callovian), X210.
- Fig. 5. *Nodosaria hortensis* (Terquem), Tojeira 1 section, sample 6.5, Planula Zone (Late Oxfordian), X105.
- Fig. 6. *Dentalina* sp., Tojeira 1 section, sample 6.10, Planula-Platynota Zones (Late Oxfordian-Early Kimmeridgian), X85.
- Figs. 7, 8. *Lenticulina muensteri* (Roemer), Tojeira 1 section, sample 6.2, Planula Zone (Late Oxfordian), X150 (fig. 7); sample 6.13, Platynota Zone (Early Kimmeridgian), X95 (fig. 8).
- Fig. 9, 10. *Lenticulina quenstedti* (Guembel), Brenha section, sample 30.18, Bajocian, X45 (fig. 9); sample 30.15, Aalenian, X65 (fig. 10).
- Fig. 11. *Lenticulina quenstedti* (Guembel), Cormorant N-83, cts. 3240–3270', *Epistomina regularis* Zone (Callovian), X110.

Plate 5



Plate 6

- Fig. 1. *Lenticulina d'orbigny* (Roemer), Cormorant N-83, cts. 5860–5890', *Lenticulina d'orbigny* Zone (Toarcian-Aalenian; Gradstein, 1977, 1978), X90.
- Fig. 2. *Lenticulina d'orbigny* (Roemer), Brenha section, sample 30.12, Toarcian, X130.
- Fig. 3. *Lenticulina algarviensis* Ruget, Mareta Beach, sample 3.1, Macrocephalus Zone (Early Callovian), X155.
- Fig. 4. *Lenticulina tricarinnella* (Reuss), Mareta Beach, sample 31, Coronatum Zone (Middle Callovian), X125.
- Figs. 5, 6. *Discorbis parapsis* (Schwager), Mareta Beach, sample 24 (fig. 5) and sample 3.6 (fig. 6), Macrocephalus Zone (Early Callovian), X190 (fig. 5), X140 (fig. 6).
- Fig. 7. *Paalzowella feifeli* (Paalzow), Mareta Beach, sample 3.2, Macrocephalus Zone (Early Callovian), X190.
- Fig. 8. *Paalzowella feifeli* (Paalzow), Tojeira 1 section, sample 6.5, Planula Zone (Late Oxfordian), X110.
- Fig. 9. *Spirillina tenuissima* Guembel, Tojeira 1 section, sample 6.20, Platynota Zone (Early Kimmeridgian), X210.
- Fig. 10. *Spirillina infima* (Strickland), Tojeira 1 section, sample 6.17, Platynota Zone (Early Kimmeridgian), X100.
- Fig. 11. *Spirillina elongata* Bielecka and Pozaryski, Tojeira 1 section, sample 6.5, Planula Zone (Late Oxfordian).

