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Micropaleontology of the
Kimmeridgian to Barremian deposits
of Portugal and the Grand Banks
of Newfoundland

by

Winton Gledhill Wightman

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
September, 1990

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ABSTRACT

Analyses of foraminifera and ostracoda are made from Kimmeridgian-Barremian outcrops in the Lusitanian Basin of Portugal, and wells in the Grand Banks of Newfoundland. In the Praia Azul section, a slightly brackish to marine assemblage of ostracoda including *Cytherella*, *Cytherelloidea* and *Schuleridea* characterize outer lagoon or bay paleoenvironments; associated foraminifera include *Everticyclammina*, *Mesoendothyra*, *Freixialina* and *Haplophragmoides*. The mesohaline to polyhaline ostracoda *Pararanotacythere*, *Galliaecytheridea* and *Schuleridea* characterize brackish lagoons with local oyster patch reefs; associated foraminifera include *Choffatella* and *Rectocyclammina*. Landward of the patch reefs, freshwater influence is indicated by the ostracoda *Fabanella*, *Darwinula* and *Cypridea*; *Choffatella* is the associated foraminifera. The foraminifera *Eoguttulina* is ubiquitous to these environments. Classification of the foraminifera on test morphology permits recognition of sub-environments, based on habitat. In the Cabo Espichel section, *Choffatella* and smaller agglutinated foraminifera are associated with rapid basin subsidence in the early Tithonian, whereas *Anchispirocyclina* is associated with lower rates of basin subsidence and shallow carbonate sedimentation during the latest Jurassic and early Berriasian. Ostracoda indicate fluctuating marine-brackish salinity. Rapid ostracod speciation in the early Berriasian, combined with opportunistic associations of *Anchispirocyclina* and *Discorbis*, may be linked to environmental instability during the Berriasian regression. At Ericeira, smaller agglutinated foraminifera are associated with Berriasian-Hauterivian marginal to non-marine sedimentation. *Ammobaculites* assemblages indicate river estuary paleoenvironments, whereas *Ammobaculites-Trochammina* and trochamminid assemblages indicate marsh paleoenvironments. Two biozonations are proposed for the Lusitanian Basin.

Examination of cored intervals from Grand Banks wells revealed similarity in the microfossil assemblages from marginal marine environments. Presence of a form of *Ammobaculites subcretaceus* displaying a novel mode of growth may be a biostratigraphic marker for the top of the Berriasian in Portugal and the Grand Banks. A stratigraphic re-evaluation of the Grand Banks wells is made, and suggests the Jurassic-Cretaceous boundary occurs at greater depth than previously thought. A new foraminiferal biozonation is proposed for the Grand Banks. A review of the stratigraphic and subsidence histories of the North Atlantic rift basins indicates most transgressive-regressive events are linked to tectonic, rather than eustatic events.

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CHAPTER 1

INTRODUCTION

1.1: Purpose of investigation

The primary objective of this study is to obtain a better understanding of the paleoecological factors controlling the distribution of Foraminifera and Ostracoda in the Kimmeridgian to Barremian shallow marine deposits of the North Atlantic. These deposits are widely distributed in a number of circum-Atlantic basins, many of which have yielded significant hydrocarbons. However, biostratigraphic correlation between and within these basins is difficult due to the rarity or absence of planktonic fossils and apparent facies dependence of many of the benthic fossils.

The two study areas chosen, the Lusitanian Basin of west Portugal and the Grand Banks of Newfoundland are well suited to this investigation. Paleogeographic reconstructions of the North Atlantic (Pitman and Talwani, 1972; Jansa and Wade, 1985a; Srivastava and Tapscott, 1986) have shown that the Lusitanian Basin and the Grand Banks of Newfoundland were conjugate prior to significant sea floor spreading in the Early Cretaceous (Aptian, Figure 1.1). Hiscott *et al.* (1990a) have demonstrated a comparable tectonic and sedimentologic development for the Mesozoic syn-rift basins of the North Atlantic. Exton and Gradstein (1984) showed a similar sedimentologic and biostratigraphic history for the Early Jurassic, while Stam (1986) showed the foraminiferal assemblages of Portugal and the Grand Banks of Newfoundland to be closely similar in the Middle and Late Jurassic. The outcrop sections in the Lusitanian Basin are well exposed and are composed of a wide variety of facies representative of many different shallow and marginal marine paleoenvironments. The wells selected in the Grand Banks basins contain a number of cored intervals that provide accurate lithologic data and overcome the problem

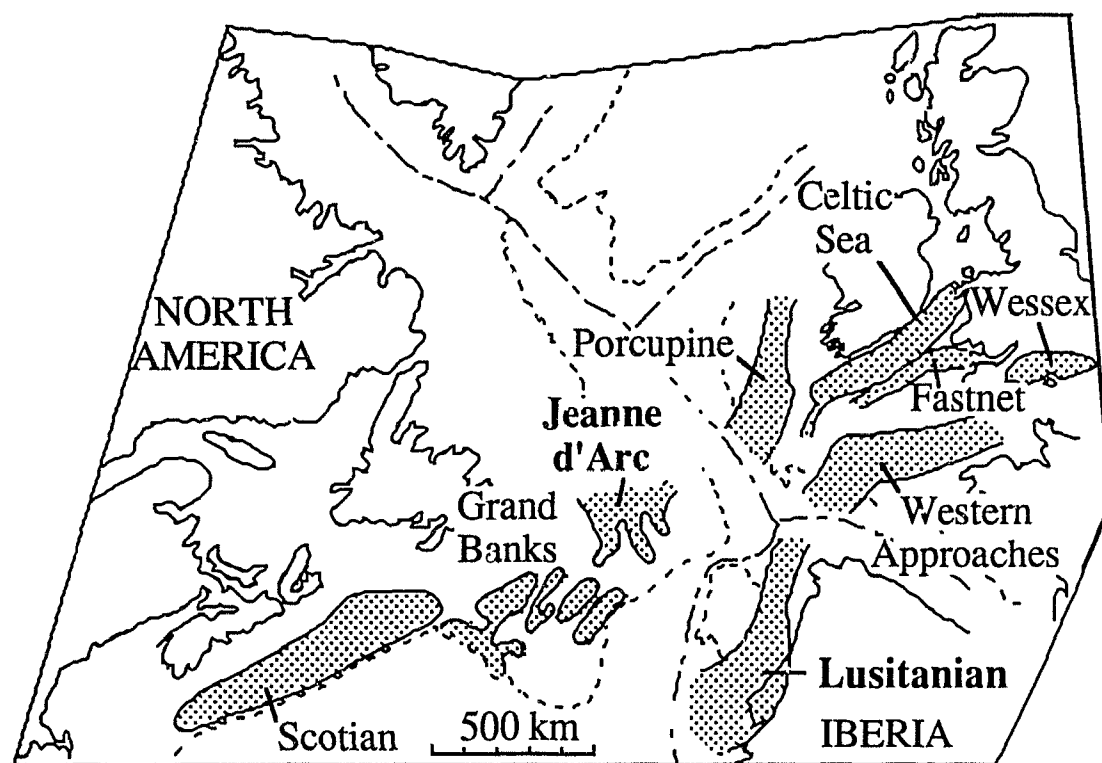


Figure 1.1: Generalized paleogeographic reconstruction of the North Atlantic syn-rift basins prior to significant sea floor spreading in the Aptian (after Hiscott *et al.*, 1990).

of downhole contamination seen in cutting samples. Study of the microfossil paleoecology and the depositional environments in Upper Jurassic and Lower Cretaceous coastal sections of Portugal will have obvious implications to our present and future understanding of the depositional environments buried deeply beneath the conjugate Grand Banks basins and subbasins.

A second objective in this study is to develop a regional biozonation scheme for correlation within the Lusitanian Basin that takes into account the facies (and paleoenvironmental) variations seen within the basin. The existing stratigraphic nomenclature for the Lusitanian Basin is complex and contains a mixture of biostratigraphic and lithostratigraphic terms. Choffat (1901) had difficulty in relating the various facies to European stages of the Late Jurassic. As a result, he introduced the new stage *Lusitanian* for the lower calcareous facies of the Upper Jurassic, and *Neojurassic* for the clastic facies in the upper part. Choffat's (1901) stratigraphic units were defined in the Upper Jurassic marine facies at Torres Vedras. Extension of Choffat's (1901) units from the type areas was based partly on fossil content, and partly on their approximate position within the stratigraphic sequence. A clear separation of biostratigraphy from lithostratigraphy is needed before an acceptable formal stratigraphic reclassification can be attempted. To date, there has been no single publication detailing the Foraminifera and Ostracoda from the Kimmeridgian to Barremian interval that accounts for the regional differences in facies. The results of the biostratigraphic study in Portugal will also have important implications to our understanding of Grand Banks stratigraphy, and the application of Portuguese biostratigraphic findings to the Grand Banks wells is another important objective in this study.

A final objective is to assess the nature of the transgressive and regressive trends seen in the two conjugate basins. Both basins have a number of closely comparable stratigraphic elements that may be related, in part, to the tectonic evolution of the North Atlantic through its Mesozoic rift development (Hiscott *et al.* 1990a), and possibly also to

the inferred global (eustatic) sea level changes of Haq *et al.* (1987). While it is beyond the scope of this thesis to undertake a regional stratigraphic study of all the North Atlantic basins, such as has been done by Hiscott *et al.* (1990a), the biostratigraphic results will have obvious implications to the dating of North Atlantic transgressive and regressive events. The approach used to achieve the final objective of the thesis is somewhat novel. It has been suggested (Lethiers, 1983; van Harten and van Hinte, 1984) that a fundamental relationship exists between the longevity of species of Ostracoda and change of relative sea level, and that Ostracoda speciation through time is related to environmental changes brought about by sea level changes. Van Harten and van Hinte (1984) introduced the term *ostracod chronoecology* to describe these relationships. More recently, it has been suggested that Ostracoda - based *chronoecologic* reconstructions could be used to fine-tune the global eustatic curve (van Harten, 1988). This notion has been tested for the Jurassic of Britain and France with apparent success (van Harten, 1988), and awaits input from other areas. The principal of Ostracoda chronoecology will therefore be applied to Portugal and the Grand Banks to determine the correspondance of any eustatic signal to that predicted in the "Exxon" curve.

1.2: General introduction to the Portuguese sections.

Outcrop sections in Portugal were selected such that they provided as complete a stratigraphic coverage of the Kimmeridgian to Barremian interval as possible. The sections also had to be representative of a wide variety of shallow marine deposits, which would illustrate the relationships between the microfossil assemblages and the depositional environments.

Using these criteria, three well-exposed coastal sections in the Lusitanian Basin of west central Portugal were selected: Cabo Espichel, Ericeira, and Praia Azul (Figure 1.2).

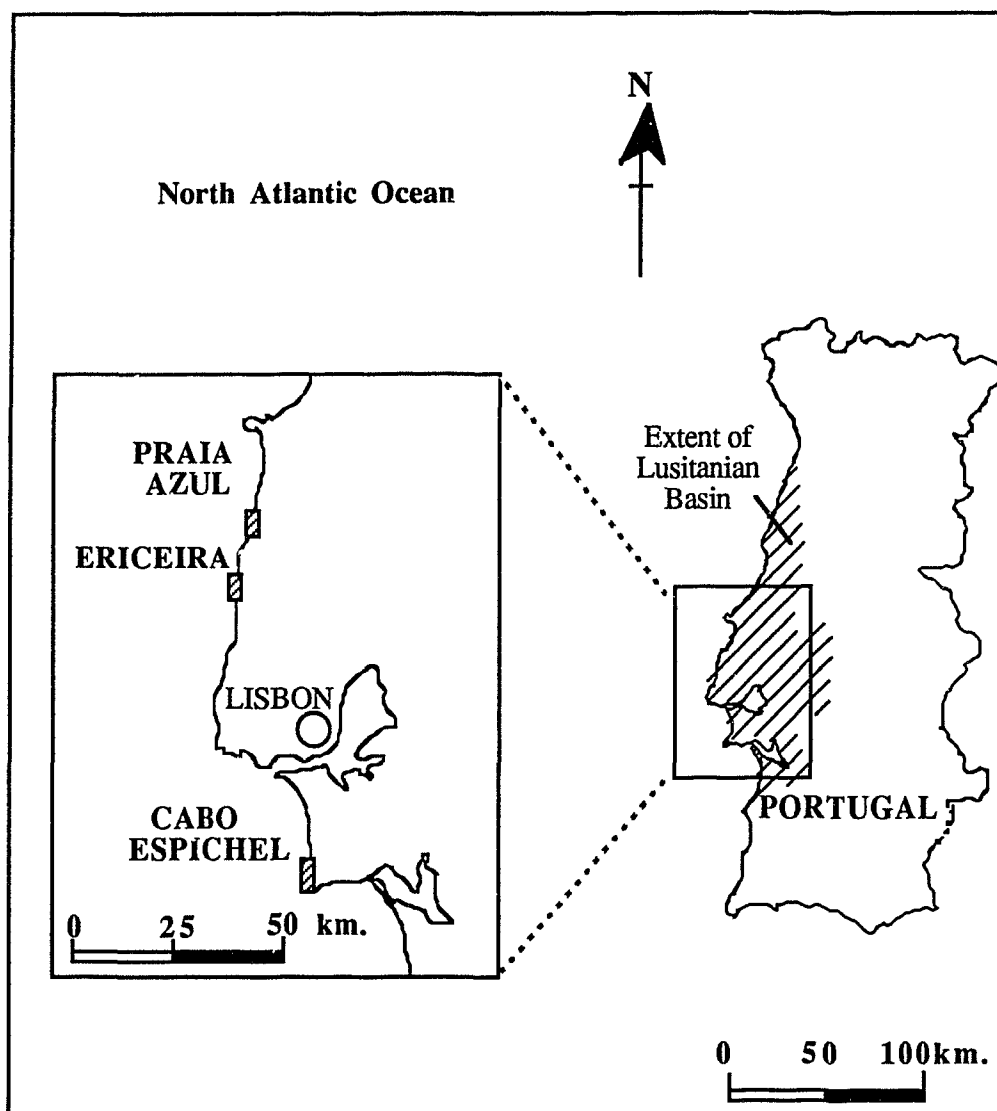


Figure 1.2: Map of Portugal showing the location of the coastal sections examined in this study.

The Lusitanian Basin has an elongate north-south trend, extending from around Porto to just south of Cabo Espichel, and bounded to the east by the Iberian Meseta (Figure 1.3). The three sections are situated in the western part of this basin.

The stratigraphic framework for the Upper Jurassic-Lower Cretaceous successions in the Lusitanian Basin, as mentioned above, is based on local stratigraphic stages defined by Choffat (1901), that are hard to relate to recognised European stages. Despite having received attention for more than a century, Portuguese stratigraphy is fraught with different terminology that often confuses lithostratigraphic and biostratigraphic terms. Portuguese stratigraphic nomenclature is currently being revised by R.C.L. Wilson and collaborators, but at present, no formal stratigraphic scheme exists for Portugal.

The earliest stratigraphic work in Portugal is a monograph on the Cretaceous by Choffat (1885). The Jurassic-Cretaceous boundary in Portugal was studied in more detail by Choffat (1901). Renewed interest in the region was shown by the oil industry (Companhia dos Petroleos de Portugal) in the 1950's that resulted in publications by Mempel (1955), Seifert (1963) and Oertel (1956). Publications of the Servicos Geologicos de Portugal include Ruget-Perrot (1961), Ramalho (1971), Rey (1972) and Mouterde *et al.*, (1972). A more recent work that summarises some of the regional stratigraphic problems is in Wilson (1979).

Although a well known biostratigraphic framework based on ammonites exists for most of the Jurassic (Choffat, 1880; Ruget-Perrot, 1961; Mouterde *et al.*, 1972), ammonites are rare or absent in the Upper Jurassic and Lower Cretaceous sequences. Thus, attempts have been made to improve the biostratigraphic framework using calcareous algae (Ramalho, 1971), echinoderms (Rey, 1972), and dinoflagellates (Leereveld *et al.*, 1989; Berthou and Leereveld, 1989). Reconnaissance fieldwork in 1986 by R.N. Hiscott, F.M. Gradstein, and the author confirmed the suitability of the three sections chosen for this study.

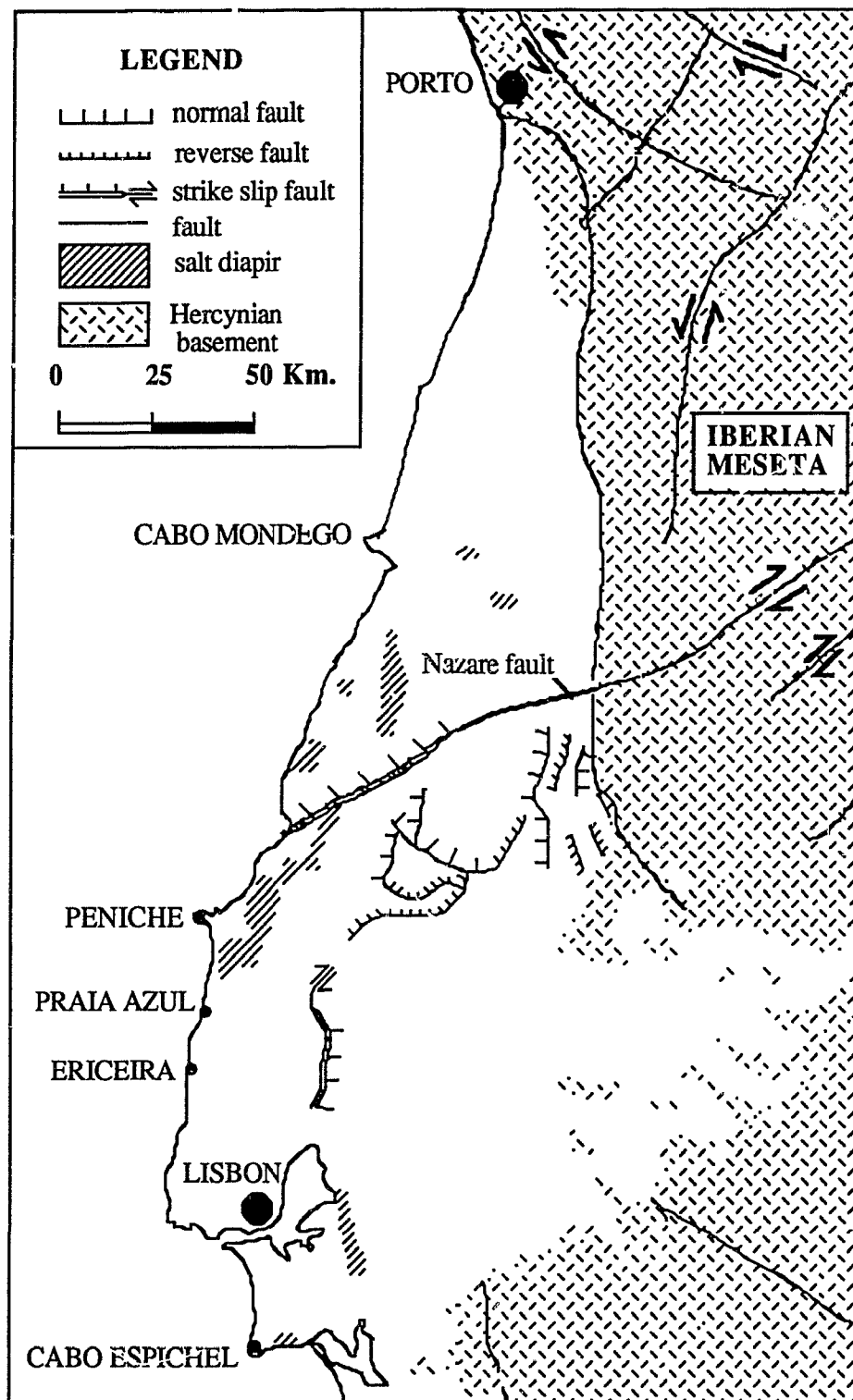


Figure 1.3: Structural sketch map of the Lusitanian Basin outlining major faults (based on Ribeiro et al., 1972).