Plate 6

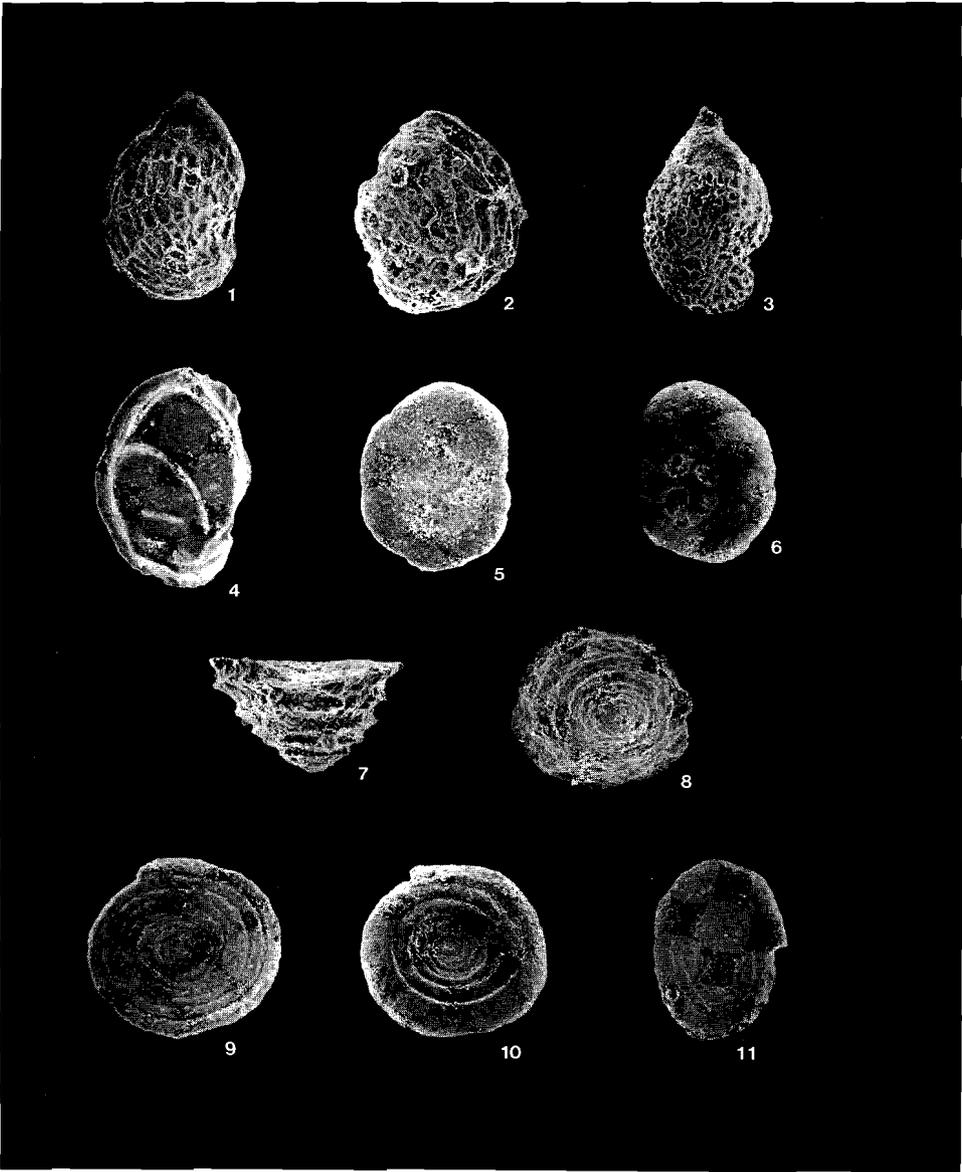


Plate 7

Globuligerina oxfordiana (Grigelis)

- Figs. 1–5. Villers sur Mer, Normandy, France, Mariae Zone (Early Oxfordian), X240 (fig. 1), X220 (figs. 2, 3), X275 (fig. 4), X330 (fig. 5).
- Figs. 6–12. Birmenstorfer Schichten, Eisengraben Section, Aargau, Switzerland, Transversarium Zone (Middle Oxfordian), X420 (figs. 6, 7), X385 (figs. 8, 9), X2475 (fig. 10), X715 (fig. 11), X365 (fig. 12). Figs. 10, 11 are close-ups of specimen of figs. 8, 9 (note coccoliths and spines).

Plate 7

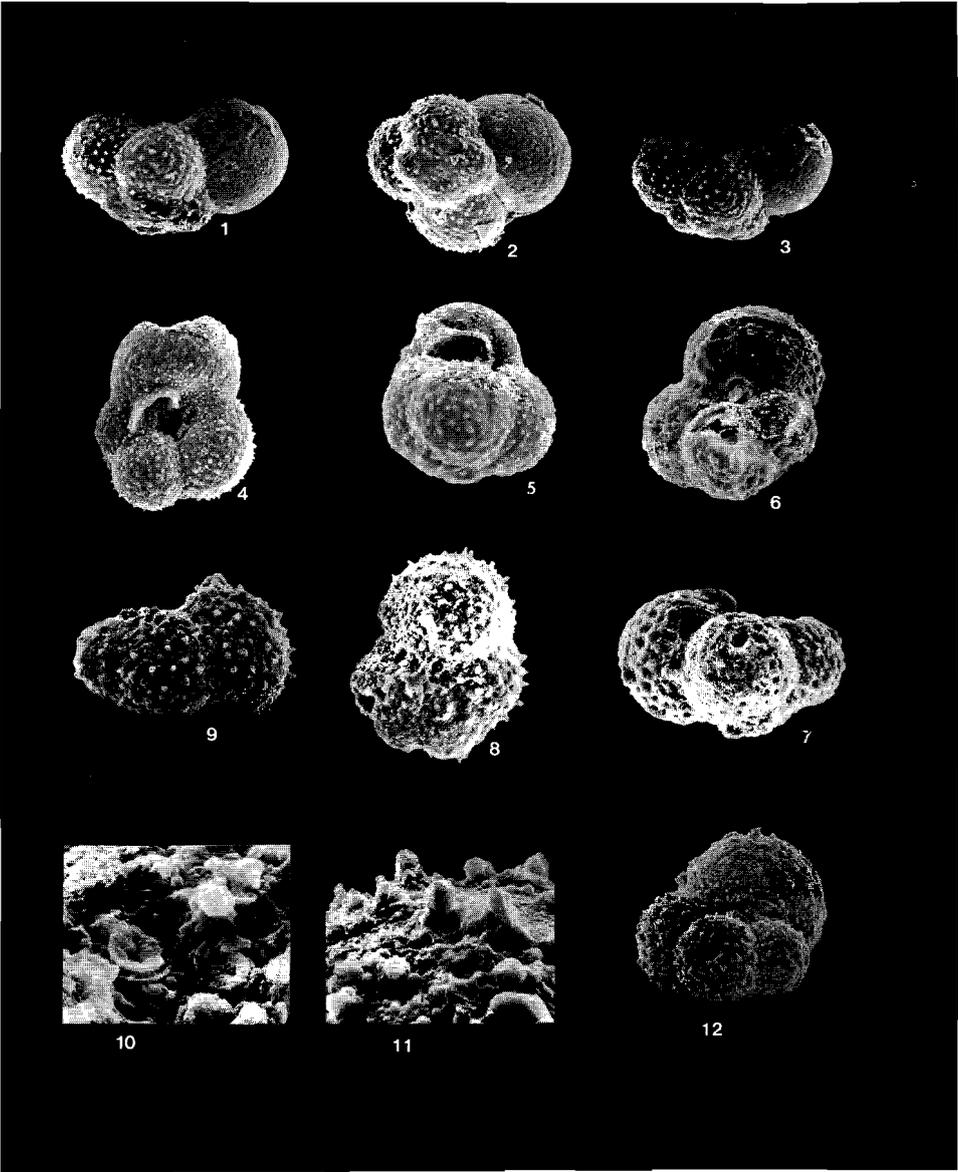


Plate 8

Globuligerina oxfordiana (Grigelis)

- Figs. 1–3. Birmenstorfer Schichten, Eisengraben Section, Aargau, Switzerland, Transversarium Zone (Middle Oxfordian), X660 (fig. 1), X750 (figs. 2, 3).
- Figs. 4–12. Tojeira 1 section, sample 6.24, X170 (fig. 4); sample 6.11, X145 (fig. 5); sample 6.21, X140 (fig. 6); sample 6.20, X170 (fig. 7); sample 6.14, X170 (figs. 8, 9); sample 6.11, X150 (figs. 10, 11); sample 6.28, X190 (fig. 12). All samples from the Platynota Zone (Early Kimmeridgian).

Plate 8

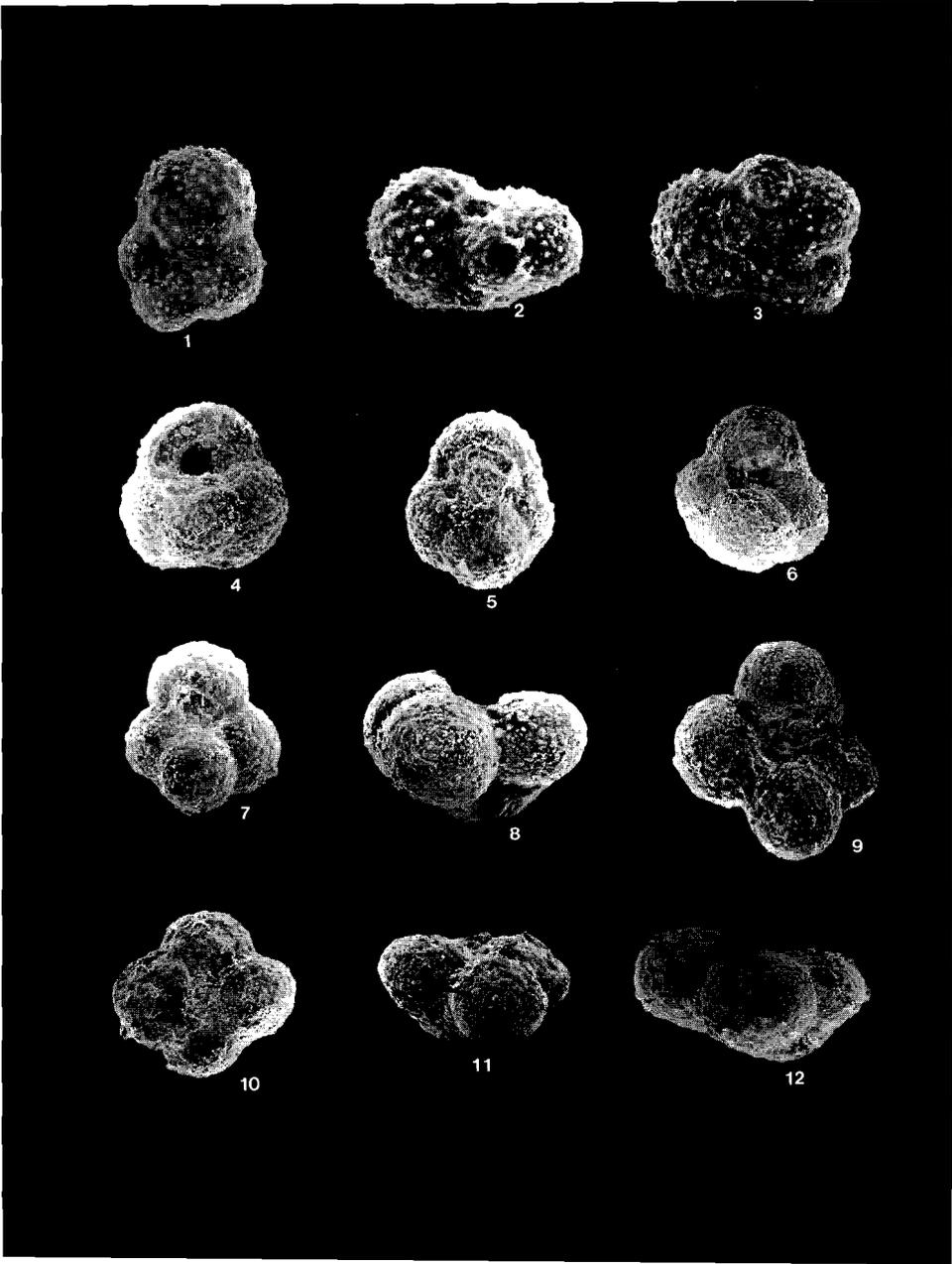


Plate 9

Globuligerina oxfordiana (Grigelis)

Figs. 1–5. Eider M-75, cts. 7560–7590', X160 (figs. 1, 2); cts. 7960–7990', X220 (fig. 3); cts. 7760–7790', X235 (figs. 4, 5). All cuttings from the *Garantella* spp. Zone (Bajocian-Bathonian).

Globuligerina bathoniana (Pazdrowa)

Figs. 6–13. Topotypes, Ogrodzieniec, Poland, Morrissi Zone (Middle Bathonian), X385 (figs. 6–8), X275 (figs. 9, 10), X530 (figs. 11–13).