1.3: Paleogeography of the Lusitanian Basin from the Late Jurassic to the Early Cretaceous.

The Lusitanian Basin lies to the west of the Iberian Meseta (Figure 1.3) and is underlain by Hercynian (Paleozoic) basement. A generalized stratigraphic scheme (Figure 1.4), published in Hiscott *et al.* (1990a), is based on sections around Ericeira and Cascais. A more detailed regional stratigraphic scheme is not available at this time.

Late Hercynian deformation resulted in the development of NE and NNE trending strike-slip faults (Ribeiro *et al.*, 1979), which were to have a significant influence on the Mesozoic and later development of the Lusitanian Basin, its sub-basins, halokinesis, and sedimentary facies distributions (Wilson *et al.*, 1990). Normal movements along these faults (a notable one being the Nazare fault) in the Late Triassic-Early Jurassic led to a general zone of subsidence in the NNE, and deposition of continental to shallow marine sandstones, shales, evaporites and dolomites in the Hettangian through Sinemurian (Wilson and Exton, 1979). Normal marine sedimentation of alternating shales and limestones persisted until the Pliensbachian. During the Early Toarcian, basinal shales were deposited, whereas shelf carbonates became increasingly prevalent through the Aalenian and into the Bathonian, indicating a general shallowing.

Block faulting in the Callovian, related to reactivation of the Hercynian basement faults, together with halokinesis, changed the configuration of the basin and led to the development of sub-basins to the north and south of the Nazare fault. This greatly influenced the pattern of Callovian marine sedimentation. Middle Callovian halokinesis, and marine regression is evidenced by an absence of Lower Oxfordian sediments in the northern basin, and the development of sandstones and oolitic and reefal limestones in the basins to the south (Wilson and Exton, 1979).

Widespread brackish and marginal marine sedimentation in the northern basin during the Late Oxfordian was followed by an influx of fluvial clastics at the base of the

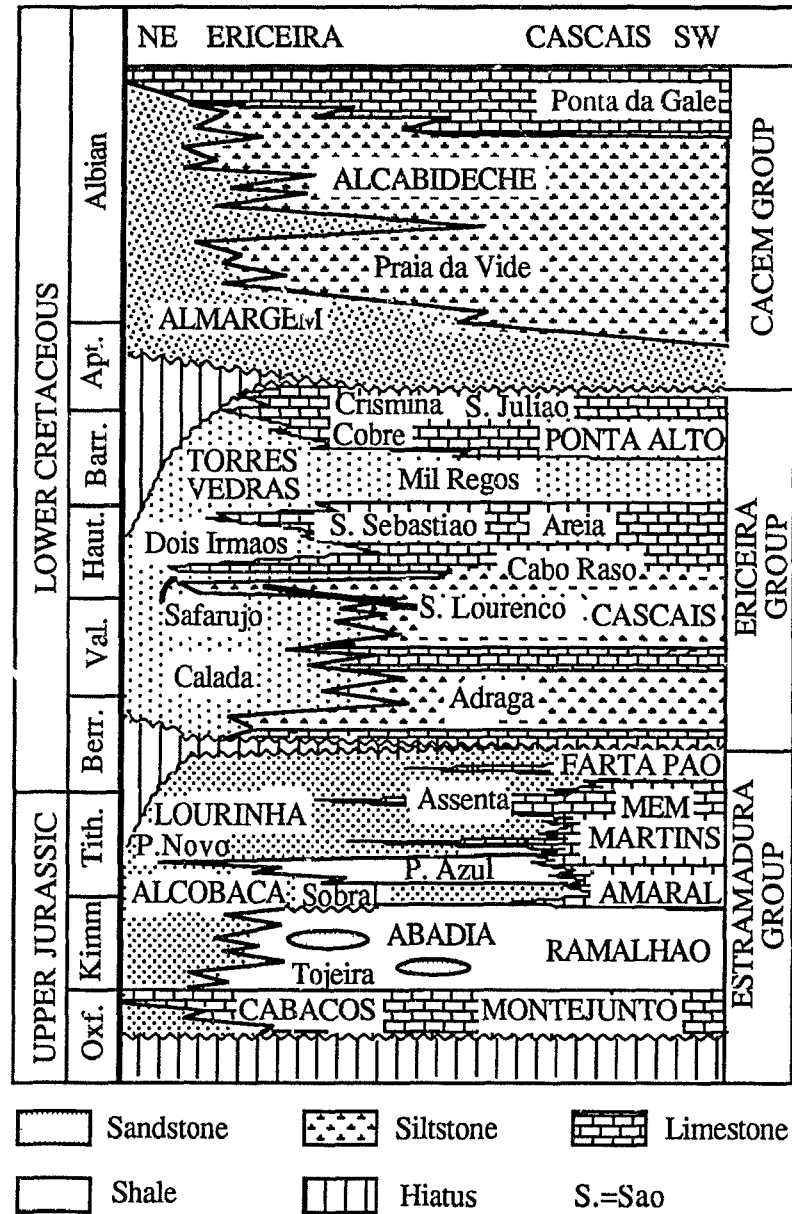


Figure 1.4: Stratigraphic scheme for the Lusitanian Basin of Portugal, based on sections in the Ericeira and Cascais areas. Formation names in upper case, members in lower case (after Hiscott *et al.*, 1990).

Kimmeridgian. Sedimentation continued to be non-marine in character throughout the remainder of the Jurassic in the northern basin.

In the southern basin, shallow water and high energy Lower Oxfordian carbonates rest unconformably on Upper Callovian strata, while rapid subsidence at the end of the Early Oxfordian resulted in normal marine sedimentation with shallow water and high energy carbonates. The Late Oxfordian-Early Kimmeridgian is characterised by rapid deepening (Stam, 1986), marked by a predominance of shales and the introduction of siliciclastics that prograded from north to south. Further basement fault reactivation and halokinesis in the Early Kimmeridgian in the southern basin resulted in complex facies distribution, with reefal carbonates being developed to the south (Cabo Espichel area) and fluvial clastics to the north (Ericeira area).

Marine transgression and regression during the Tithonian are evidenced by a series of alternating carbonates and siliciclastics in the Cabo Espichel section, and marine limestone intercalations in the Ericeira area (Hiscott *et al.* 1990a). Uplift of the fault blocks resulted in general shallowing and the gradual coarsening upward seen through the Tithonian to Berriasian interval (Hiscott *et al.*, 1990a).

Further tectonic uplift and tilting of older rocks is seen by the development of conglomeratic continental deposits of Valanginian age resting unconformably on ?Upper Berriasian sediments (Hiscott *et al.* 1990a). A general transgressive event with a change from continental to marine sedimentation marks the Valanginian to Hauterivian intervals with the development of shales and coral limestones in the sections at Cabo Espichel and north of Ericeira.

1.4: Field and laboratory methods.

Sample localities were selected with principal two goals in mind: firstly, to get as complete a stratigraphic coverage of the section as possible; secondly, to obtain as broad a

representation of the different facies types as possible. Some trade-off between these two objectives was inevitable, given the thicknesses (1100m in total) of the sections involved, and constraints on the volume of space available for shipment. Sampling was restricted mainly to lithologies likely to contain microfossils, and these rock types were determined in the field through detailed observation with a hand lens. Representative finer clastic (sandstone) beds were sampled, however, coarser grained lithologies were not as these showed no evidence of fossil remains in the field. Further details on sampling are discussed in the introduction to each section.

Samples weighing about 500g were processed using the 'Industrial Soap method', outlined in Thomas and Murney (1985). The limestones were crushed in a mortar and pestle and processed by the same method. Processing of the limestones may have resulted in the preferential destruction of some microfossils, although examination of the final residues did not suggest this was a major problem. An alternative method would have been to make thin-sections of the limestones, but this method was not used as it would likely have introduced a strongly biased result: while it is possible to identify certain species of 'larger' Foraminifera in random thin sections, it is hard to identify 'smaller' Foraminifera beyond the genus level (at best), and almost impossible to make Ostracoda determinations through this method.

Processed samples were washed through 500, 125 and 63 μm sieves. Where necessary, the residues were divided with a microsplitter into representative sub-samples to yield about 200-300 specimens from the $>125 \mu\text{m}$ size fraction. A number of samples, however, yielded only sparse microfossils, and in these situations a limit of 4 or 5 picking trays of residue were examined.

The 63-125 μm size fractions were examined for thecomoebans, but none were observed. The Ostracoda and Foraminifera in the fine residue are of early juvenile stages that in most cases could not be assigned to any particular species. The 63-125 μm size fractions are not considered further in this study.

Study of the 'larger' Foraminifera was through the use of thin sections of individual specimens. During thin sectioning, foraminiferal tests were mounted in thermoplastic resin and sectioned using ground glass plates. Tests were ground first on one side, and then on the other, after re-melting the resin and turning the specimen over. Thin-sectioned Foraminifera were photographed using a Leitz Aristophot. Other specimens were photographed using a scanning electron microscope. Faunal slides and residues are housed at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, and in the Department of Geology, Dalhousie University, Halifax, Nova Scotia. Other material (Wightman 1990, in press) is housed at the Smithsonian Institution, Washington D.C., U.S.A.

1.5: Paleoecological and paleoenvironmental analysis: some methods and considerations.

1.5.1: General comments.

Ecology is the study of the interrelationships between living organisms and the physical, chemical and biological aspects of the environment. Although considerable advances in our understanding of ecology of living Foraminifera and Ostracoda have been made in recent years, much remains to be learned. Paleoecology of Foraminifera and Ostracoda is even less-well understood since the controlling physical, chemical and biological parameters are rarely quantifiable in the ancient rock record. Nevertheless, a number of important ecological and paleoecological studies have emerged in recent years through international workshops, symposiums and conferences on both Foraminifera and Ostracoda.

Important work dealing with foraminiferal ecology and paleoecology are found in Murray (1973), Boltovskoy and Wright (1976), Haynes (1981) and the volumes of the benthic foraminiferal symposia edited by Schafer and Pelletier (1976), and the International

Workshops on Agglutinated Foraminifera symposia edited by Verdenius and van Hinte (1983), Gradstein and Rogl (1988) and Hemleben *et al.* (in press). Work dealing with Ostracoda ecology and paleoecology includes van Morkhoven (1962), and symposia volumes edited by Puri (1964), Oertli (1971), Loffler and Danielopol (1977) and DeDeckker *et al.*, (1988).

Many micropaleontologists tend to concentrate on either the Foraminifera or the Ostracoda. Both groups are important paleoenvironmental and biostratigraphic indicators. This study attempts to integrate both Ostracoda and Foraminifera in a single paleoecological and biostratigraphic study.

1.5.2: Problems in working with Mesozoic fossil groups.

Notwithstanding the difficulties in determining physical, chemical, and biological factors controlling the distribution of microfossil assemblages in the ancient rock record, the Mesozoic, in particular pre-Barremian-Aptian fossil assemblages with rare exception are 'pre-actualistic' (Gradstein, 1986). There are few, if any, modern representatives of Mesozoic microfossil genera available for direct ecological comparison. The few exceptions are the 'marsh' Foraminifera that have existed in the same niche since at least the Mesozoic (Scott *et al.*, 1983), and possibly as far back as the Carboniferous (D. Scott, pers. comm. 1990). In spite of this difficulty, certain concepts based on Recent foraminiferal and Ostracodal ecology may be applied to the ancient record.

In addition to the difficulties in working with pre-actualistic fossils, several other factors combine to affect our interpretation of micropaleontological data. Hart (1973) made a general statement about some of the factors affecting the interpretation of agglutinated foraminiferal assemblages. The factors include modification of the assemblages during life, post-mortem, and post-burial. In addition, Hart (1973) recognised that human error may effect interpretation at all stages of analysis. Many of these factors are equally important to

the interpretation of other groups of Foraminifera and Ostracoda.

1.5.3: Methods of data analysis used in this study.

From the preceeding discussions, paleoecological and paleoenvironmental interpretations in many cases are hard, if not impossible, to quantify. Analysis and presentation of data, in contrast, may be accomplished quantitatively. Several indices measure the relationship of the number of species to the number of individuals in a sample (species diversity reviewed by Murray (1973) and Buzas (1979). The simplest measurement of species diversity is the number of species observed in a sample; however, this is obviously influenced by the sample size. Other indices of species diversity are commonly used in analysis, including the Fisher alpha index (Fisher *et al.* 1943), Simpson's Index (Simpson, 1949) and the Shannon-Wiener information function (MacArthur and MacArthur, 1961). Buzas (1979), however, warned that when the number of species and number of individuals in a sample are small, the latter measurements of species diversity should be used with extreme caution. Buzas (1979) suggested such indices may only be used reliably when the number of individuals in a sample equals or exceeds 300.

Whereas the number of foraminiferal specimens in a sample equals the number of individuals preserved, the number of Ostracoda does not. Since Ostracoda moult through their ontogeny, a theoretical total of eight pairs of valves may represent a single individual. One method of obtaining a conservative estimate of the number of individuals in a sample is to count the total number of adult carapaces, and add to the sum the total number of adult left valves or right valves, whichever the greater (Whatley, 1988). The problem with the latter method is that it does not take account of juvenile mortality, and will only give the minimum number of individuals in a sample. Modern Ostracoda diversity patterns have been have been extrapolated back into the Cenozoic, and sometimes into the Cretaceous to

reconstruct shelf biofacies, but no further back because of differences in taxa and very different and variable diversities of Ostracoda faunas in the Mesozoic (Whatley, 1988). Ostracoda counts used in this study are of the number of specimens, which includes both adults and juveniles, whole carapaces and single valves and identifiable fragments.

The number of Foraminifera and Ostracoda specimens recovered from the samples in the Portuguese sections is highly variable. Many samples are barren; others contain sparse assemblages; and some yield rich assemblages. Because of the low numbers of Ostracoda and Foraminifera in many samples, and the difficulties in interpreting species diversity patterns for the Mesozoic, diversity is expressed as the number of species in each sample. The shortcomings of the data will be kept in mind through the analyses.

Many numerical methods have been used to quantify biofacies (Buzas, 1979). It is not within the scope of this study to review these. Since the number of specimens of Foraminifera and Ostracoda is variable through the sections, a qualitative rather than quantitative approach is adopted in this study.

In the analysis of the Foraminifera, one somewhat unusual approach involves the categorization of Foraminifera into morphogroups, and the use of these as paleoecological and paleoenvironmental indicators. Chamney (1976) used a similar, but more detailed approach in his analysis of 'pre-actualistic' Albian faunas with success. Jones and Charnock (1985) collated data on life positions and feeding habitats of agglutinated Foraminifera, recognised four main morphogroups of Foraminifera, and related the relative abundances of these groups to changing environmental parameters. More recently, Koutsoukos *et al.* (1989, 1990) demonstrated that Foraminifera morphogroups could be used to recognise hypoxic/anoxic events in the mid Cretaceous. The major shortcoming of detailed studies in this field is the general lack of consensus on life habitats of many groups of living Foraminifera. The 'morphogroup' approach is adopted here in an attempt to understand some of the limitations of this type of analysis in marginal marine environments.

Analysis of the Ostracoda is centred around their use as paleosalinity indicators, an approach that has been used with success in many previous Mesozoic studies (Neale, 1988). The recent concept of Ostracoda chronoecology is also addressed in the thesis, since, as mentioned above, this may have important implications to our understanding of transgressions and regressions in the conjugate basins.

Throughout the analysis it has been kept in mind that distribution of the fossils may be related to several interrelated paleoecological factors, rather than the seemingly most obvious one; changes in one or several other as yet undetermined parameters could have the same effects on the microfossil distributions as for example, substrate or salinity.

The name(s) of the author(s) of species are not included in the text when those species are treated in the taxonomic notes.

1.6: Organization of this thesis:

The thesis is organised into eight chapters. Chapters 2, 3 and 4 deal with the Portuguese sections. For each section, the lithologic succession is documented, the micropaleontologic data is presented, and is discussed in terms of paleoecology and paleoenvironments. Chapter 5 presents biostratigraphic zonations for the Lusitanian Basin, and discusses correlation of depositional units in the Lusitanian Basin, and the extension of the zonations outside the Lusitanian Basin.

Chapter 6 deals with the Grand Banks of Newfoundland, compares the Grand Banks' microfossil assemblages with the coeval Portuguese ones, and discusses the paleoenvironmental and biostratigraphic implications of microfossil assemblages observed in cored intervals from selected wells in the Hibernia oil field. Regional and other conclusions are presented in Chapter 7. Finally, taxonomic notes on the "smaller" benthic and "larger" agglutinated Foraminifera and the Ostracoda are provided in Chapter 8.

CHAPTER 2

PRAIA AZUL SECTION

2.1: Introduction and previous work.

This section is located 12 km west of Torres Vedras, and forms the cliffs to the south of Santa Cruz (Figure 2.1). Access to the section from Torres Vedras is via the Santa Cruz turn-off from the west-bound Ponte do Rol road. The cliff section may be reached from the track at the base of the sea front hotel, to the north of the Rio Sizandro river.

The sedimentology and benthic associations of this section were examined in some detail by Fursich (1981), who proposed that the section represented the final stage of basin infilling. He recognised a number of benthic (macro) fossil associations and concluded that they were controlled mainly by salinity and, when integrated with sedimentological data, allowed a number of paleoenvironments to be recognised within the marginal marine sequences. Many of the benthic invertebrates are reported elsewhere from Upper Jurassic and Lower Cretaceous sediments associated with reduced salinity (eg. Casey 1955; Fursich 1977; Hallam 1976; Hudson, 1963). This study is the first to deal with the microfossils in the Praia Azul section. Study of the microfossil assemblages within the framework afforded by Fursich (1981) is used to assist in their paleoecological interpretation.

The measured section in Fursich (1981) is hard to follow, since it is unclear where the section commences. The measured section logged in this study (Figure 2.2) commences 420m to the north of the hotel. At this point, a normal fault offsets the distinctive, red lower and grey, upper units in the cliff. The section starts at the base of the cliff on the downthrow side (south) of the fault. The sedimentary facies, faunas, and their

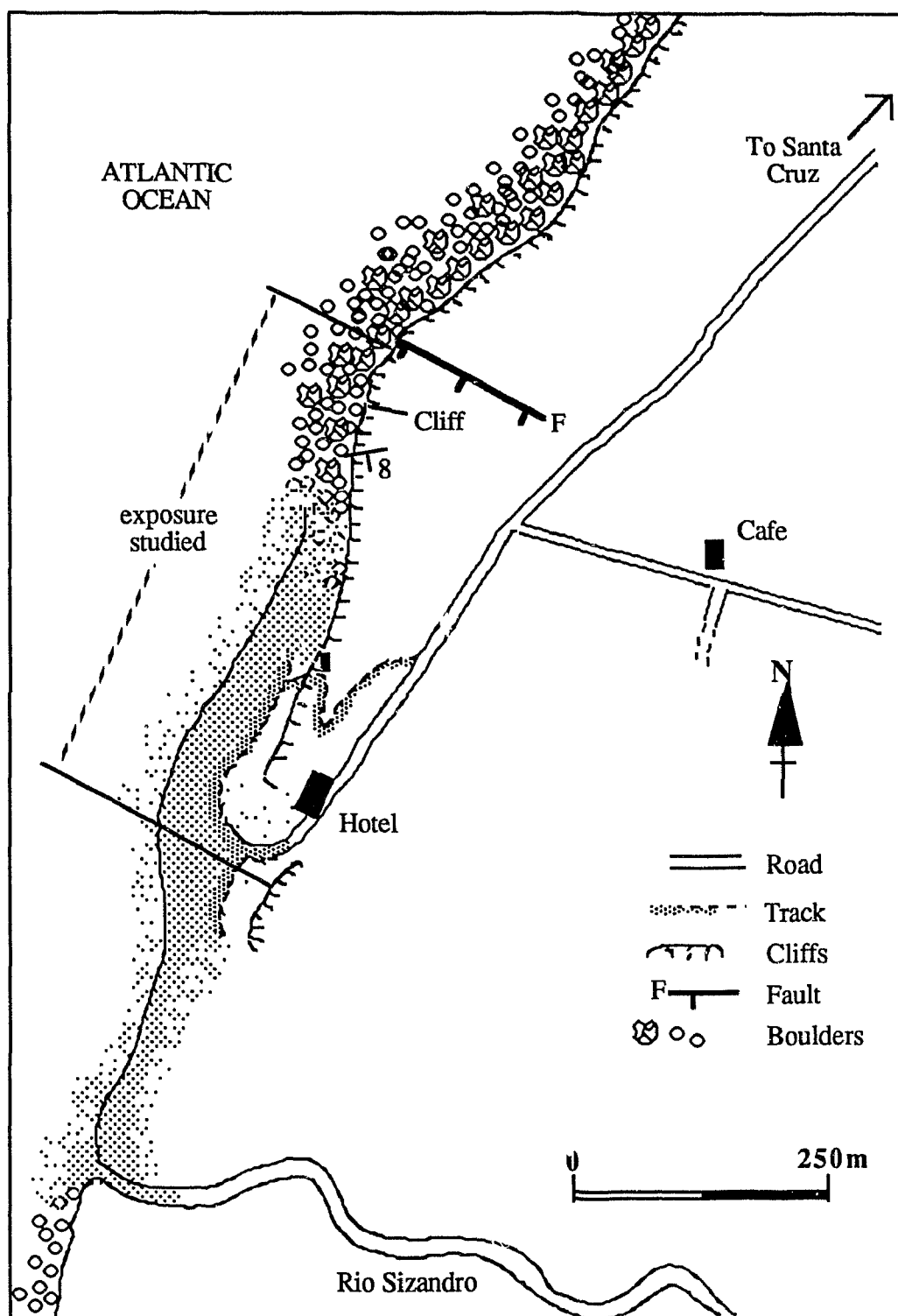


Figure 2.1: Location map of the Praia Azul section. Section commences immediately south of the fault. Rock exposure is in the cliff face.

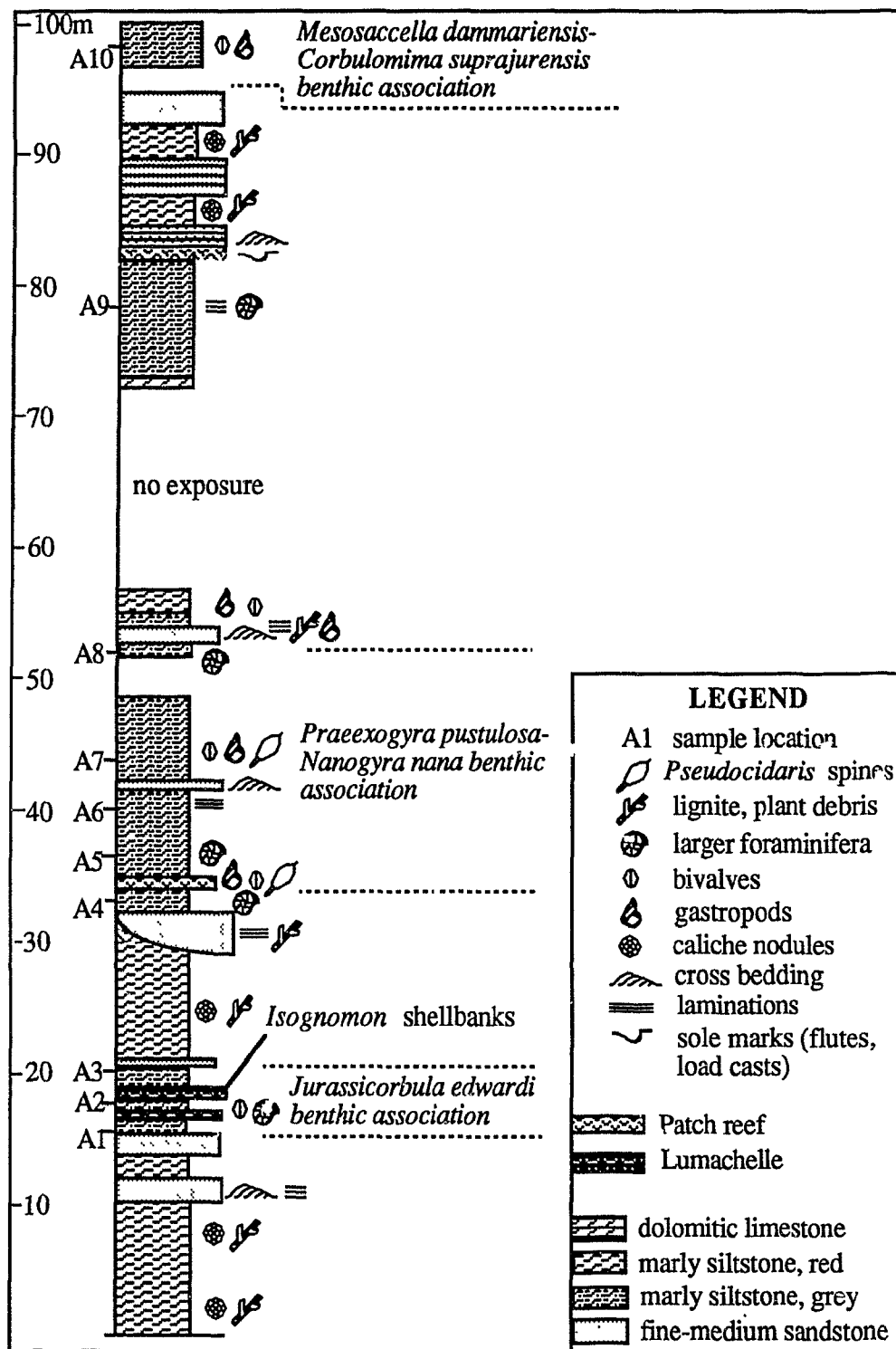


Figure 2.2: Lithology and sample distribution in the Praia Azul section. Benthic bivalve associations (described in text) after Fursich (1981).

interpretation are summarised in Table 2.1. Fursich (1981) concluded, on the basis of the sedimentologic features and associated invertebrates, that the facies succession reflected a change from a fluvial environment to marginal marine bay, and to lagoons subject to deltaic influence. The sedimentary facies outlined in Figure 2.2 and Table 2.1 are discussed below.

2.2: Lithostratigraphy.

The section at Praia Azul consists of a lower unit, interpreted by Fursich (1981) as predominantly fluvial (red beds), overlain by about 100m of grey siliciclastic sediments interpreted as marine in origin (Fursich, 1981). Only the upper (marine) part of the succession is of interest to this study. Sedimentology and sample distribution in the section is shown in Figure 2.2. The sequence examined at Praia Azul contains a number of rock types, but is treated as a single lithostratigraphic unit since it has some degree of internal homogeneity with respect to arrangement of facies, and may be mapped as such.

The lower 35m is dominated by red marly siltstone containing grey nodules up to 10cm in diameter. Woody fragments and local thin (<10cm) layers rich in quartz occur in these beds. Intercalated with the red marly siltstones are thin to medium bedded, fine-grained, laminated sandstones. These are micaceous and contain thin shaley interbeds and local thin laminae of detrital organic material. At the 10m level, the laminated sandstones alternate with thin beds showing small scale cross-bedding. The red marly siltstones and sandstones are unfossiliferous, although Fursich (1981) reported rare bioturbation. Fursich (1981) interpreted the red marly siltstones as flood plain deposits, with the grey nodules as caliche nodules, the thin quartz rich layers representing crevasse splay sediments, and the interbedded sandstones as levee deposits.

Within the 15-20m interval the marly siltstone is grey, and contains abundant bivalves, dominated by *Jurassicorbula edwardi* (Sharpe). *Placunopsis suprajurensis*

ROCK	GEOMETRY	LITHOLOGY	STRUCTURES	FOSSILS	ENVIRONMENT
Sandstone	Channelled, lenticular, <5m thick	medium-coarse, pebbly in places, fining upwards; quartz, mica, lignite clasts on foresets.	Large-scale trough cross-bedding	Tree trunks	Fluvial channel
	Massive planar beds <3m thick	fine-grained with thin laminae of lignite in places	Local climbing ripples, flutemarks and loadcasts	<i>Thalassinoides</i> <i>Planolites</i> <i>Eomiodon</i>	Delta front
	Laminated	Thinly-bedded, alternating planar laminated & cross-bedded. fine to medium grained, locally micaceous.	Small-scale cross-bedding	Absent	Levee (laminated) Crevasse splay (cross-bedded)
Marly Siltstone	Massive	Red, local quartz and lignite clasts, and grey caliche nodules <10 cm diameter. Local thin intercalations of sandstone.	Intercalated sandstones often cross-bedded	Absent	Flood plain
		Grey, locally with lignite clasts	Bioturbated	<i>Thalassinoides</i> <i>Jurassicorbula</i> <i>Placunopsis</i> <i>Protocardia</i> <i>Thracia</i> <i>Myophorella</i> <i>Pseudocidaris</i>	Brackish Lagoon
Bioclastic Limestone	Medium to thick bedded	Lumachelle banks composed of cemented bivalves.	Massive; Bivalves in growth position	<i>Isognomon</i> <i>Placunopsis</i> <i>Nanogyra</i> <i>Praeexogyra</i> <i>Myophorella</i>	Brackish bay

Table 2.1: Sedimentary facies, fossils and paleoenvironmental interpretations of Fursich (1981).

(Buvignier), *Thracia depressa* (J. de C. Sowerby), and *Protocardia* sp. are also common in these beds. The bivalve assemblage corresponds to the *Jurassicorbula edwardi* association of Fursich (1981). Two 20-40 cm thick beds of lumachelle occur within the grey marly siltstone, at 16m and 18m, and are laterally continuous for several hundred metres to the end of the outcrop. The lumachelles contain the large bivalve *Isognomon lusitanicum* (Sharpe), and the smaller bivalves *Placunopsis suprajurensis*, and *Nanogyra nana* (J. Sowerby). Although *Isognomon lusitanicum* dominates the bivalve assemblage in terms of biomass, Fursich (1981) reported that the species represented at most 5% of the fossil assemblage, whereas the other two species together formed about 90% of the assemblage. A characteristic of *I. lusitanicum* in these shell banks is that they are commonly in life position, with their umbones pointing downward. Serving as a substrate for *I. lusitanicum* is a thin bed of bivalve debris, dominated by *Placunopsis* (Fursich, 1981). The formation of the lumachelles is, according to Fursich (1981), related to short term storm events that provided the necessary firm substrate (the *placunopsis* bivalve debris) for encrustation by *I. lusitanicum*; *I. lusitanicum* itself provided a substrate for other encrusters including *Praeexogyra* during life, and *Nanogyra*, *post mortem*; the densely packed bivalve assemblage in the shell bank may have acted as a baffle, resulting in trapping of mud and subsequent demise of the shell bank. Fursich (1981) interpreted the *Jurassicorbula edwardi* association of the grey marly siltstones and the associated *Isognomon lusitanicum* lumachelles as indicative of brackish to normal marine salinities (<33 ‰) in a brackish bay.

At the 30m level, a sandstone with a concave-upward base is seen. This sandstone has an erosive lower contact with the underlying red marly siltstones. The sandstone is up to 5m thick, and about 15-20m in apparent width. Several other sandstone bodies of similar geometry are seen at this level are reported to occur at other points in the section (Fursich, 1981). Grain size is medium to coarse, fining upwards. Large scale trough cross-bedding is apparent, and woody fragments are seen on the foresets. The sandstone is unfossiliferous. Fursich (1981) interpreted the sandstones to be fluvial-channel deposits,

and added that the presence of other channels at this point in the section indicated that they were of high sinuosity.

The upper 65m of the section, where exposed, is predominantly grey, fossiliferous, marly siltstone, although minor intercalations of red marly siltstones, similar to those in the lower part of the section, occur at the 52m, 85m and 90m levels. Sandstone intercalations and shelly layers are also seen at a number of levels. At the 32 m level (overlying the sandstone with the concave base), the marly siltstone is relatively coarser and contains woody fragments and coarse (>1mm) quartz grains. At the 35m level, a small patch reef occurs, approximately 2m wide and 50 cm high. The patch reef contains abundant fossil oysters and gastropods, and locally, spines of the echinoderm *Pseudocidaris* that may be assigned to the *Praeexogyra pustulosa-Nanogyra nana* association of Fursich (1981). Similar fossil associations occur in the remaining marly siltstone in the sequence above the patch reef, and these are often concentrated into shelly horizons - for example at the 42m and 85m levels. Shaley intervals, for example at the 38m and 78m levels, contain sparse fossil debris. Fursich (1981) assigns his *Praeexogyra pustulosa-Nanogyra nana* association to a low salinity (brackish) regime in a protected lagoon.

The sandstone intercalations at 40m and 52m are thinly bedded, fine grained and micaceous and cross bedded. In the upper part of the section, the sandstones are medium to thick, planar bedded, generally fine grained and well sorted, are climbing ripple cross-laminated and cross bedded. The sandstone at the 86m level has flute marks and load casts. The trace fossil *Thalassinoides* occurs in some sandstone beds together with gastropods (for example, 52m). The sandstones in this part of the section are regarded by Fursich (1981) as delta-front sandstones.

The upper part of section is composed of grey marly siltstone containing numerous specimens of *Myophorella lusitanicum*. This is a large (<70 mm) bivalve characteristic of the *Mesosacella dammariensis-Corbulomima suprajurensis* association of Fursich (1981),

interpreted by him to be indicative of a brackish to marine prodelta.

2.3: Microfossil analysis.

Samples were collected from intervals that contained the bivalve associations discussed in Fursich (1981), from which the author provided a detailed paleoenvironmental framework. The purpose of this study was to verify and expand Fursich's (1981) interpretations using microfossil assemblages. Emphasis was on shale sampling, rather than sandstone intercalations that turned out to be largely barren. One sample (A9) was taken from a laminated siltstone that lacked invertebrate fossils. All shale/silt samples contained microfossils. The Foraminifera are generally more abundant than Ostracoda (Figure 2.3). Fourteen Foraminifera and fourteen Ostracoda species groups are recognised. Using simple counts of the number of species per sample (Figure 2.4), both Foraminifera and Ostracoda species decrease in abundance upward in the section to sample A6, followed by a rise and then a fall in the upper part of the section. Specimen counts were greater than 200 in all but two samples: A4 (74 specimens) and A6 (161 specimens).

2.3.1: Ostracoda.

2.3.1.a: Ostracoda Families.

The Praia Azul Ostracoda belong to the sub-orders Platycopina and Podocopina. The platycopines are represented by the Family Cytherellidae whereas the Podocopina are represented by the families Cytheruridae, Cytherideidae, Cytheridea, Paracyprididae, Ilyocyprididae, Cyprididae, Cyclocyprididae and Darwinulidae.

2.3.1.b: Distribution of species.

The distribution of species in the samples is shown in Table 2.2. Relative

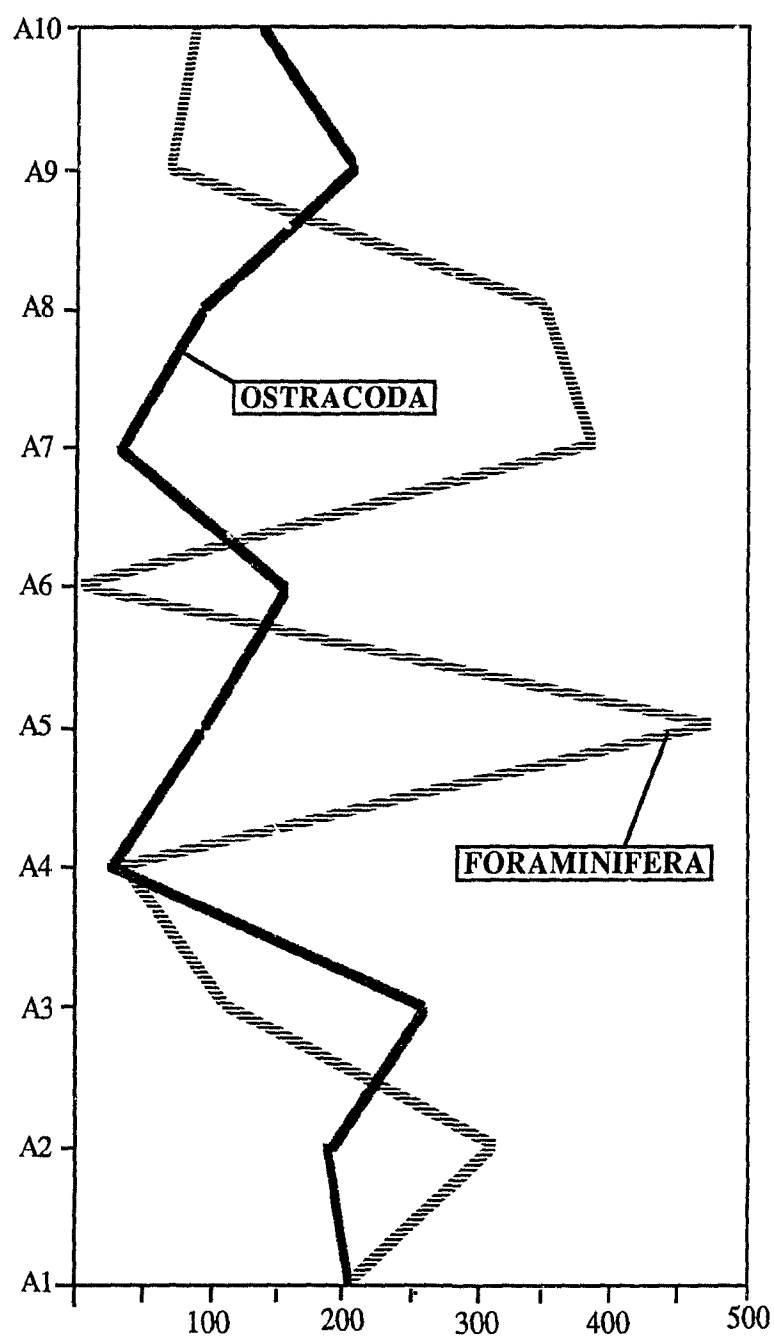


Figure 2.3: Number of ostracod and foraminifera specimens per sample in the Praia Azul section.