Plate 9

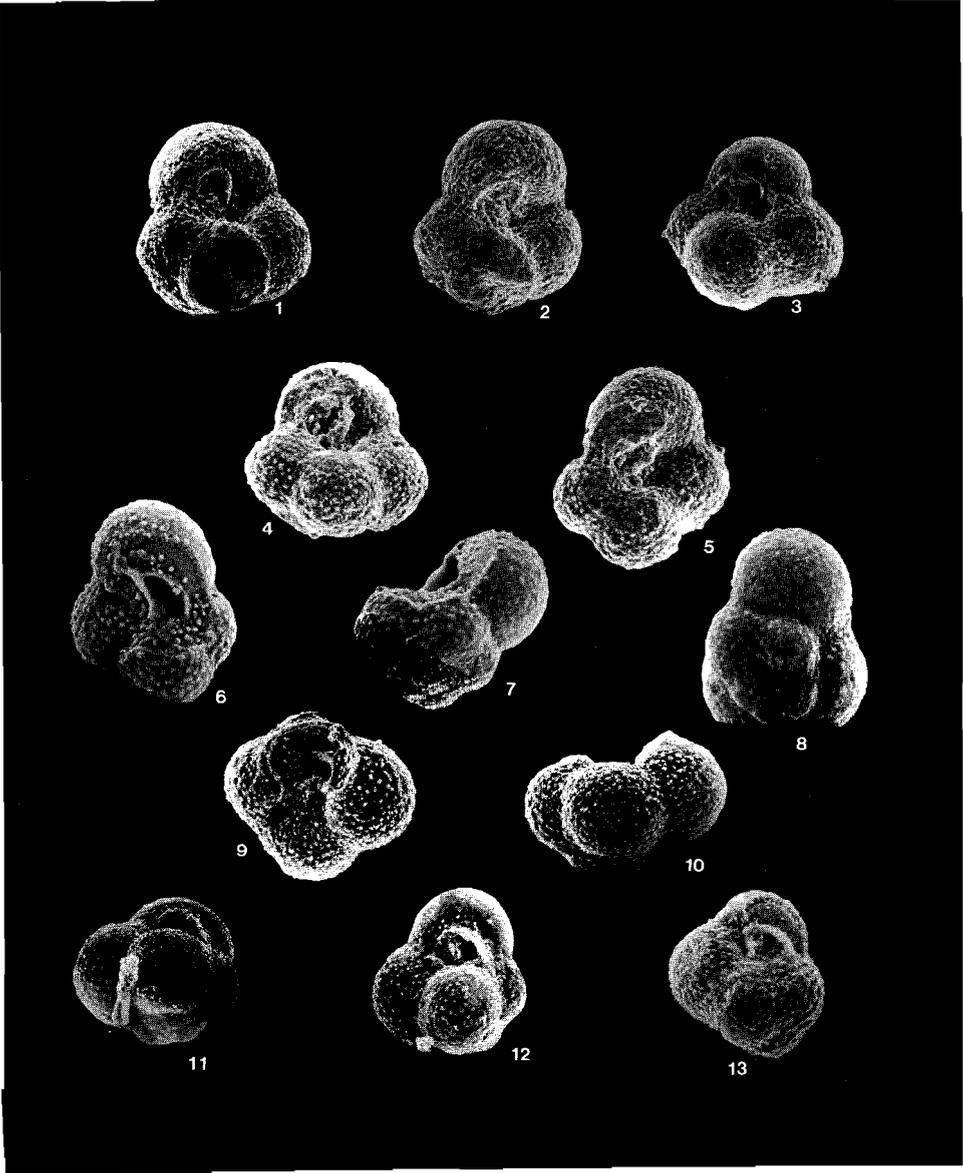


Plate 10

Globuligerina bathoniana (Pazdrowa)

- Figs. 1, 2. Brenha section, sample 30.24, Early Bathonian, X240.
- Figs. 3–8. Mareta Beach, sample 36, X165 (figs. 3, 4); sample 32, X205 (figs. 5, 6); sample 41, X165 (figs. 7, 8). Samples 32 and 36: Coronatum Zone (Middle Callovian). Sample 41: Athleta Zone (Late Callovian).
- Figs. 9–12. Tojeira 1 section, sample 6.10, X170 (fig. 9), X120 (figs. 10, 11); sample 6.21, X115 (fig. 12). Both samples from the Platynota Zone (Early Kimmeridgian).