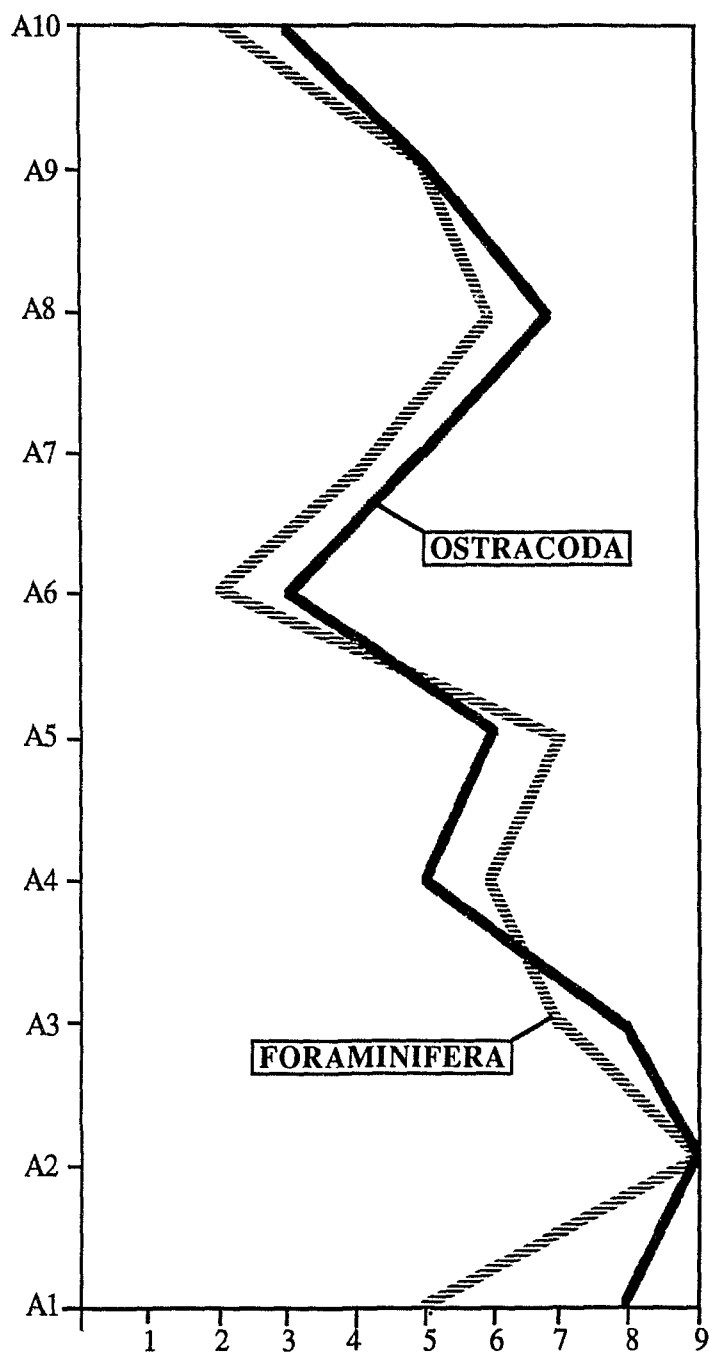


Figure 2.4: Number of ostracod and foraminifera species per sample in the Praia Azul section.

A10						Cetacella armata
A9						Cytherella fullonica
A8		34	9	14		Cytheropteron aquitanum
A7			12	2		Cytherelloidea weberi
A6					34	Cypridea spp.
A5	6		13		17	Darwinula leguminella
A4					2	Fabanella boloniensis
A3					10	Galliaecytheridea postrotunda
A2					137	Galliaecytheridea sp.2
A1					19	Mantelliana cyrton
					18	Paranotacythere pustulata
					28	Paracypris sp.
					113	Rhinocypris jurassica
					4	Schuleridea sp.1
					3	
					9	
					27	
					14	
					26	
					5	
					33	
					1	
					29	

Table 2.2: Distribution of ostracod species in the Praia Azul samples.

abundance of species (percent) is shown in Table 2.3. Since Ostracoda carapaces frequently separate on death, fossil assemblages often contain a proportion of valves as well as carapaces. Counts of specimens therefore include single valves and whole carapaces (counted as 2 valves) of both adults and juveniles, and identifiable fragments. An alternative method of counting would be to count the number of adult whole carapaces plus the number of adult left or right valves, whichever the greater (Whatley, 1983). The latter method would give a conservative estimate only of the minimum number of individuals in the population, not taking into account effects of juvenile mortality or reworking. In later analysis (part 2.3.1.d, below), the Ostracoda populations are given more consideration.

Species composition and relative abundance fluctuates markedly between samples (Tables 2.2 and 2.3). Some species are found only in low abundance (a few percent) in some of the samples, including *Cetacella armata* (A5), *Paracypris* (A1 to A3, A6 and A10), and *Rhinocypris jurassica* (A9). Other species are found in low to moderate abundances (< 20%), including *Cytheropteron aquitanum* (A1 to A5, A7 and A8), *Cytherelloidea weberi* (A1, A2, A7 and A8), *Cypridea* spp. (A3 and A9), *Galliaecytheridea* sp.2 (A1, A2 and A8), *Mantelliana cyrton* (A9), *Cytherella fullonica* (A1-A3 and A8), *Galliaecytheridea postrotunda* (A2-A5), and *Schuleridea* sp.1 (A1-A5, A8 and A10) locally dominate the samples where two or all of these co-occur, and individually any one of these species may comprise over 20% of the assemblage. Three species occur in high abundance, where individuals may make up about 40% to 90% of the sample: *Darwinula leguminella* (A4-A6 and A9); *Fabanella boloniensis* (A1-A4, A6, A8 and A9); *Paranotacythere pustulata* (A1-A3, A5, A8 and A10).

Each sample contains a unique Ostracoda assemblage. Sample A1 is dominated by *Cytherella fullonica* and *Galliaecytheridea* sp.2, with *Schuleridea* sp.1 in moderate abundance. Samples A2 and A3 are dominated by *Paranotacythere pustulata*. *Darwinula leguminella* and *Fabanella boloniensis* dominate sample A4, the former having highest abundance, whereas the opposite is the case where these two species dominate sample A6.

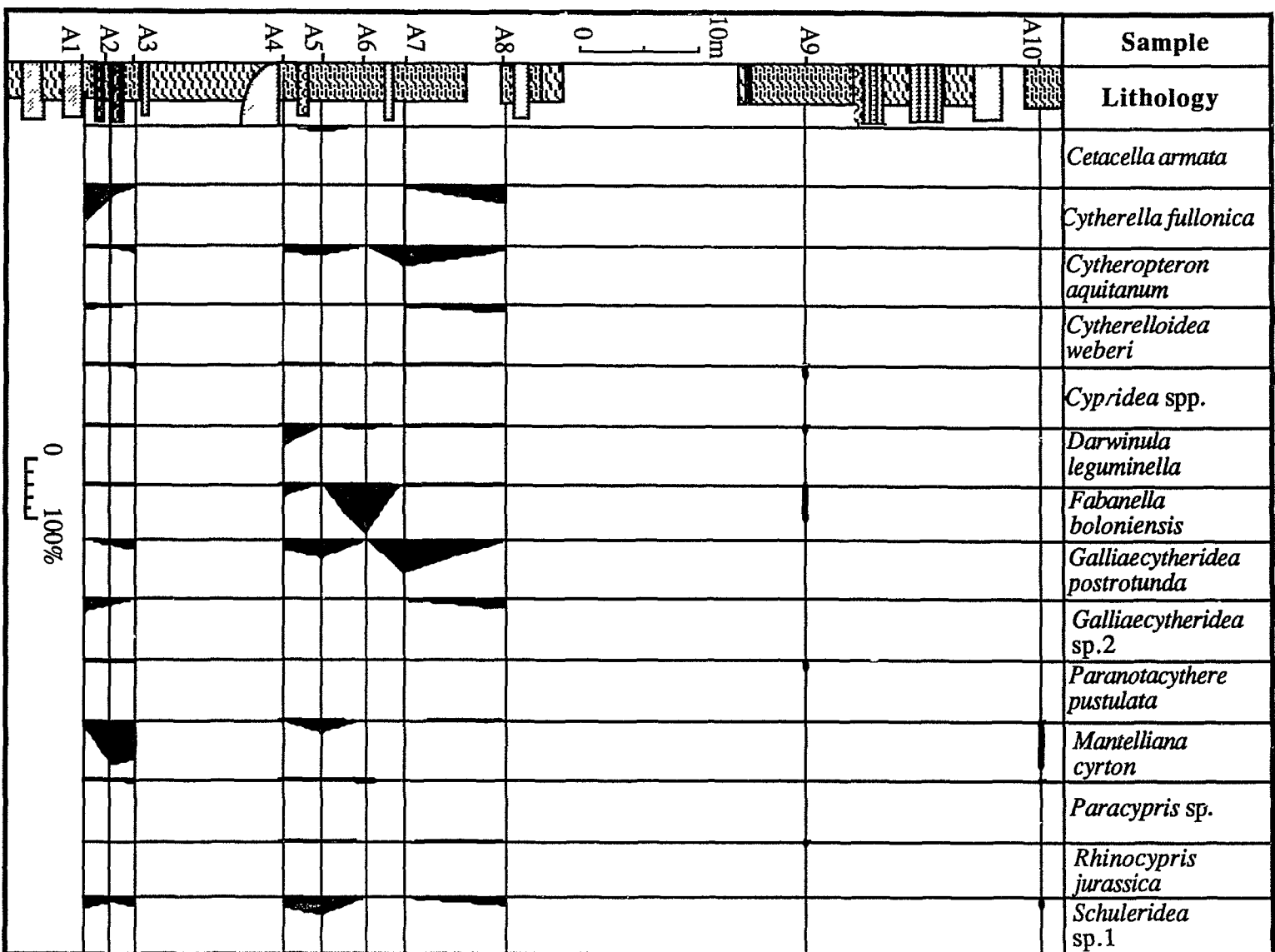


Table 2.3: Relative abundance (percent) of ostracoda species at Praia Azul.

Galliaecytheridea postrotunda and *Schuleridea* sp.1 are the dominant species in sample A5 whereas *G.* sp.2, *S.* sp.1 and *C. fullonica* are the abundant species, along with *Cytherelloidea weberi* in sample A8. Sample A9 is dominated by *Fabianella boloniensis*, whereas sample A10 has a high abundance of *P. pustulata*. Certain trends in the species distribution are apparent when the Ostracoda are considered in terms of their salinity tolerance, as dealt with below.

2.3.1.c: Praia Azul Ostracoda as salinity indicators.

Ostracoda inhabit all modern aqueous environments and are found in freshwater to hypersaline salinity regimes. Few species, however, are distributed over the whole salinity spectrum. Many have a broad tolerance over a range of salinities (euryhaline), whereas others have highly restricted salinity ranges (stenohaline), which makes them particularly useful as paleosalinity indicators in ancient sediments (Sohn, 1951).

The extant Ostracoda superfamilies Darwinulacea and Cypridacea (with the exception of families Paracyprididae and Pontocyprididae in the latter group) are regarded as freshwater, whereas the Cytheracea (excepting the family Limnocytheridae) are marine (Neale, 1988). The majority of modern marine Ostracoda are euryhaline, that is they are brackish tolerant, whereas some species of freshwater Ostracoda are able to withstand slightly elevated salinity (Neale, 1988). In general terms of salinity, living Ostracoda may therefore be classified as freshwater (stenohaline), marine (stenohaline) and brackish (euryhaline). Neale (1988) discussed the salinity ranges of extant Ostracoda species.

Direct ecological comparison of the Praia Azul and modern Ostracoda is possible for only a few extant genera. The approach used here is to examine studies dealing with the distribution of Ostracoda in ancient (Mesozoic) marginal marine and non-marine sedimentary rocks to provide a general outline for the salinity preferences of Ostracoda in the Praia Azul section. Fursich's (1981) analysis of the sedimentology and benthic associations in the Praia Azul section provides an additional framework.

Several studies have helped to determine the salinity ranges of Late Jurassic-Early Cretaceous Ostracoda genera and species. Notable in this respect are the works of Kilenyi and Allen (1968) on the lower Weald Clay (Lower Cretaceous) of SE. England, Anderson (1963, 1967, 1971 and 1985) on the Purbeck-Wealden facies of SE. England, Bate (1978) on the Bathonian of Yorkshire, and Ware and Whatley (1983) on the Bathonian of Oxfordshire, England. See also Kilenyi (1978), Kilenyi and Neale (1978) and Neale (1978). Neale (1988) reviewed the use of Ostracoda for paleosalinity reconstructions. Salinity tolerances for the Ostracoda found at Praia Azul are shown in Figure 2.5. The salinity classification used in Figure 2.5 follows that outlined in Neale (1988). The salinity values shown must be considered as guides only for the ancient record.

From the literature, *Cypridea*, *Mantelliana*, *Darwinula*, *Cetacella* and *Rhinocypris* stand out as freshwater genera, the latter two forms also reported from slightly brackish paleoenvironments. Recent species of *Darwinula* are found in freshwater with salinity of less than 1‰ (Neale 1964), although some are reported from brackish lakes with salinity as high as 15‰ (De Decker 1981). *Rhinocypris* is closely allied to, if not congeneric with, the Recent lacustrine genus *Ilyocypris* (Kilenyi and Allen 1968). Anderson (1985) reported *Cypridea*, *Mantelliana*, *Darwinula* and *Rhinocypris* from freshwater intervals of the Purbeck and Wealden facies of the U.K. *Fabanella boloniensis* is widely reported as a brackish species, but is also associated with gypsum beds in the Purbeck facies of southern England, suggesting it may have also tolerated hyperhalinity. Populations of *Fabanella boloniensis* may have been killed by rising salinity, and incorporated in evaporite deposits, as *in situ* assemblages (J.W. Neale, pers. comm. 1989). *Schuleridea*, *Galliaecytheridea*, *Paranotacythere* and *Cytheropteron* are reported as marine species that were brackish tolerant. In the Purbeck-Wealden beds of southern England, Anderson (1963, 1967, 1971, 1985), reported similar associations together with *Fabanella boloniensis*, from marine strata. Elsewhere in Europe these genera have been reported in brackish-marine associations (Oertli, 1963; Donze, 1960). *Amphicythere*, *Cytherella*, *Cytherelloidea* and *Paracypris* are

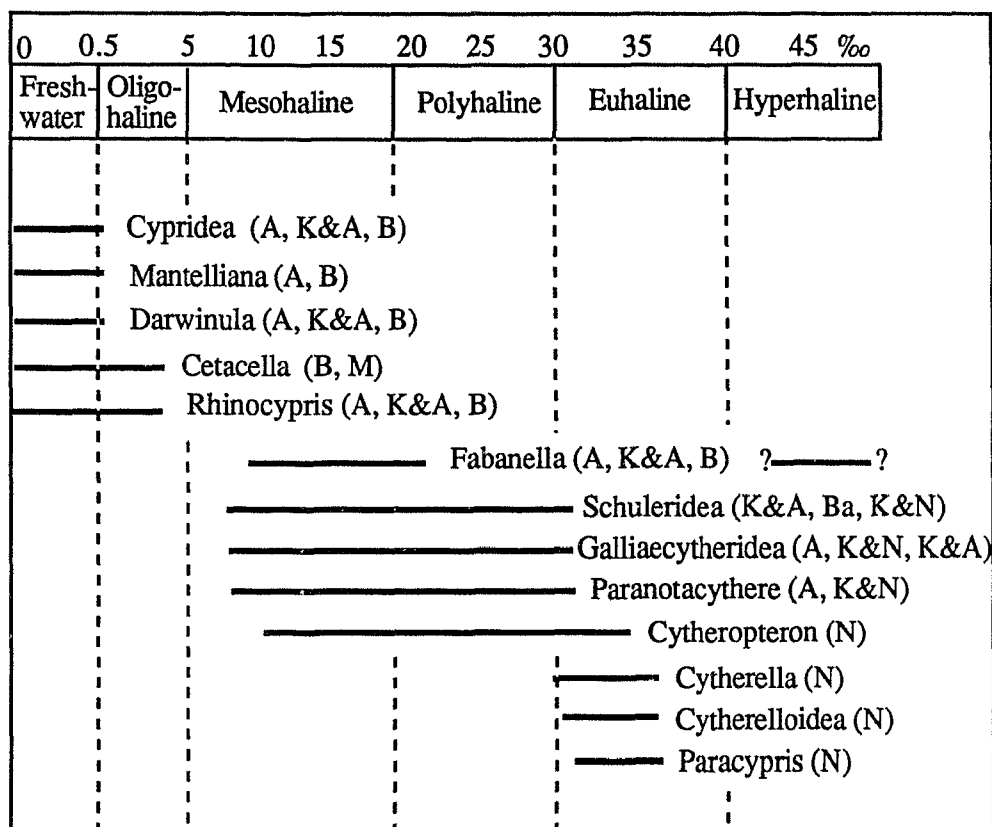


Figure 2.5: Salinity tolerances of the Praia Azul ostracoda based on paleoecology reported in the literature. A=Anderson 1963, 1971, 1985; B=Brenner 1976; Ba=Bate 1987; K=Kilenyi 1961, 1978; K&A=Kilenyi and Allen 1968; K&N=Kilenyi and Neale 1978; M=Martin 1963; N=Neale 1964, 1973, 1988. Salinity classification after Neale (1988).

reported as stenohaline marine genera typical of carbonate shelf deposits (Kilenyi, 1978; Neale, 1978).

An important bridge between Recent and ancient ostracod assemblages is also provided by Keen (1977) in his work on the Headon, Osborne and Bembridge beds (upper Eocene). Keen (1977) recognised species of *Darwinula* in his freshwater (0-3‰) assemblage I, species of *Cytherella*, *Schuleridea*, and *Cytherelloidea* in his upper brackish to marine (16.5-33‰) assemblage V. One species of *Cytherella* was recognised in his marine (33‰) assemblage VI. Keen (1977) demonstrated that his Tertiary ostracod assemblages were primarily salinity controlled and comparable to Recent assemblages.

From the above, the Praia Azul Ostracoda can be divided into three broad salinity groups: freshwater, brackish and marine. The marine (stenohaline) group predominates in samples A1 and A8, forming just over half of each assemblage (Figure 2.6). Values in sample A7 should be treated with caution because of low Ostracoda counts. In the remainder of the section, the marine stenohaline group is poorly represented. The brackish group predominates in most samples, whereas the freshwater group is well represented in samples A4 and A9.

2.3.1.d: Reworking.

In a near-shore environment subject to tidal currents, wave activity and storms, reworking of bottom sediments can result in displacement of benthic assemblages. Ostracoda, unlike many of the larger benthic invertebrates, are motile during life and are subject to such reworking. However, population studies offer a method through which autochthonous Ostracoda assemblages may be recognised. Ostracoda, like other arthropods, grow in discontinuous stages (instars, usually eight) through their ontogeny between the egg and the adult stage. When the Ostracoda soft parts outgrow the secreted carapace, moulting (ecdysis) takes place and a larger carapace is grown. The out-grown juvenile carapaces are disarticulated during ecdysis, and may become fossilized in the same

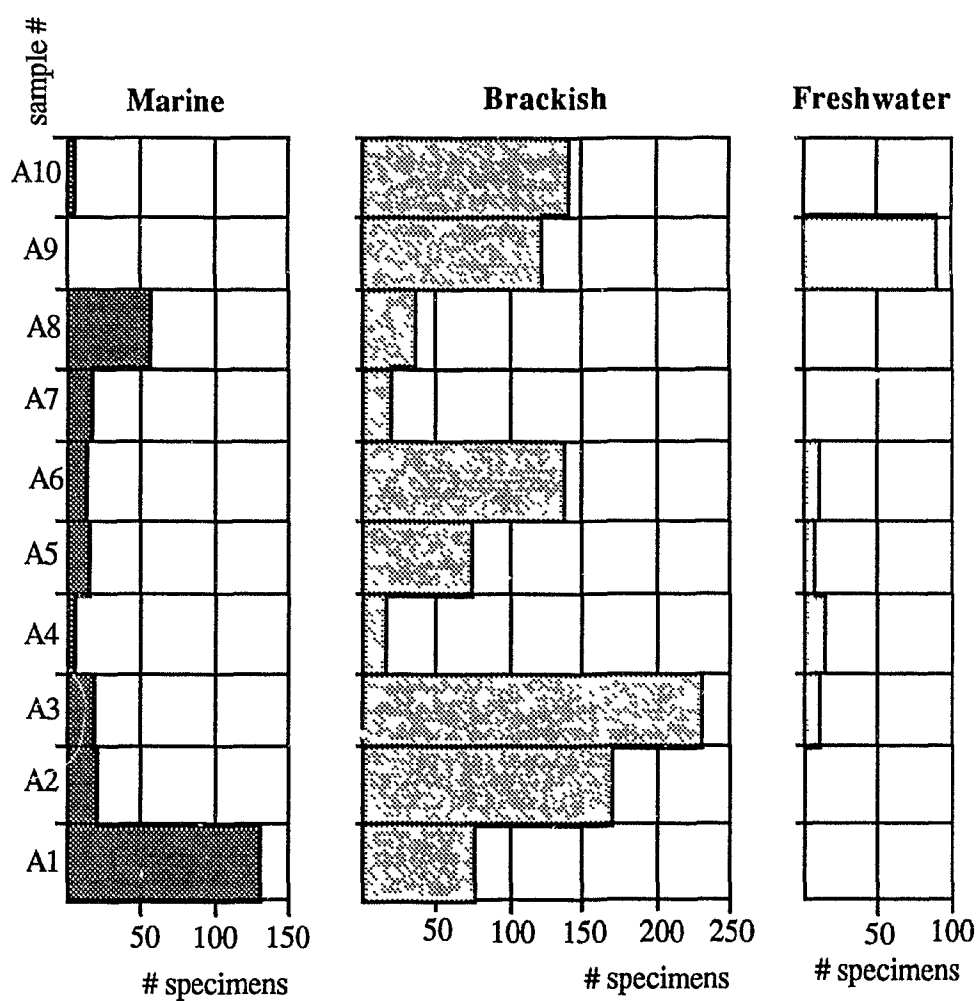


Figure 2.6: Bar graphs showing the distribution of the Ostracodal salinity groups in the Praia Azul samples.

way as the adult hard parts. A method used to distinguish Ostracoda biocoenoses from reworked assemblages (thanatocoenoses) involves the use of detailed serial counts of all adults and juveniles (instars) in the Ostracoda populations. In theory (Whatley, 1983; 1988), an Ostracoda biocoenosis will have a population structure consisting of large numbers of adults (of both sexes) and juvenile instars going well back in the ontogeny of the species (Figure 2.7.a), whereas a biocoenosis from a high energy environment will contain only adults and late ontogenetic stages (Figure 2.7.b), and a thanatocoenosis will contain mainly juveniles (Figure 2.7.c). Ware and Whatley (1983) applied this method in their study of the depositional history of the Bathonian Forest Marble Clay of Oxfordshire, England, and recognised a non-marine phase. Ware and Whatley's (1983) findings were corroborated by an independent palynological study (Hunt, 1983).

Another method involves analysis of the adult valve:carapace ratio (Whatley 1988). Ligaments keeping the Ostracoda valves in articulation will disintegrate upon death, allowing the valves to separate. A high percentage of articulated adult specimens should indicate little post-mortem transport (although rapid sedimentation may preserve the carapaces intact: (Oertli, 1971).

Many factors combine to affect the population structure and valve:carapace ratio in fossil (and living) Ostracoda assemblages including the incidence of infant mortality, the habitat of the species in question (i.e. infaunal, epifaunal, phytal), the density of the water body (ie. the degree of salinity), the type of hinge articulation, and to some extent the method of sample preparation. Many factors are variable between species and commonly are not quantifiable. The reader is directed to Kilenyi (1971) and Whatley (1988) for further discussion.

The use of detailed population counts is potentially useful in the Praia Azul section where Ostracoda are abundant, and mixing of stenohaline marine, brackish and freshwater species is apparent in many samples. Brackish Ostracoda are transitional to both the marine stenohaline and the freshwater species, and overlap at the boundaries of their ecologic

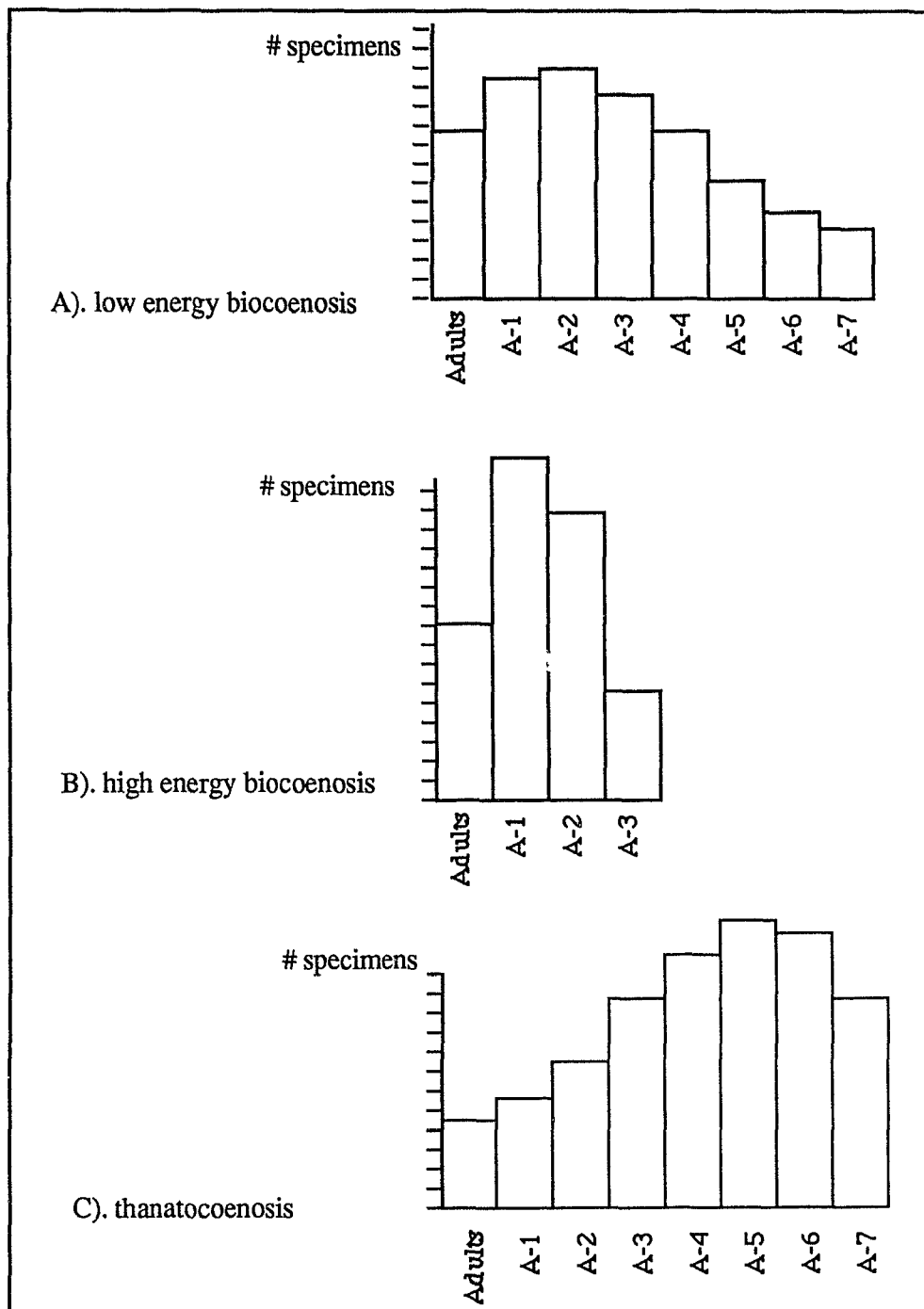


Figure 2.7: Interpretation of ostracod population structures based on serial counts of adults and instars (After Whatley 1983, 1988).

niches would be expected. However, the rare co-occurrence of stenohaline marine species and strictly freshwater species suggests that: (1) the salinity tolerances of the species in either group is much wider than previously thought; or (2) freshwater species were transported seaward and/or (3) the stenohaline marine species were transported landward. Transportation of marine or freshwater species into adjacent regions by tidal currents or fluvial discharge is an obvious cause of reworking; aeolian and avian vectors are also effective means of transport (Pokorny, 1971). A further possibility is that certain species could have migrated to environments beyond the optimum for full life and reproduction, but where survival was still possible.

Data on the serial counts of the Ostracoda is shown in Table 2.4. Interpretation of the Ostracoda population data is summarised in Table 2.5. and briefly discussed below within the context of the general lithologic and macro invertebrate framework discussed in Fursich (1981) and observed in the field.

2.3.1.e: Relationship to Fursich's (1981) framework and field observations.

The Ostracoda in the Praia Azul section consist of marine, brackish, and freshwater groups. Although the environments proposed by Fursich (1981), (Table 2.1) are regarded as brackish, episodes of normal marine salinity (33‰) allowed stenohaline Ostracoda species to live and reproduce. Samples A1, A8 and possibly A7 reflect such episodes. The high proportion of articulated *Cytherella* juveniles in sample A1 indicate *in situ* infant mortality. Possibly the high mortality rate is related to a drop in salinity from normal marine values. If the juveniles had been transported *post mortem*, they would be represented by valves rather than carapaces. There is no other evidence (for example, bored carapaces indicating predation) that would account for the articulated juveniles. Some caution should be used in interpreting high proportions of juvenile *Cytherella* in sample A1 as this form is particularly robust and the early instars have a greater preservation potential (Pokorny, 1971). Sample A1 was recovered from siltstones containing the *Jurassicorbula edwardi*

A1	B C D G I K L N	A6	F G L
A	37 2 6 2 18 17 2 29	A	10 116 2
A-1	19	A-1	15 10
A-2	22	A-2	2
A-3	14	A-3	4
A-4	28	A-4	
A2	B C D G H I K L N	A7	C D H
A	9 2 1 2 3 9 144 3 1	A	2 6
A-1	6	A-1	5 8
A-2	4	A-2	7 5
A-3			
A-4			
A3	B C E G H K L N	A8	B C D G I K N
A	3 9 10 1 2 163 6 30	A	20 9 2 18 4 12
A-1	1	A-1	11 1 5
A-2		A-2	2 8 2
A-3		A-3	1
A-4		A-4	
A4	C F G H N	A9	E F G J M
A	2 12 4 1 5	A	34 17 88 22 9
A-1	1	A-1	21 3
A-2	3 1	A-2	7 3
A-3		A-3	4
A-4		A-4	
A5	A C F H K N	A10	K L N
A	6 13 2 28 20 26	A	64 3 16
A-1		A-1	33 11
A-2		A-2	16
A-3		A-3	
<p style="text-align: center;">KEY TO SPECIES</p> <p> <i>A</i> <i>Cetacella armata</i> <i>B</i> <i>Cytherella fullonica</i> <i>C</i> <i>Cytheropteron aquitanum</i> <i>D</i> <i>Cytherelloidea weberi</i> <i>E</i> <i>Cypridea</i> spp. <i>F</i> <i>Darwinula leguminella</i> <i>G</i> <i>Fabanella boloniensis</i> <i>H</i> <i>Galliaecytheridea postrotunda</i> <i>I</i> <i>Galliaecytheridea</i> sp.2 <i>J</i> <i>Mantelliana cyrtos</i> <i>K</i> <i>Paranotacythere pustulata</i> <i>L</i> <i>Paracypris</i> sp. <i>M</i> <i>Rhinocypris jurassica</i> <i>N</i> <i>Schuleridea</i> sp.1 </p>			

Table 2.4: Counts of ostracod instars (A, A-1, A-2, A-3, A-4) in the Praia Azul samples; A-N = species; sample numbers A1 to A10 in bold.

Biocoenoses		Thanato- coenoses	COMMENTS / INTERPRETATION
low energy		high energy	
SAMPLE	adults only	adult valves	
	adults and instars -4 -3 -2 -1 A	juveniles only A -1 -2 -3 -4	
A1	B K I N D L G C		High proportion of articulated <i>Cytherella</i> juveniles indicates high infant mortality, possibly related to pathologic change in salinity. Other species are euryhaline. Onset of brackish salinity.
A2	H B K I		Brackish water <i>Galliaecytheridea-Paranotacythere</i> assemblage; most <i>Cytherella</i> juveniles articulated.
A3	H K L N B E C G		Brackish water <i>Galliaecytheridea-Paranotacythere</i> assemblage: <i>Cypridea</i> indicates freshwater influence.
A4	H C F G	N	Brackish to freshwater assemblage; articulated <i>Darwinula</i> suggests limited post-mortem transportation as this form has a weak hinge. Charophyte sporangia present.
A5		H N K C A F	Brackish water <i>Galliaecytheridea-Paranotacythere</i> assemblage: <i>Cctacella</i> and <i>Darwinula</i> indicate freshwater influence.
A6	G F L		Brackish-freshwater <i>Fabanella</i> assemblage.
A7	H D	C	Many <i>Galliaecytheridea</i> juveniles articulated. <i>Cytherelloidea</i> indicates marine influence.
A8	B N D I K G	C	Marine <i>Cytherella-Cytherelloidea-Schuleridea</i> assemblage.
A9	G J E F M		Brackish-freshwater <i>Fabanella</i> dominated biocoenosis.
A10	K N L		Brackish-marine <i>Paranotacythere</i> dominated assemblage.

Table 2.5: Interpretation of ostracod population census data (data in Table 2:3).

bivalve association of Fursich (1981). The interpretation of the Ostracoda assemblage as slightly brackish (polyhaline) supports Fursich (1981) who assigned the *Jurassicorbula edwardi* association to a near euhaline to middle mesohaline paleosalinity regime in lagoon or bay paleoenvironments. Samples A7 and A8 came from siltstones containing fossil oysters and gastropods assigned to the *Praeexogyra pustulosa-Nanogyra nana* bivalve association, interpreted by Fursich (1981) to have inhabited mesohaline to polyhaline lagoons. Presence of *Cytherella* juveniles in sample A8, however, may indicate normal marine salinity as is also suggested by *Pseudocidaris* spines at the sampled horizons (Fursich, 1981).

Ostracoda associations from samples A2, A3, A5, and A10 indicate brackish (polyhaline) salinity. Samples A2 and A3 are from levels characterized by the *Jurassicorbula edwardi* association of Fursich (1981) and were recovered from beds adjacent to the *Isognomon lusitanicum* shell banks. The polyhaline to middle mesohaline brackish bay paleoenvironment interpreted for the benthic bivalve associations at these horizons (Fursich, 1981) is supported by Ostracodal evidence. Samples A5 and A10 are from levels containing the *Praeexogyra pustulosa-Nanogyra nana* and *Mesosaccella dammariensis-Corbulomoma suprajurensis* bivalve associations of Fursich (1981). The brackish lagoonal paleoenvironment interpreted for the former bivalve association (Fursich, 1981) is also supported by Ostracodal evidence in sample A5 - the freshwater species *Cetacella armata* and *Darwinula leguminella* are present, whereas stenohaline marine Ostracoda are absent. The Ostracoda in sample A10 supports the polyhaline to euhaline salinity regime interpreted for the *Mesosaccella dammariensis-Corbulomima suprajurensis* association (Fursich 1981). However, the virtual absence of stenohaline Ostracoda (with the exception of one valve and one carapace of the thin-shelled pelagic genus *Paracypris*, likely to have been transported in) and dominance of euryhaline *Paranotacythere* and *Schuleridea* in sample A10 suggests a more restricted paleoenvironment than the prodelta proposed by Fursich (1981).

Freshwater (oligohaline) to slightly brackish (lower mesohaline) paleosalinity is interpreted from the Ostracoda associations in samples A4, A6 and A9. Sample A4 is of the coarser siltstone commencing at the 32m level. Larger fossils were not apparent at this level. Presence of articulated *Darwinula leguminella* and charophyte sporangia in sample A4 are evidence of a freshwater influence. The field relationship of the coarser siltstone above the sandstone with the concave upward erosive base supports Fursich's (1981) interpretation of this feature as a fluvial channel. Sample A6, dominated by *Fabanella boloniensis* and *Darwinula leguminella* also came from a level lacking larger fossils. The sample is from the shaley interval 5m above the oyster patch reef (*Praeexogyra pustulosa*-*Nanogyra nana* association of Fursich 1981), 35m into the section. The position of these sediments above the reef, and their restricted (near freshwater) fauna suggests these facies were deposited landward of the *Praeexogyra pustulosa*-*Nanogyra nana* patch reefs. The presence of freshwater Ostracoda (*Cypridea* sp, *Rhinocypris jurassica* and *Darwinula leguminella*) and absence of marine forms in sample A9 indicates a restricted inner lagoon paleoenvironment at this level.

2.3.1.f: Discussion.

Figure 2.8 shows a salinity profile for the Praia Azul section. A number of sharp fluctuations are seen in the salinity profile, corresponding to sample localities. A trend of increasingly brackish conditions to the lower end of the brackish spectrum is seen through samples A1 to A4. Sample A5 shows a slight increase in salinity, whereas A6 shows another fall. A return to more 'normal' marine salinity is seen in samples A7 and A8, whereas sample A9 has a much reduced salinity, approaching freshwater. A return to more brackish conditions is witnessed in sample A10.