Plate 10

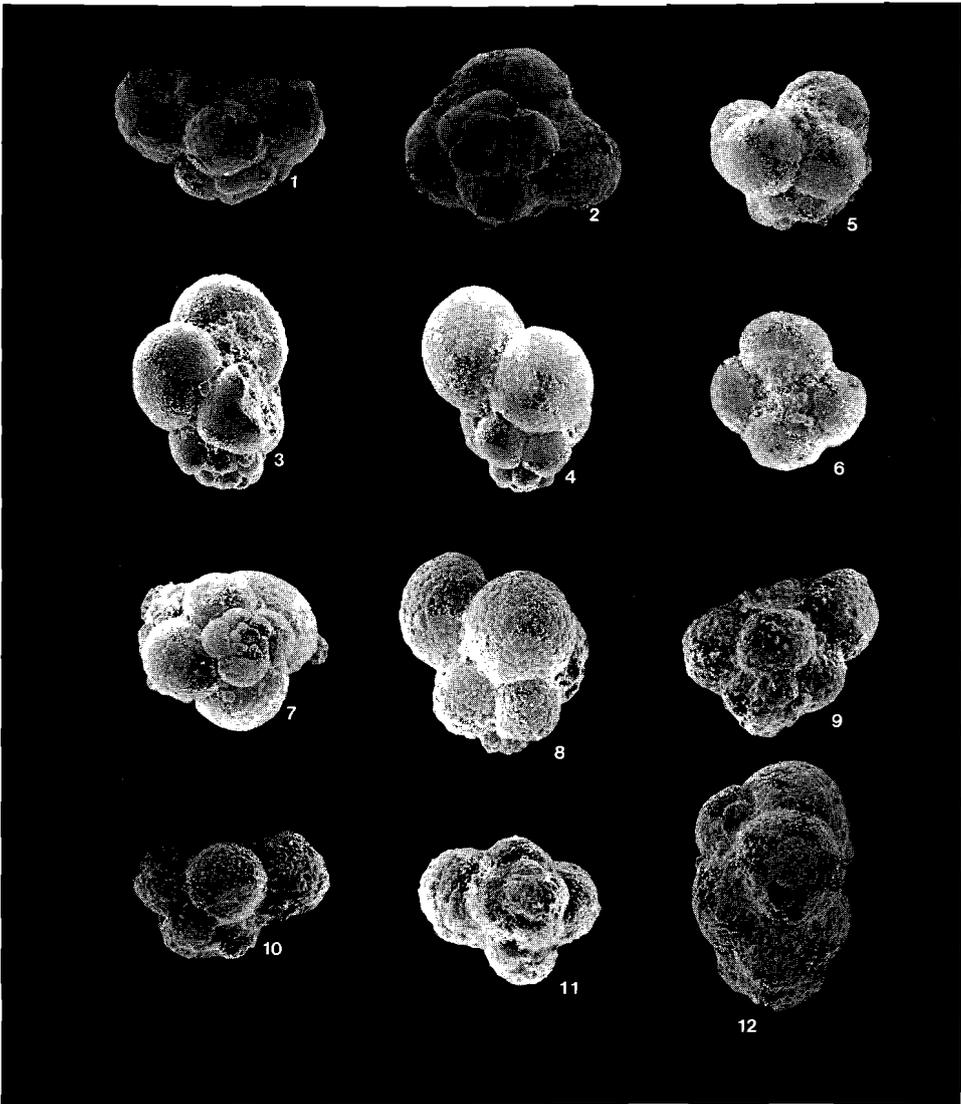


Plate 11

Globuligerina bathoniana (Pazdrowa) figs. 1–10

- Figs. 1–6. Eider M-75, cts. 8260–8290', X230 (figs. 1, 2); cts. 8060–8090', X230 (figs. 3, 4); X245 (figs. 5, 6). All cuttings from the *Garantella* spp. Zone (Bajocian-Bathonian).
- Fig. 7. Murre G-67, cts. 5460–5490', *Reinholdella* spp. Zone (Late Bathonian), X195.
- Figs. 8, 9. Eider M-75, cts. 8260–8290', *Garantella* spp. Zone (Bajocian-Bathonian), X245.
- Fig. 10. Cormorant N-83, cts. 4320–4350', *Reinholdella* spp. Zone (Late Bathonian), X205.
- Figs. 11, 12. *Globuligerina balakbatovae*? (Morozova), Tojeira 1 section, sample 6.11 (fig. 11) and sample 6.13 (fig. 12); X170, Platynota Zone (Early Kimmeridgian).