The adult valve:caparace ratio is also shown in Figure 2.8. Interpretation of the latter is not easy as it will have been influenced by sedimentation rate, Ostracoda habitat, and hinge structure of the Ostracoda. A low ratio may indicate either limited post-mortem

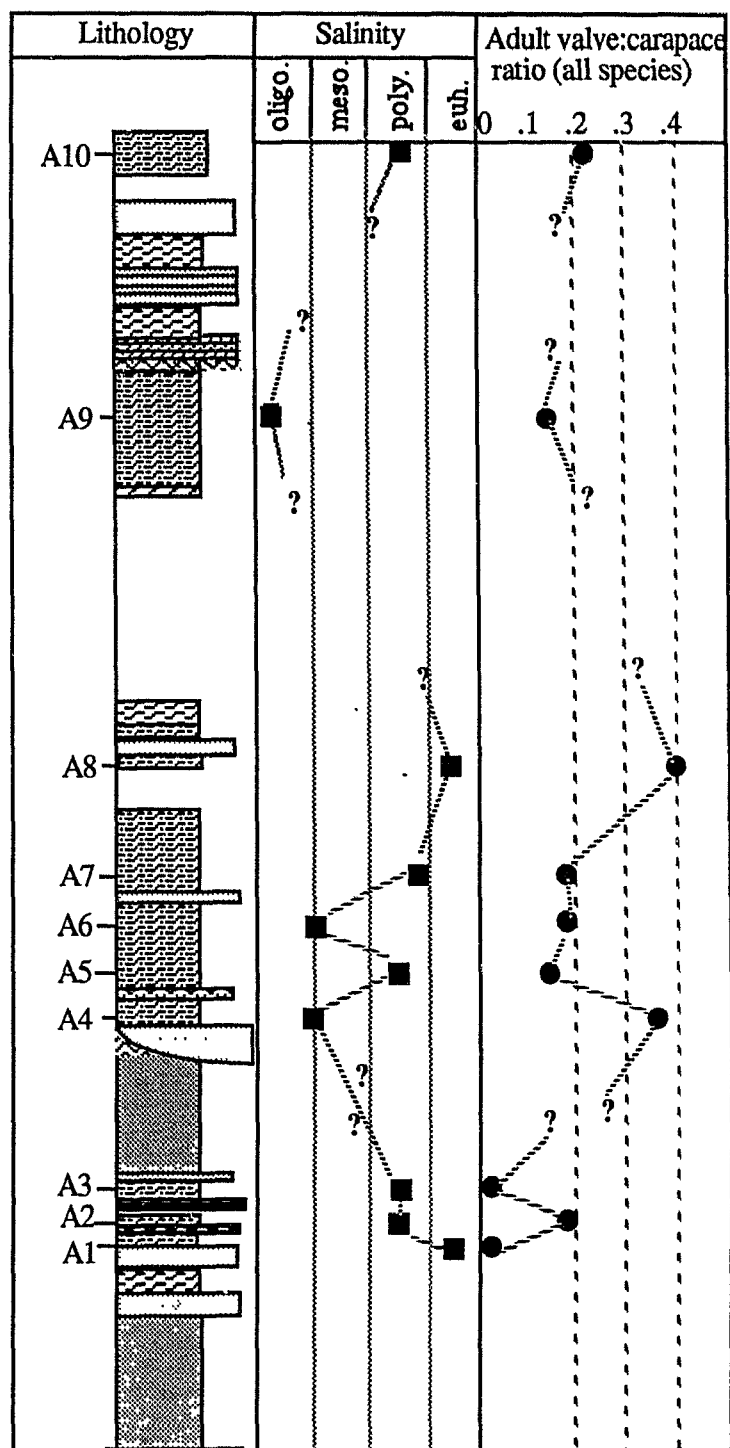


Figure 2.8: Salinity profile and adult valve:carapace ratio for the Praia Azul section, determined from serial counts of the ostracod populations.

transportation or rapid burial of specimens prior to decay of the ligament tissue. The implication of rapid burial is that the rate of sedimentation was high. The life habitat of the Ostracoda will also have had an important effect on the proportion of free valves. Epifauna would have been more prone to valve disarticulation after death than infauna. Species with relatively stronger hinge articulation (eg. *Cytheropteron*) also would have been less susceptible to disarticulation on death. With these points in mind, an examination of the adult valve:carapace ratio reveals low values for samples A1-A3, possibly indicating low energy levels. In comparison with the other samples, specimen counts for samples A1-A3 are not especially low, and sedimentation rate is not thought to have been unusually high. Abundant *Paranotacythere*, regarded as epifaunal (Wilkinson 1983), supports this inference. A low specimen count in sample A4 makes interpretation difficult. The high ratio suggests relatively high energy conditions, but the presence of articulated *Darwinula leguminella* in this sample may indicate relatively low energy levels since this species has a weak hinge. Low valve:carapace ratios are seen in samples A5-A7 and may reflect reduced energy conditions. The high ratio in sample A8 may reflect increased energy levels. A reduction in energy levels is suggested by the low ratio in sample A9, whereas the increase in the ratio in A10 may indicate a slight increase in energy. Estimating energy levels using the Ostracoda valve:carapace ratio alone is difficult. Reworking of Ostracoda populations or sediments would be hard to detect using this ratio, and paleoenvironmental implications from this would be tenuous.

In summary, the use of serial counts of adult and juveniles Ostracoda is of value in determining associations between different species. The interpretation (see Table 2.5) of *Galliaecythereidea postrotunda*, *Fabanella boloniensis* and *Darwinula leguminella* as part of an autochthonous assemblage in Sample A4, for example, suggests the latter species was more tolerant of lowered salinity than previously thought. In terms of defining paleosalinity, use of serial counts does not offer more precision than simple abundance data. The latter suffices to identify the main trends. Interpretations based on serial counts

probably differ little from those based on raw data because the assemblages have undergone little reworking; most appear autochthonous. This supports Fursich's (1981) conclusion that the bivalve associations are autochthonous.

Following analysis of the Ostracoda in the Praia Azul section, the salinity tolerances of the Praia Azul Ostracoda may be revised (Figure 2.9). *Mantelliana cyrton*, previously regarded as freshwater, is now thought to have been tolerant of slightly brackish conditions (salinity up to 5‰); *Cetacella armata* and *Rhinocypris jurassica* are considered to have had higher salinity tolerances than previously thought, and may co-occur with *Fabanella boloniensis*; *Darwinula leguminella* has a significantly higher salinity tolerance than previously estimated, and is found with *Galliaecytheridea* and *Fabanella* in the lower Mesohaline paleosalinity; species of *Paranotacypthera* and *Cytheropteron* are regarded as less tolerant than previously thought, and appear to have been restricted to upper brackish paleosalinity; *Galliaecytheridea postrotunda* seems to have been tolerant of a wider range in paleosalinity than *Galliaecytheridea* sp2, the latter occurring in more euhaline conditions along with *Cytherella*, *Cytherelloidea* and *Paracypris*.

2.3.2: Foraminifera.

2.3.2.a: Distribution of superfamilies.

The Foraminifera are classified (Chapter 8) according to Loeblich and Tappan (1964). The assemblages are dominated by the superfamilies Lituolacea and Nodosariacea. Miliolacea are represented in one sample (A3). Planktonic Foraminifera are not represented. The distribution of the superfamilies is shown in Figure 2.10, in which the Lituolacea are divided into their 'larger' and 'smaller' components. Interpretation of the relative abundance of the groups must be made with caution due to low specimen counts in some samples. This makes quantitative analysis difficult even though the majority of samples contain 150- 200 specimens.

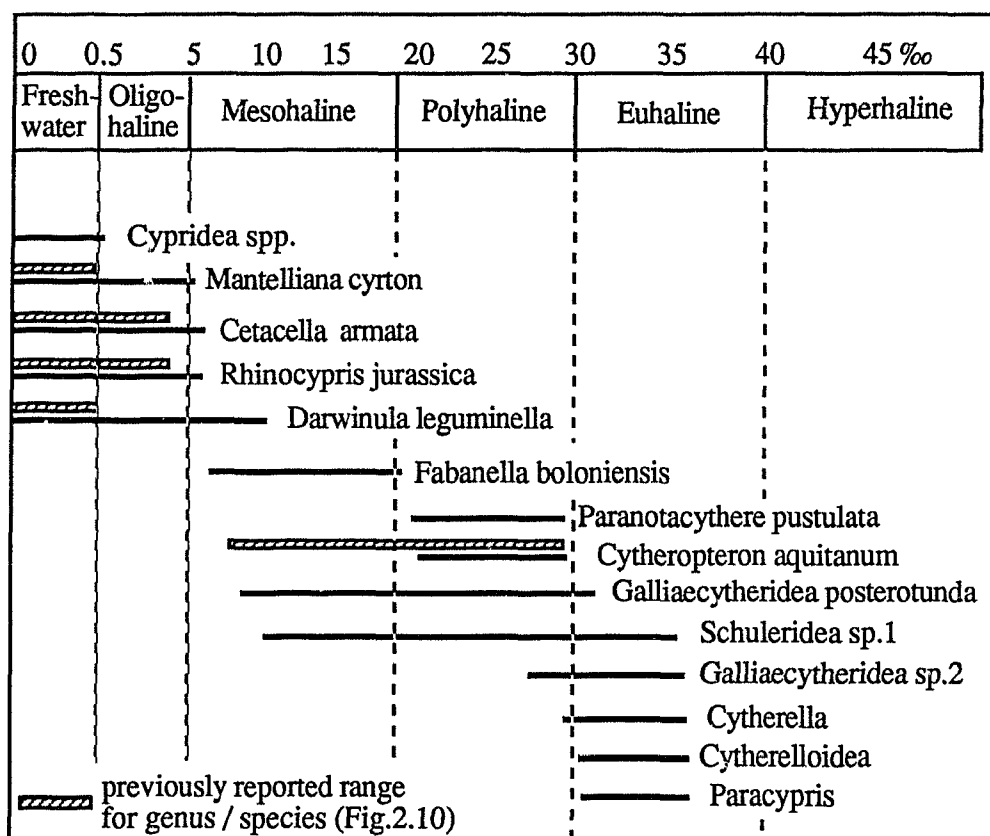


Figure 2.9: Salinity tolerances of the Praia Azul ostracoda based on species associations determined through serial counts of the ostracod populations. Salinity classification after Neale (1988).

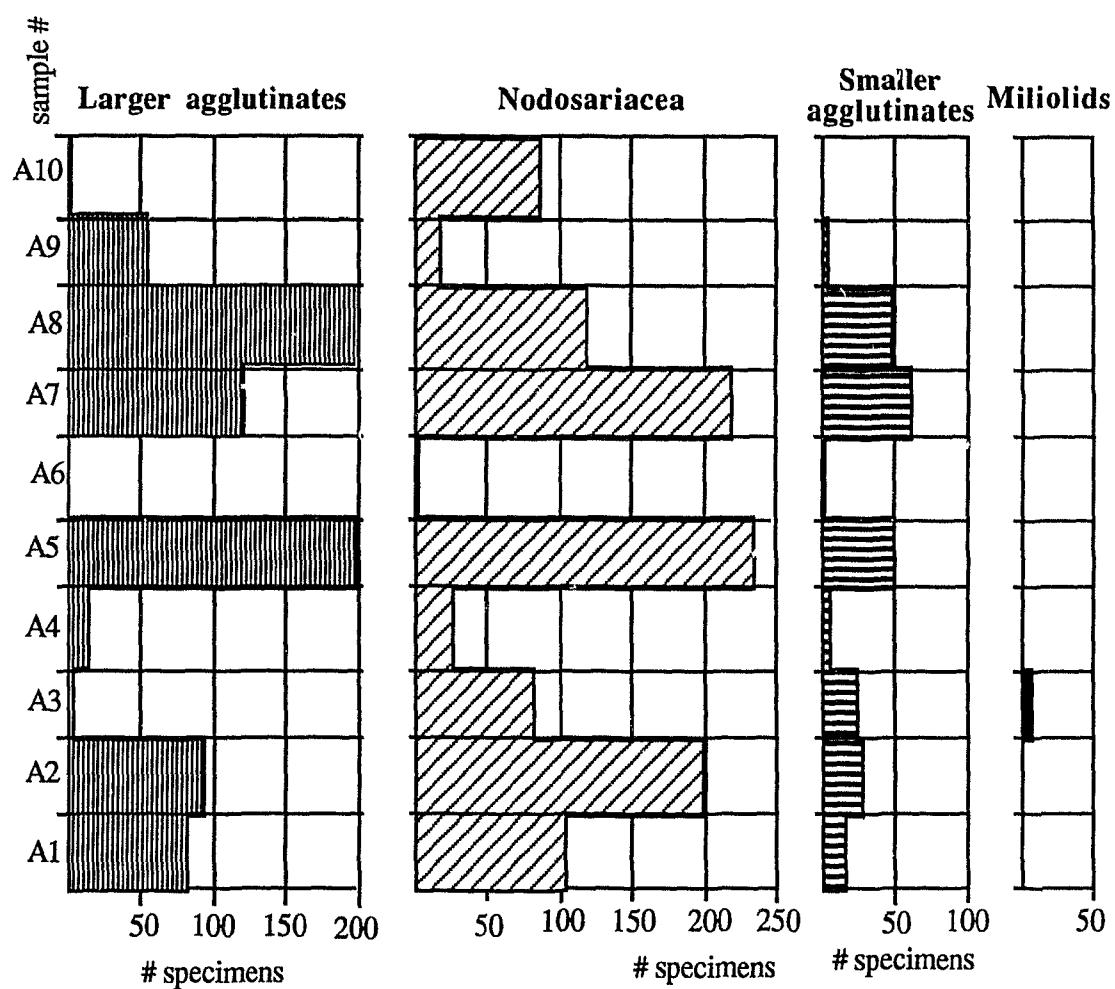


Figure 2.10: Bar graphs showing the distribution of the Foraminiferal Superfamilies in the Praia Azul samples. The Lituolacea are sub-divided into 'larger' and 'smaller' agglutinates.

Complex 'larger' forms predominate at some sample locations, and show abundance peaks (Figure 2.10). The simple 'smaller' representatives of the Lituolacea are less abundant. The high abundance of the smaller lituolids in sample A6 is regarded as spurious because of the low specimen count (this may be partly true for samples A9 and A10 where specimen counts are less than 100). The Nodosariacea are well represented, commonly making up about 50% of the assemblage. An apparent dearth and abundance of nodosariids occurs in samples A9 and A10 respectively, although specimen counts are low.

2.3.2.b: Distribution of species.

The distribution of species in the samples (Tables 2.6 and 2.7) is variable and not obviously related to lithology. The number of Foraminiferal species in each sample is also variable (Figure 2.4) ranging from two to nine.

With the exception of *Eoguttulina*, all genera represented show only one species. *Eoguttulina* is the only representative of the nodosariids and shows four species, of which *E. liassica* is the most common and numerically the most abundant in all but one sample (excluding sample A6). The "larger" lituolids are represented by *Choffatella tingitana*, *Everticyclammina virguliana*, *Mesoendothyra* sp.A and *Rectocyclammina arrabidensis*. *Everticyclammina virguliana* is abundant only in sample A1 where it is found with lower counts of *Freixialina planispiralis* and *Rectocyclammina arrabidensis*. The latter species is more abundant in sample A2, where it is found in a relatively higher diversity assemblage along with low numbers of *Haplophragmoides concavus*, *Choffatella tingitana* and other species.

Eoguttulina shows high abundance and is represented by all four species in the lower part of the section. In sample A3 abundant *Eoguttulina liassica* is found with moderate abundances of *Haplophragmoides concavus*, low numbers of *E. inovroclaviensis*, *Quinqueloculina* sp., *Rectocyclammina arrabidensis*, *E. oolithica* and

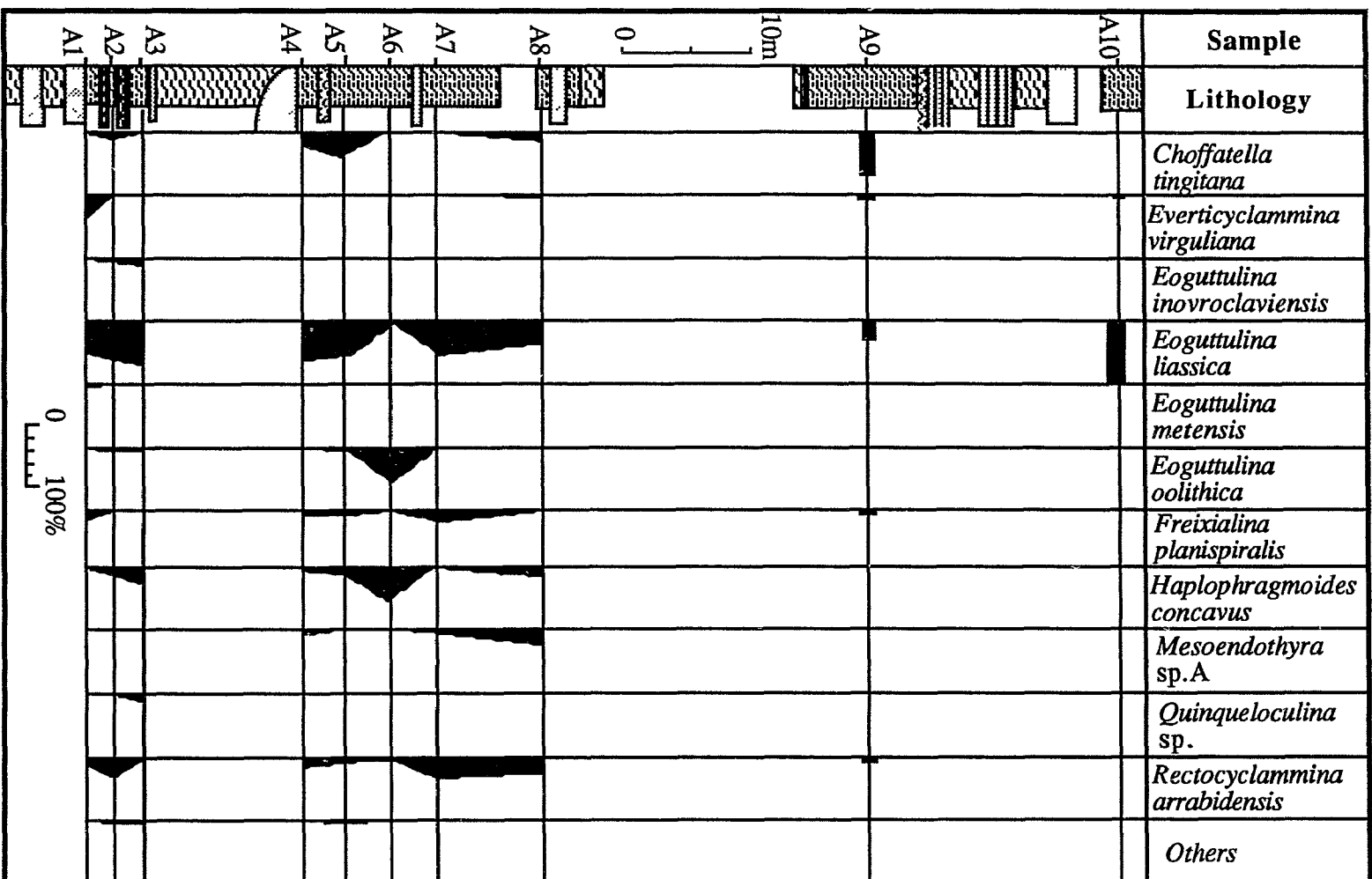


Table 2.7: Relative abundance (percent) of Foraminiferal species at Praia Azul.