Plate 11

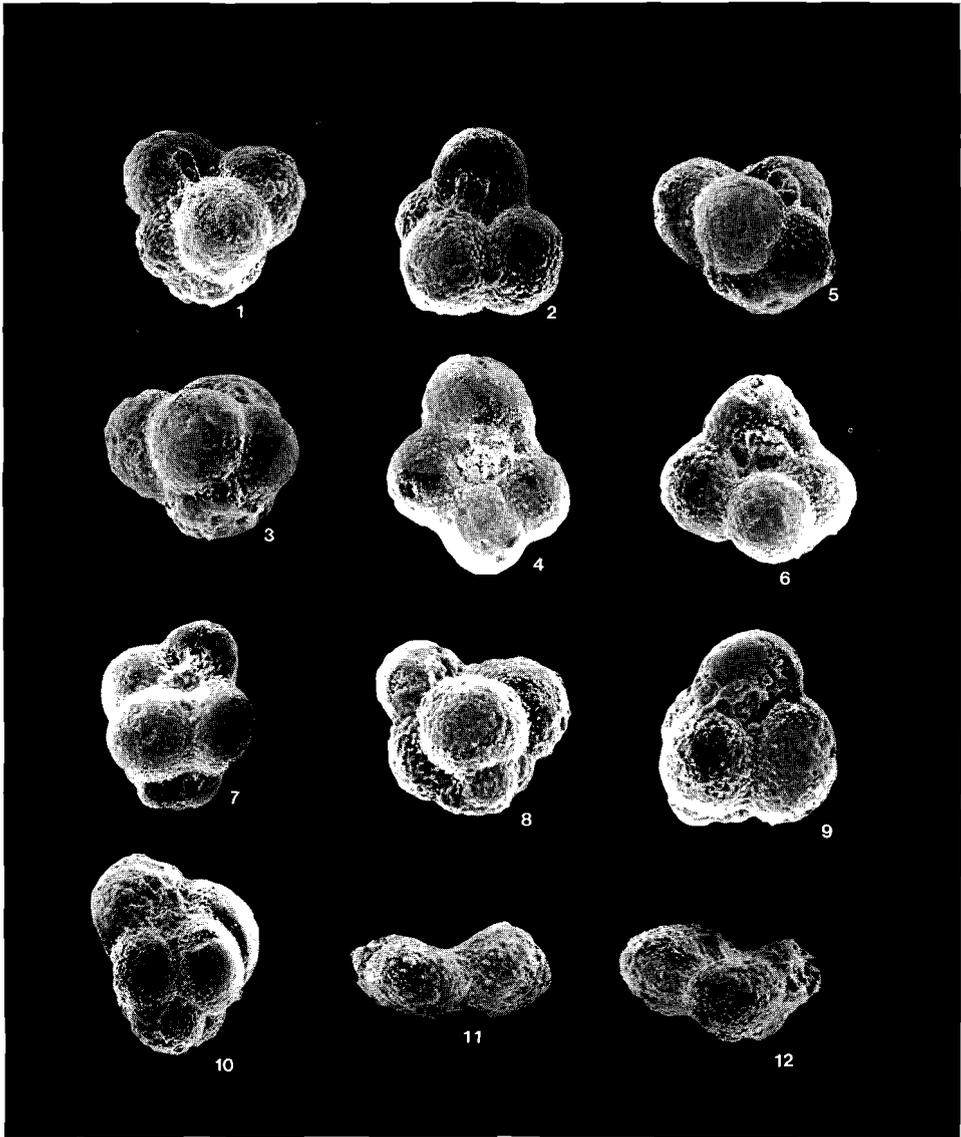


Plate 12

Globuligerina balakhmatovae (Morozova) figs. 1–8

- Figs. 1, 2, 8. Murre G-67, swc. 5230', *Reinholdella* spp. Zone (Late Bathonian), X200. Fig. 8: almost keeled specimen, with imperforate equatorial band.
- Figs. 3–7. Eider M-75, cts. 8260–8290', *Garantella* spp. Zone (Bajocian-Bathonian), X200.
- Figs. 9–12. *Globuligerina bathoniana* (Pazdrowa), Eider M-75, cts. 8260–8290', *Garantella* Zone (Bajocian-Bathonian), X240 (figs. 9, 10), X200 (figs. 11, 12), note bulla-like structure on both specimens.

Plate 12

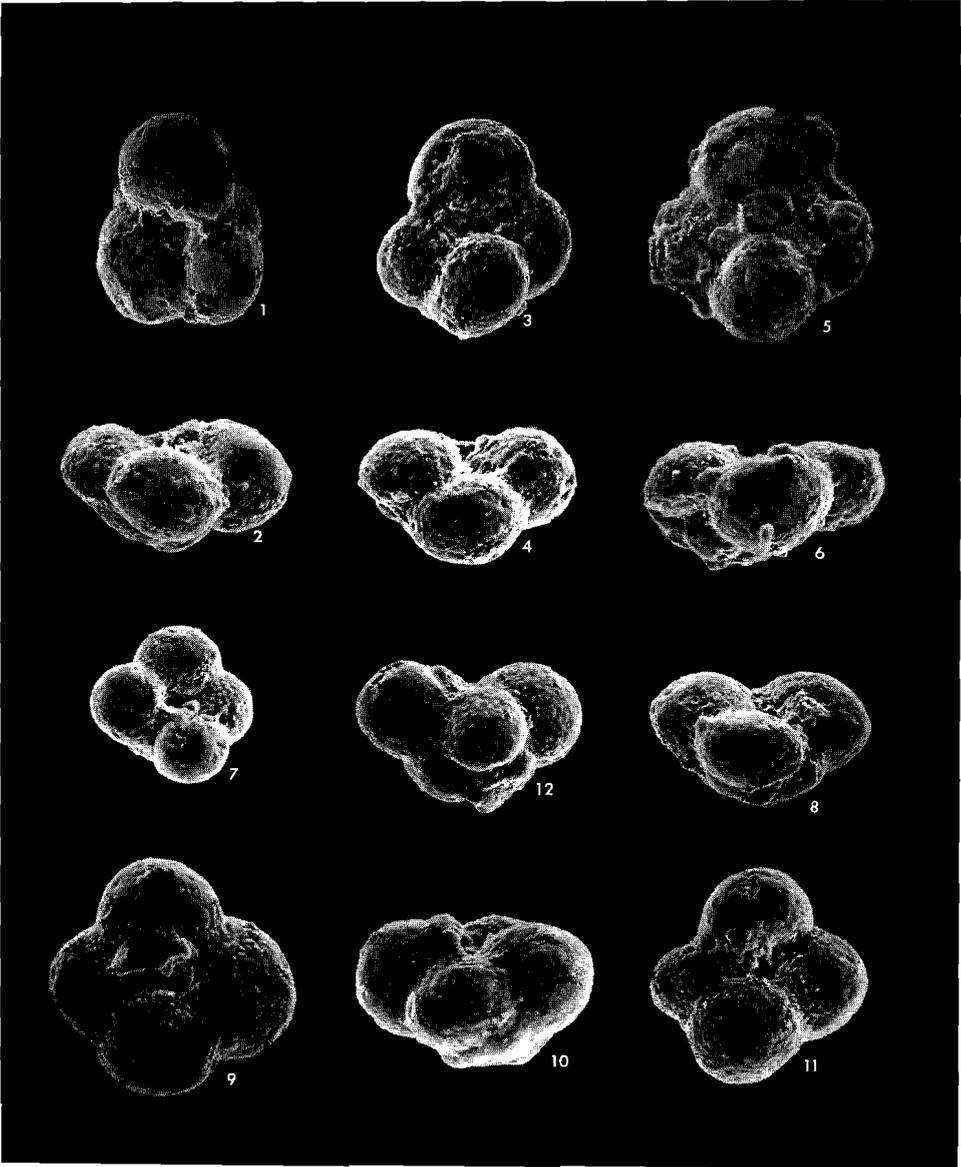


Plate 13

Globuligerina bathoniana (Pazdrowa)

Figs. 1–12. Eider M-75, cts. 8260–8290', *Garantella* spp. Zone (Bajocian-Bathonian), X200. Figs. 1–4: note bulla-like structures.