Ammomarginulina sp. Sample A4 contains moderate abundances of *Choffatella tingitana* and *Rectocyclammina arrabidensis* together with low abundances of *Haplophragmoides concavus* and *Mesoendothyra* sp.A. *Choffatella tingitana* is of high abundance in sample A5, along with lower abundances of *Haplophragmoides concavus* and *Rectocyclammina arrabidensis*.

Sample A7 contains abundant *Rectocyclammina arrabidensis*, a moderate abundance of *Freixialina planispiralis* and rare *Mesoendothyra* sp.A. Sample A8 also has abundant *Rectocyclammina arrabidensis* and *Mesoendothyra* sp.A. *Haplophragmoides concavus* and *Choffatella tingitana* occur in moderate to low abundance in this sample, along with rare *Everticyclammina virguliana*. *Choffatella tingitana* is the dominant species in sample A9, also rare *Rectocyclammina arrabidensis* and *Freixialina planispiralis* are found. Sample A10 is composed almost entirely of *Eoguttulina liassica*.

Choffatella tingitana, *Everticyclammina virguliana*, *Rectocyclammina arrabidensis* and *Mesoendothyra* sp. stand out as having locally high relative abundances (>20%), although with the exception of the latter two species in sample A8, do not co-occur in high numbers.

2.3.2.c: Foraminiferal morphogroups as indicators of habitat.

With the exception of the calcareous taxa, the Praia Azul Foraminifera are members of the superfamily Lituolacea, and this group may be subdivided into informal "larger" and "smaller" components as discussed above. A characteristic of the "larger" Foraminifera, apart from their frequently large (>1mm) size, is that they have complex endoskeletons in which the chambers are commonly subdivided into chamberlets. "Smaller" benthic Foraminifera, in contrast, do not have subdivided chambers and are usually small (<1mm). Species within each group show considerable variety in test architecture and shape (see Chapter 8).

Little work has dealt with the relationship between Foraminiferal test morphology,

habitat and the environment, although it is thought that such a relationship exists (Brazier, 1975; Severin, 1983; Corliss, 1985). Jones and Charnock (1985) analysed data on life positions and feeding habits of recent agglutinating Foraminifera, and recognised four main Foraminiferal morphogroups whose distribution appeared related to an appropriate food supply. The Foraminiferal morphogroups, their life positions and feeding habits are summarized in Table 2.8.

Using a uniformitarian approach, classifying the Praia Azul Foraminifera into morphogroups may assist in paleoenvironmental and paleoecological interpretations. As Jones and Charnock's (1985) morphogroup classification deals only with agglutinating taxa and does not take account of calcareous species, it is necessary to modify their scheme. The calcareous taxa *Eoguttulina* and *Quinqueloculina* have smooth, elongate to fusiform streptospirally coiled tests that may be adaptations to an infaunal lifestyle (Brazier, 1979). Elongate streptospiral test form is assigned by Jones and Charnock (1985) to morphogroup C2, typified by the agglutinated genus *Milliamina*. The latter species is reported as wholly infaunal (Frankel, 1975).

Jones and Charnock's (1985) scheme groups both the larger and smaller planispiral or trochospiral lituolids together in subgroup B3. Little is known of the ecology of 'larger' Foraminifera, although Murray (1973) indicates the majority live in the protection of sea-grass and seaweed within the photic zone, and feed on associated calcareous and filamentous algae. It is also reported (Murray, 1973; Hottinger, 1978) that algae are often found within tests of living Foraminifera, and Haynes (1965) suggested such relationships were symbiotic. Smaller lituolids, in contrast, are reported from virtually all water depths and are not restricted to the photic zone. In view of the likely differences in feeding habits, the general difference in size, and the obvious difference in internal morphology, it is reasonable to treat the larger and smaller lituolids as separate morphogroups. The classification of the Praia Azul Foraminifera into morphogroups, and their relationships to Jones and Charnock's (1985) scheme is shown in Table 2.8. Possible relationships

Morpho-group	Sub-group	Chambers	Test form	Life position	Feeding strategy	Examples
A	A	uni/multi-locular	tubular or branching	erect	suspension-feeders	Komakiaceans Astrorhizids
B	B 1	unilocular	globular	epifaunal/ infaunal	passive deposit-feeders	Saccamminids
	B 2	unilocular, ?multilocular	coiled (flattened)	epifaunal	active deposit-feeders	Ammodiscids, ?Rzehakinids
	(i) B 3	multilocular	planispiral/ trochospiral (lenticular)	epifaunal	active herbivores, detritivores, omnivores	Most Lituolids, <i>Trochammina</i> s.l.
C	(iii) C 1	multilocular	elongate (mixed growth etc.)	infaunal	detrital/ bacterial scavengers	Hormosinids, Uncoiling Lituolids, Textulariids, Verneuulinids, Eggerellids, Ataxophragmiids, Valvulinids
	(iv) C 2	multilocular	elongate quinque- loculine	infaunal	detrital/ bacterial	<i>Miliammina</i> , ?some Rzehakinids
D	(ii) D	multilocular	trochospiral (conical)	epifaunal (attached)	herbivores	most Trochamminids

Table 2.8: Foraminiferal morphogroups, their life positions and feeding habits (After Jones and Charnock, 1985); equivalent groups in this study shown in open black circles. See Figure 2.11 for interpreted life habitats of morphogroups identified in this study.

between Foraminiferal test morphology, life position and feeding strategy are presented in Figure 2.11.

Some overlap exists between certain members of the Praia Azul Foraminiferal morphogroups. *Everticyclammina virguliana*, for example, sometimes has a reduced uncoiled portion, and *Freixialina planispiralis* may have a short uncoiled stage. Morphogroup iii includes both "larger" and "smaller" uncoiled forms: absence of subdivided chambers in *Everticyclammina* and *Rectocyclammina* justifies this approach. *Mesoendothyra* sp.A, although having only minor chamber subdivisions, is grouped with Morphogroup i.

The relative abundance of the four morphogroups in the Praia Azul section is shown in Figure 2.12. The following trends are noted: Group i) shows two 'peaks', (sample A5 and A9); Group ii retains a low 'background' distribution but has tendency toward lower abundance where the planispiral complex forms (Group i) are most abundant; Group iii) has two peaks (sample A1 and A7), with an upward decline as planispiral complex forms increase; Group iv) has a high abundance, with a higher abundance in samples up to A3, and a lower abundance to sample A9, and an increase in A10.

2.3.2.d: Relationship to Fursich's (1981) framework, Ostracoda associations and field observations.

Work on the life positions and feeding habits of Recent Foraminifera is limited and often inconclusive. Application of these concepts to extinct Foraminiferal genera is therefore speculative. Jones and Charnock (1985) observed, however, that the habitats of their Foraminiferal morphogroups compared well with those of the associated macrofaunal feeding groups outlined in Sokolova (1959) and Zenkevitch (1963). Comparison of inferred life habitats of the Praia Azul Foraminifera with the associated invertebrate fossils outlined in Fursich (1981), as well as the Ostracoda, supports Jones and Charnock's

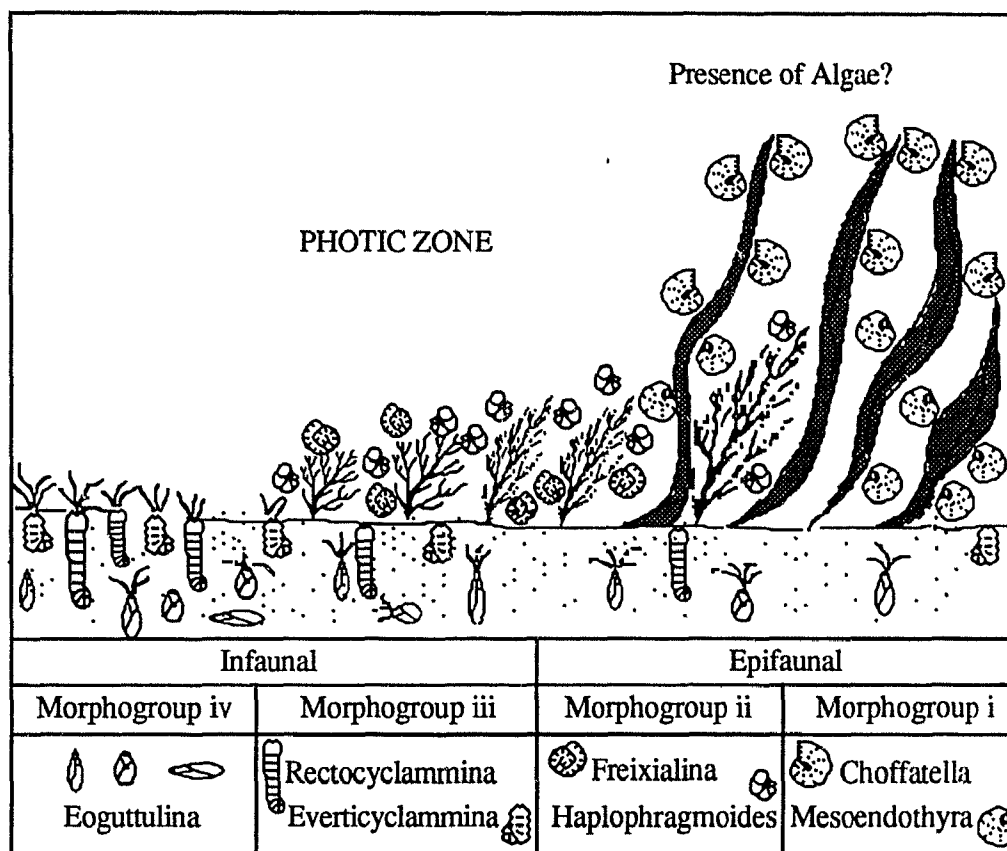


Figure 2.11: Interpreted life habitats for the Praia Azul Foraminiferal morphogroups. Phytal interpretations are speculative; the agglutinated Foraminifera would have had to have been in close proximity to the sedimentary substrate for a supply of grains for test construction. Epifaunal forms were probably motile, since adherant morphologies (those with flat or concave ventral surfaces) are not seen.

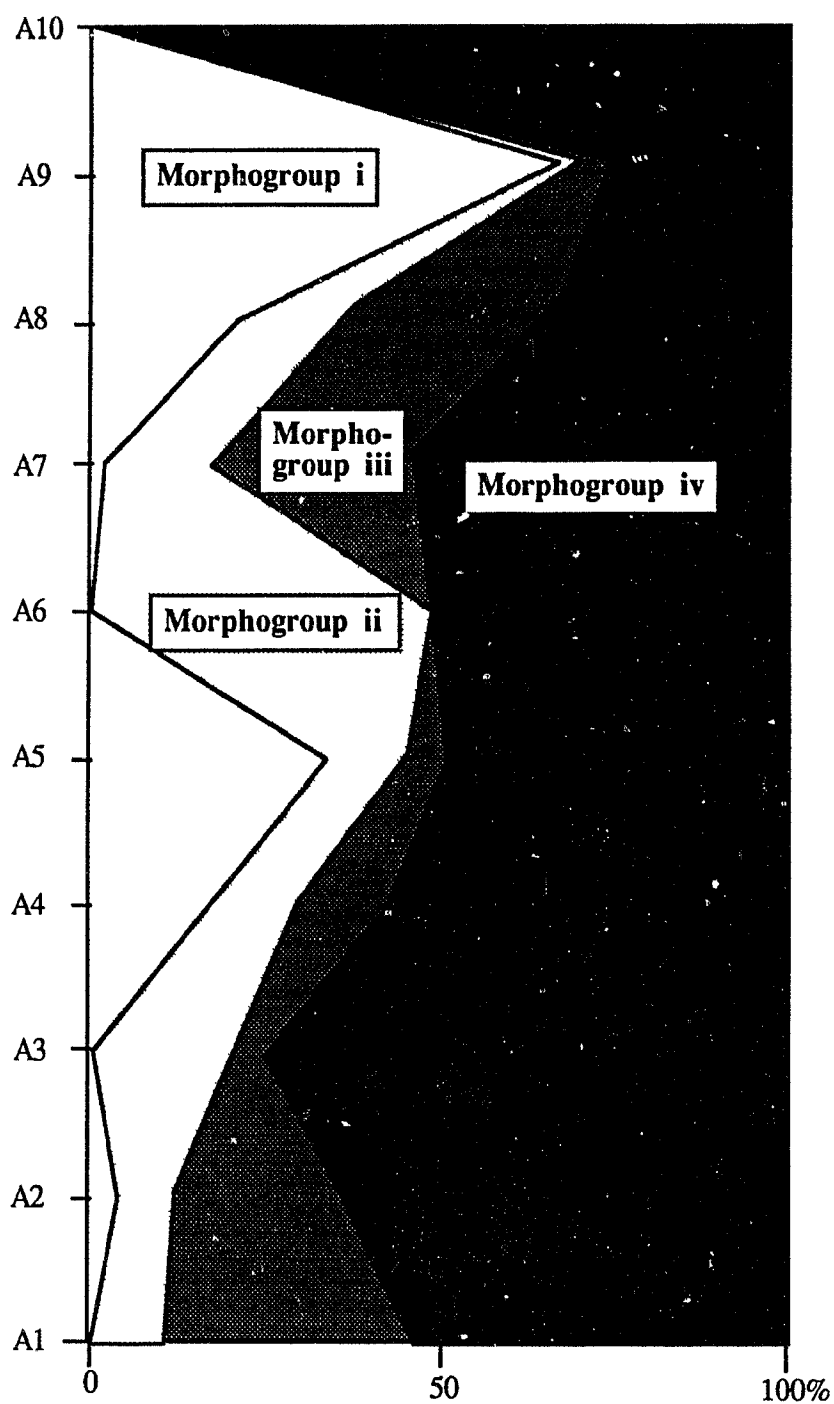


Figure 2.12: Area graph showing the distribution of the foraminiferal morphogroups in the Praia Azul section.

(1985) observations.

The Praia Azul Foraminifera may be classified into two broad groups: epifaunal and infaunal. The epifaunal group includes planispiral-lenticular "larger" lituolids (morphogroup i) and planispiral/trochospiral "smaller" lituolids (morphogroup ii). The infaunal group encompasses the uncoiling (both "larger" and "smaller") lituolids (morphogroup iii), and the streptospiral calcareous taxa (morphogroup iv). The inferred life positions and feeding habits of the morphogroups depicted in Figure 2.11 are generalizations, based on Jones and Charnock (1985) and data in Murray (1973), and there are exceptions to these interpretations: 1) certain species of *Haplophragmoides* and *Trochammina* (morphogroup ii) live infaunally (D. Scott, pers. comm., 1989); 2) *Ammobaculites* (morphogroup iii) has also been reported as vagrant epifauna (Dobson and Haynes, 1973); 3) the Recent "larger" Foraminifera *Amphistegina* has been reported from sedimentary substrates lacking flora (Seiglie, 1970).

The presence of morphogroup iv in all samples indicates an infaunal habitat within soft sediment existed throughout deposition of the unit. An epifaunal habitat was developed at certain times only, as indicated by local abundances of morphogroups i and ii. Samples A4, A5, A8 and A9 stand out as having the largest proportions of epifaunal morphogroups i and ii, suggesting the presence of a well established phytal community. Sea-grasses are not apparent in the fossil record before the mid-Cretaceous (Brazier, 1975b), so it is likely that the phyta consisted of seaweeds and algae. The samples were recovered from siltstones that contained oysters, gastropods, and echinoid spines assigned to the *Praeexogyra pustulosa*-*Nanogyra nana* benthic association of Fursich (1981). The latter association consists almost entirely of epifaunal elements, of which the gastropods and the echinoderms were probably algal browsers, and the bivalves suspension feeders (Fursich, 1981). The interpretation of Foraminiferal morphogroups i and ii in samples A4, A5 and A8 as epifaunal, accords with Fursich's (1981) conclusions. The position of morphogroups i and ii with respect to the vegetation depicted in Figure 2.11 is speculative;

the Foraminifera would have had to be within close proximity to the sedimentary substrate for test building materials.

Sample A10 contains morphogroup iv only, suggesting absence of a floral community. The sample was taken from siltstone containing bivalves belonging to the *Mesosaccella danmariensis*-*Corbulomima suprajurensis* benthic association of Fursich (1981). The latter association is dominated by shallow burrowing infaunal bivalves of very small size, of which 25% were deposit feeders and 75% suspension feeders (Fursich, 1981). The infaunal habitat inferred for Foraminiferal morphogroup iv is supported by Fursich's (1981) interpretation. The Ostracoda in sample A10 are dominated by *Paranotaclythere pustulata*, which Wilkinson (1983) interpreted as an epifaunal deposit feeder. Wilkinson's interpretation for the latter species does not go against the findings of Fursich (1981) or this study, and supports the idea that flora was absent or poorly developed when these strata were deposited.

Samples A1-A3 and A7 contain mixed proportions of Foraminiferal morphogroups. Moderate abundances of morphogroup ii, but rarity of morphogroup i, suggests limited flora at the time of deposition, lacking the flora to which morphogroup i was presumably suited. Samples A1-A3 came from siltstones containing the *Jurassicorbula edwardi* association of Fursich (1981), in which epifaunal bivalves make up about 25% of the assemblage, and infauna making up the remainder. The majority (98%) of bivalves in the benthic assemblage are suspension feeders (Fursich, 1981). The interpretations for the Foraminiferal morphogroups in samples A1-A3 are in accord with Fursich's (1981) findings.

The inferred habitats of the Foraminiferal morphogroups are broadly comparable with those of the bivalve feeding groups in Fursich (1981), and support the conclusions reached by Jones and Charnock (1985) who compared their morphogroup habitats with those of macrofaunal feeding groups in Sokolova (1959) and Zenkevitch (1963).

2.4: Praia Azul paleoecology and paleoenvironments.

The distribution of living Ostracoda and Foraminifera is governed by a number of ecological factors including salinity, temperature, light, availability of calcium carbonate, oxygen, substrate, food, and predation. Many of the forgoing are controlled by water depth, and although in many studies this is the only parameter determined, depth is not thought to be a direct control in itself (Funnell, 1967). Each species has a particular range of tolerance for each ecological parameter, within which it may survive and reproduce (Murray, 1973; Brazier, 1979). The above ecological parameters for Foraminiferal and Ostracodal species are sometimes determined through field observation, but usually by laboratory studies, and as such, may not take account of diurnal or seasonal variability. Paleoecological studies rely on the principal of uniformitarianism, which may not always be valid, and deal with fossil assemblages that may have undergone significant postmortem changes. These difficulties combine to make interpretation tentative. Despite these shortcomings, analysis of Ostracoda and Foraminifera in the Praia Azul section has resulted in some interesting paleoecological conclusions.

2.4.1: Salinity.