Globigerinita bradyi (Wiesner)

Figs. 13–16. Plankton tow inner shelf offshore Nova Scotia, Recent, X220. Compare with *Globuligerina bathoniana* of figs. 8–12.

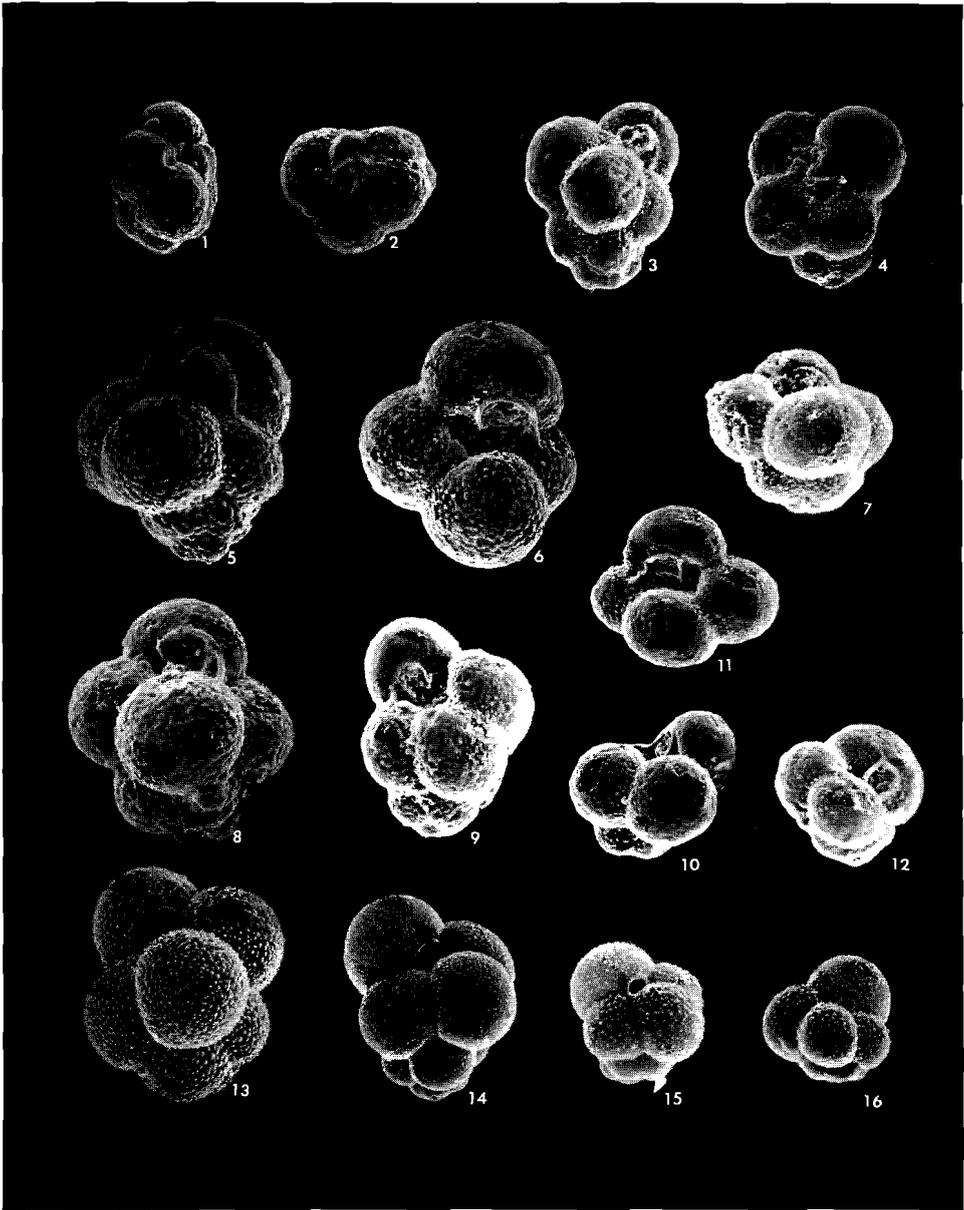
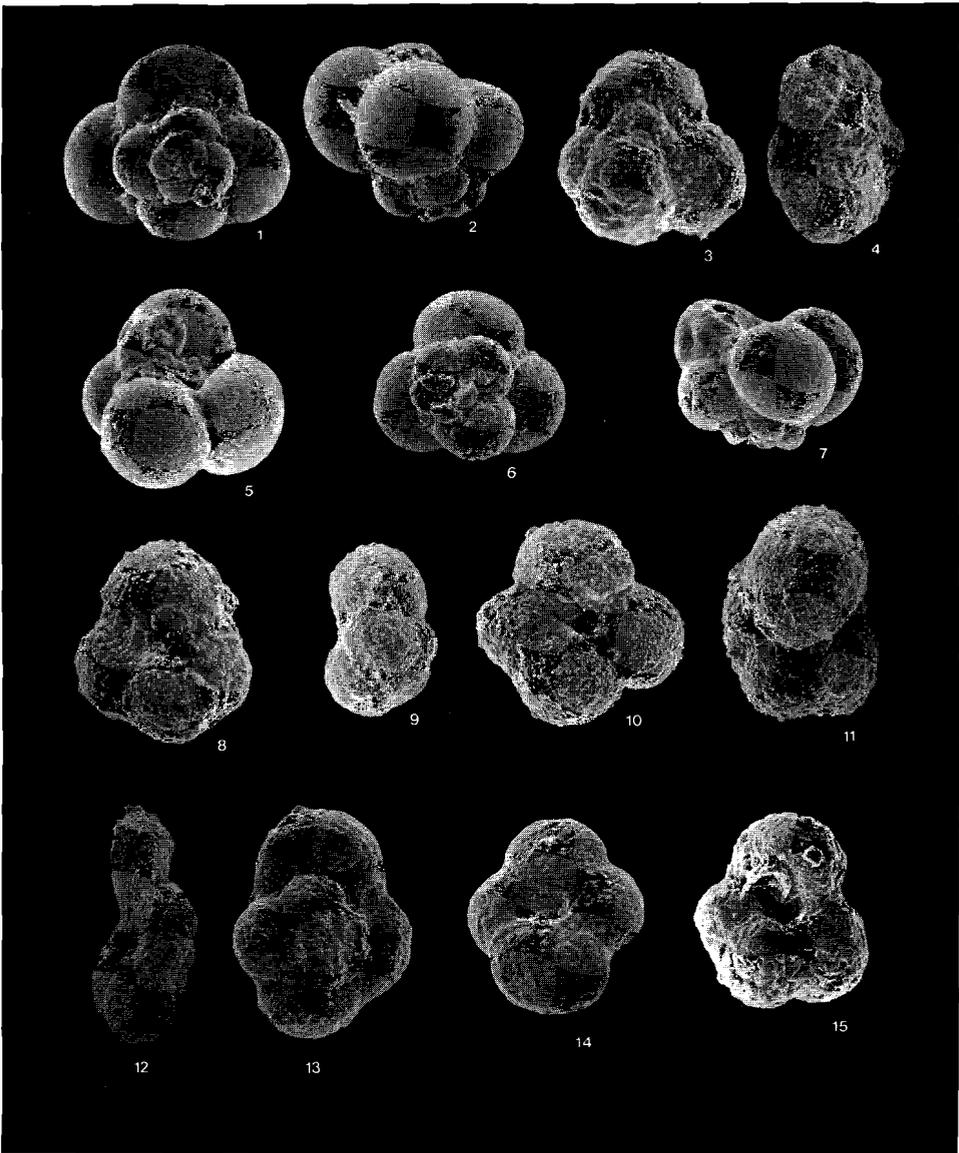


Plate 14

- Figs. 1, 2, 5–7. *Globuligerina bathoniana* (Pazdrowa), Marena Beach, sample 31, Coronatum Zone (Middle Callovian), X200 (figs. 1, 2), X240 (figs. 5–7).
- Figs. 3, 4, 8–14. *Globuligerina oxfordiana* (Grigelis), sample 6.17, X175 (figs. 3, 4); sample 6.29, X150 (figs. 8, 9); sample 6.17, X150 (figs. 10–13); sample 6.11, X155 (fig. 14). All samples from the Platynota Zone (Early Kimmeridgian).
- Fig. 15. *Globuligerina oxfordiana* (Grigelis), Tojeira 2 section, sample 11.6, Planula-Platynota Zone (Late Oxfordian-Early Kimmeridgian), X300.

Plate 14



- Bull. 34. B. STAM – Quantitative analysis of Middle and Late Jurassic foraminifera from Portugal and its implications for the Grand Banks of Newfoundland. 168 p., 14 pl., 50 figs. (1986) *f* 54,–
- Bull. 35. G.J. VANDER ZWAAN, F.J. JORISSEN, P.J.J.M. VERHALLEN and C.H. VON DANIELS (ed.) – Atlantic-European Oligocene to Recent *Uvigerina*. 237 p., 69 pl., 25 figs. (1986) *f* 66,–

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- Bull. 17. W. J. ZACHARIASSE, W. R. RIEDEL, A. SANFILIPPO, R. R. SCHMIDT, M. J. BROLSMA, H. J. SCHRADER, R. GERSONDE, M. M. DROOGER and J. A. BROEKMAN – Micropaleontological counting methods and techniques – an exercise on an eight metres section of the Lower Pliocene of Capo Rossello, Sicily. 265 p., 23 pl., 95 figs. (1978) f 59, –
- Bull. 18. M. J. BROLSMA – Quantitative foraminiferal analysis and environmental interpretation of the Pliocene and topmost Miocene on the south coast of Sicily. 159 p., 8 pl., 50 figs. (1978) f 49, –
- Bull. 19. E. J. VAN VESSEM – Study of Lepidocyclinidae from South-East Asia, particularly from Java and Borneo. 163 p., 10 pl., 84 figs. (1978) f 53, –
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- Bull. 24. A. A. H. WONDERS – Planktonic foraminifera of the Middle and Late Cretaceous of the Western Mediterranean area. 158 p., 10 pl., 44 figs. (1980) f 52, –
- Bull. 25. G. J. VAN DER ZWAAN – Paleocology of Late Miocene Mediterranean foraminifera. 202 p., 15 pl., 65 figs. (1982) f 57, –
- Bull. 26. M. M. DROOGER – Quantitative range chart analyses. 227 p., 3 pl., 32 figs. (1982) f 59, –
- Bull. 27. W. J. J. FERMONT – Discocyclinidae from Ein Avedat (Israel). 173 p., 11 pl., 58 figs. (1982) f 51, –
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- Bull. 31. H. A. JONKERS – Pliocene benthonic foraminifera from homogeneous and laminated marls on Crete. 179 p., 12 pl., 46 figs. (1984) f 56, –
- Bull. 32. S. THEODORIDIS – Calcareous nannofossil biozonation of the Miocene and revision of the Helicoliths and Discoasters. 272 p., 37 pl., 67 figs. (1984) f 68, –
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