The Praia Azul Ostracoda assemblages may be grouped into marine, brackish and freshwater assemblages, suggesting that salinity was a major ecological control at the time of deposition. Salinity ranged from oligohaline or lower mesohaline (about 5‰) to upper polyhaline or euhaline (30-35 ‰). Salinity tolerances of the Foraminifera may be inferred from their association with the Ostracoda salinity groups, and are proposed in Figure 2.13. *Choffatella tingitana* is associated with brackish Ostracoda, and its high abundance with the Ostracoda *Fabanella*, *Cypridea* and *Darwinula* indicates that it thrived under lower brackish conditions and suggests that it may be an opportunistic species (Levinton, 1970). The brackish tolerance of *C. tingitana* contrasts with the salinities in which Recent larger

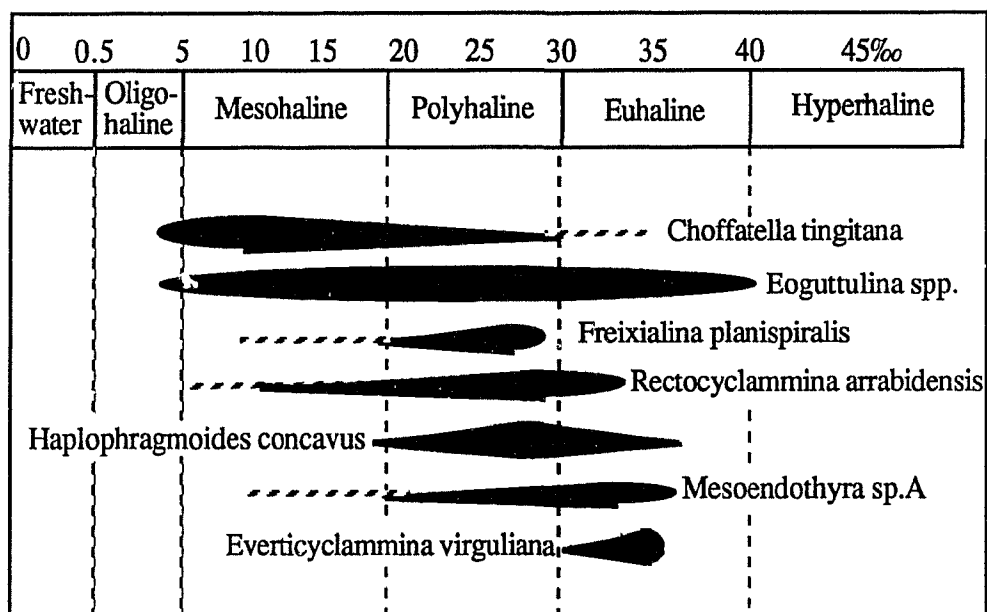


Figure 2.13: Salinity tolerances of the Praia Azul foraminifera, based on their association with ostracoda. Thickness of the line proportional to the degree of tolerance.

Foraminifera are found; Murray (1973) indicated normal marine to hypersaline environments (34-53‰) for living larger Foraminifera. *Choffatella* and the other cyclamminids were previously regarded as normal marine or hypersaline indicators (M.B. Hart, personal communication, 1990). *Eoguttulina* occurs in abundance with brackish to euhaline Ostracoda although is less common when associated with lower mesohaline and oligohaline forms, which suggests it was euryhaline but probably not an opportunist. *Freixialina planispiralis* seems to be euryhaline, although is more abundant in association with upper brackish (polyhaline) Ostracoda. *Rectocyclammina*, *Haplophragmoides* and *Mesoendothyra* occur with upper mesohaline to upper polyhaline Ostracoda, although are slightly more abundant with the latter group. Data in Murray (1973) indicate *Haplophragmoides* is a euryhaline form. *Everticyclammina* appears restricted to euhaline conditions, as indicated by the association with *Cytherella*.

2.4.2: Temperature.

Recent "larger" Foraminifera occur in warm (>25°C) water (Murray 1973), although they may colonize areas with lower temperatures but are unable to reproduce. The Ostracoda *Cytherelloidea weberi* is thought to be a warm water (>20°C) indicator (Neale, 1973). The paleolatitude of about 25° north at the time of deposition (Hiscott *et al.*, 1990) suggests temperature was not a factor affecting distribution of Foraminifera or Ostracoda at Praia Azul, as the July sea-surface temperature over the Lusitanian Basin would have been about 28°C (Lloyd, 1982). Diurnal or seasonal temperature changes, however, would have had a broader range within more marginal environments.

2.4.3: Light.

There is no evidence that light directly controls the distribution of living Foraminifera (Murray, 1973), although it may partly control the distribution of flora with which Foraminifera may be associated. Presence of "larger" Foraminifera in most samples

indicate paleoenvironments were within the photic zone. Presumed absence of vegetation in sample A10 may be the result of other factors (e.g. turbulence), and it is thought that illumination was not a controlling factor during deposition. The majority of the Ostracoda have eye spots, a characteristic of Ostracoda from the photic zone (Brazier, 1979).

2.4.4: Calcium carbonate.

Temperature, salinity, and availability of oxygen control the solubility of calcium carbonate in sea water. It is generally plentiful in low latitude warmer waters. Abundant calcareous *Eoguttulina* indicate that calcium carbonate availability was not a limiting factor in at the time of deposition.

2.4.5: Oxygen.

Oxygen availability is not a limiting factor affecting the distribution of living Foraminifera (Murray, 1973). Wilkinson (1983), however, reported abundant *Paranotacythere pustulata* from the Kimmeridge Clay of England, and regarded it as an 'explosive opportunist' capable of rapid reproduction in anaerobic environments brought on by high organic productivity. Oxygen availability was not thought to have been a limiting factor in the Praia Azul paleoenvironments since bivalves are plentiful through most of the section including strata where *Paranotacythere pustulata* is abundant. The high abundance of the Ostracoda indicates that it was probably an opportunistic species that took advantage of rapid salinity changes that killed off immediate competition.

2.4.6: Substrate and food.

The substratum includes, apart from the sediment itself, firm surfaces such as the leaves and stems of seaweed and other plants. Although there was no evidence of plants in the section, the larger Foraminifera suggest that they were present, as discussed above. In this sense, substrate was a significant ecological factor controlling the distribution of the

Praia Azul assemblages since it also reflects the source of nutrients. Absence of plano-convex or concavo-convex morphologies typically associated with adherant life styles (on plant, rock, or faunal substrates) suggests the Foraminifera were capable of motility during life. Soft muddy sediment was an essential prerequisite for the infauna and probably much of the flora, although the sediment itself does not appear to have had an impact on the distribution of the microfossils since different species associations are found in adjacent samples from the same lithology. Sample lithology is predominantly siltstone, and any variability within this would require detailed petrological analysis.

Purdey (1964) suggested that argillaceous facies probably acted as a 'stable reservoir' for detrital organic matter, which may explain why infaunal morphogroup iv is abundant in most samples. As infauna, morphogroup iv would probably have been buffered from the immediate effects of short-term environmental changes (i.e. diurnal or seasonal fluctuations in salinity, turbidity or local temperature) that may have been unfavorable to other morphogroups. Morphogroup iii, interpreted as infaunal detrital/bacterial scavengers (Jones and Charnock, 1985) living in the sediment immediately beneath the sediment-water interface, would likely have been more susceptible to environmental changes. The epifaunal morphogroups, regarded as essentially phytal, would have been exposed to the immediate effects of short term environmental fluctuations. *Choffatella* appears to have been the most euryhaline Foraminiferal species, and as such, was probably tolerant of salinity variability.

A relationship between the Ostracoda, substrate and food is not so evident. Most Recent marine Ostracoda are infaunal burrowers or epifaunal crawlers, thriving on (or in) silts, muddy sands, or on aquatic plants; they may be scavengers or filter feeders, living on detritus or living organisms (Brazier, 1979). *Paranotacythere* and *Schuleridea* are considered epifaunal (Wilkinson, 1983), and the coarse reticulation on the former Ostracoda is characteristic of forms from coarser, near-shore substrates (Brazier, 1979). Smooth elongate Ostracoda typically live infaunally, as burrowers within silts and muds

(Brazier, 1979), and the high incidence of *Cytherella* juveniles may be an indication that it was infaunal. *Galliaecytheridea* species are smooth, slim and elongate, characteristic of Recent phytal Ostracoda (Brazier, 1979). *Cytheropteron* may be an epifaunal vagrant that crawled on soft fine-grained substrates, prevented from sinking into the soft sediment by its alar projections (Brazier, 1979). Recent freshwater species swim a short distance above the substrate for much of the time (E. Robinson, pers. comm., 1985), and the same is probably true for the ancient forms found at Praia Azul. There is no evidence of predation amongst the Ostracoda in this section.

2.4.7: Paleoenvironments.

Fursich (1981) recognised prodelta, delta front, brackish bay and brackish lagoonal paleoenvironments on the basis of the sedimentology and the bivalve assemblages. Three salinity-controlled paleoenvironments are determined from the Ostracoda, and these may be sub-divided according to habitat, determined from the Foraminiferal morphogroups: 1) Marine (euhaline) to slightly brackish (polyhaline), (Figure 2.14 and Table 2.9), corresponding to Fursich's brackish bay or lagoon environment; 2) Brackish (polyhaline), (Figure 2.15 and Table 2.10), corresponding to Fursich's brackish lagoon environment; 3) Lower brackish to freshwater, (Figure 2.16 and Table 2.11), not recognised on Fursich's benthic associations, but representing back-reef environments subject to fluvial discharge. Figure 2.17 shows the relationship of the samples to salinity and habitat/substrate. Lithologic and biofacies trends, and paleoenvironmental interpretations are summarized in Figure 2.18, which shows a floodplain environment changing upward into brackish lagoon and alternating back-reef lagoon environments. Paleoenvironmental interpretations of Fursich (1981), based on sedimentology and benthic associations, are generally supported by the Ostracodal evidence. The Foraminiferal morphogroups allow sub-environments, possibly related to aquatic vegetation, to be distinguished.

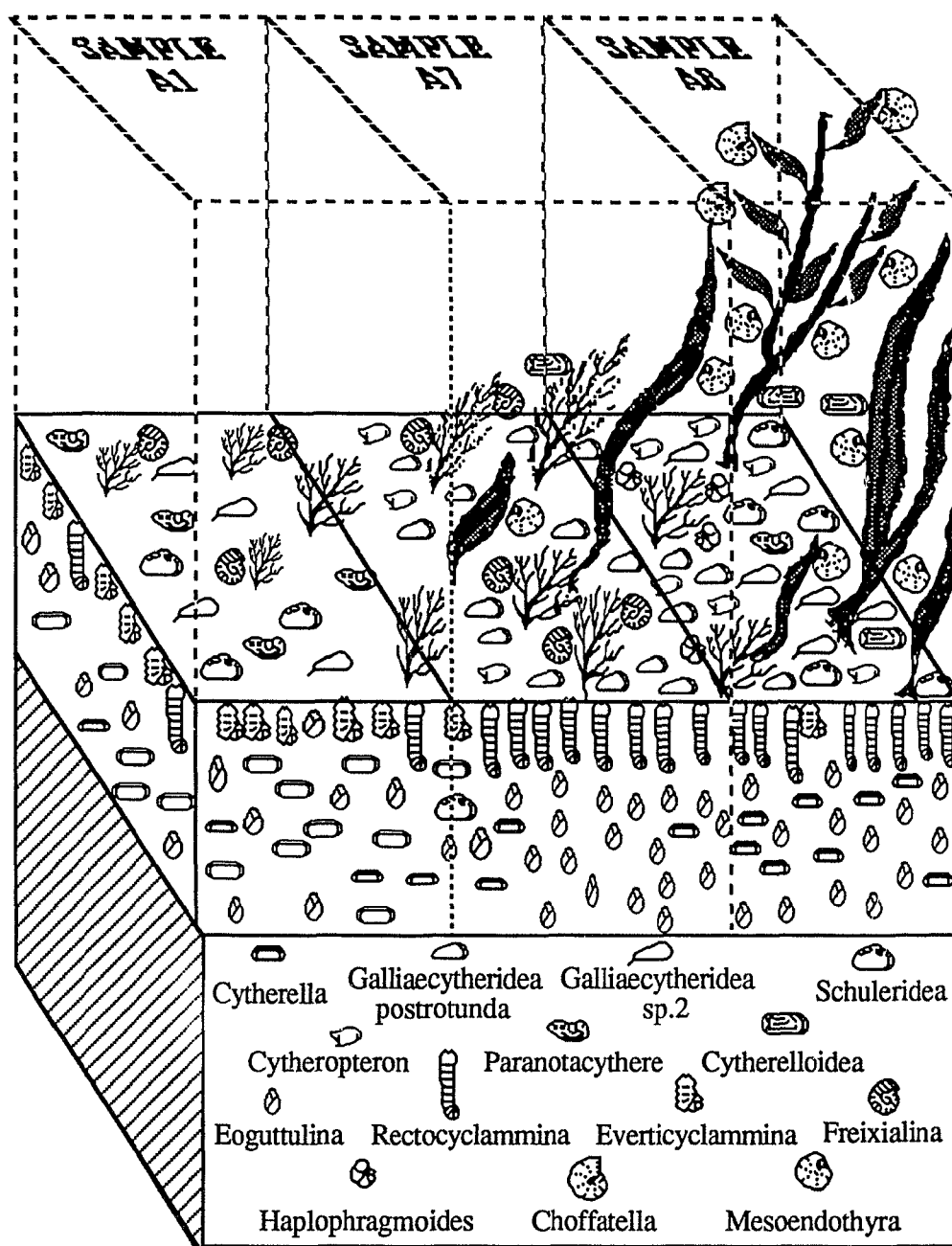


Figure 2.14: Distribution of samples in marine (euhaline) paleosalinities in the Praia Azul section. Sample A1 represents an unstable substrate, sample A8 a stable substrate with a 'climax' community of plants, infauna and epifauna. See Table 2.9 for additional remarks.

MARINE TO SLIGHTLY BRACKISH PALEOENVIRONMENTS					
OSTRACODA	AUTOCHTHONOUS			ALLOCHTHONOUS	
	<i>Schuleridea</i> sp.1, <i>Galliaecytheridea</i> sp.2, <i>Cytherella fullonica</i> , <i>Paranotacythere pustulata</i> , <i>Cytherelloidea weberi</i> , <i>Paracypris</i> sp.			<i>Cytheropteron aquitanum</i>	
FORAMINIFERA	<i>Rectocyclammina</i> , <i>Evericyclammina</i> , <i>Mesoendothyra</i> , <i>Freixialina</i> , <i>Eoguttulina</i> , <i>Choffatella</i> .				
	Sample A1		Sample A7		Sample A8
	Morphogroup	%	Morphogroup	%	Morphogroup %
	iv	55	iv	53	iv 35
	iii	35	iii	30	iii 30
	ii	10	ii	15	ii 15
			i	2	i 20
INTERPRETATION	Dominance of infauna suggests absence of vegetation, perhaps due to current activity. Ostracoda dominated by smooth forms interpreted as infaunal (Whatley 1983).		Infauna and epifauna suggests transitional environment with limited vegetation and moderate currents. Alate ostracoda (<i>Cytheropteron</i>) may indicate a soft muddy substrate.		Dominance of Morphogroup i and presence of all other forms suggests well established flora, with limited current activity. Optimum environment for all trophic levels.

Table 2.9 : Subenvironments interpreted from foraminiferal morphogroups within euhaline to slightly polyhaline Ostracodal biofacies. See Figure 2.14.

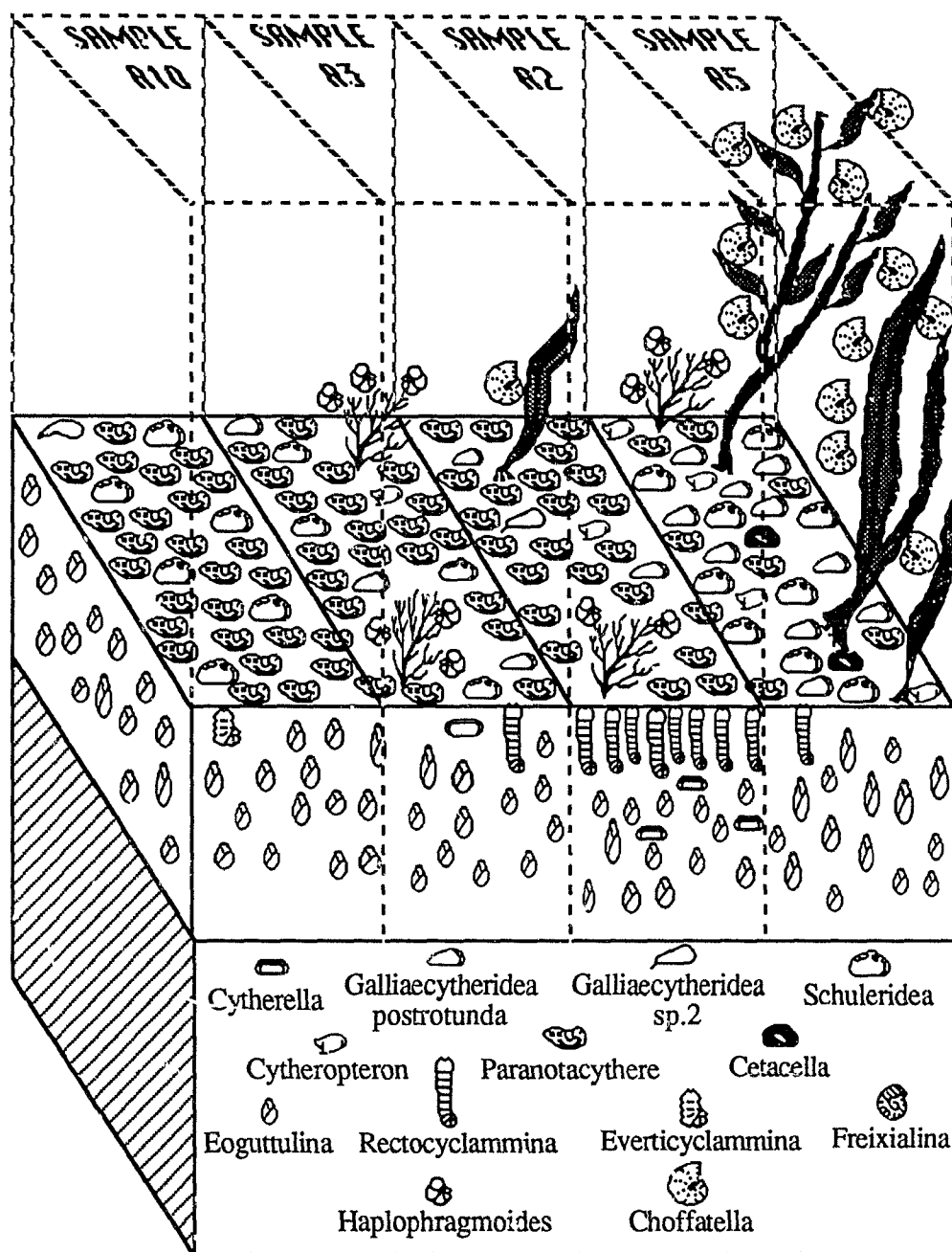


Figure 2.15: Distribution of samples in brackish (polyhaline) paleosalinities in the Praia Azul section. Sample A10 represents an unstable environment, colonized by opportunistic species, sample A5 a stable substrate. Phytal interpretations speculative. See Table 2.10 for additional remarks.

BRACKISH (POLYHALINE) PALEOENVIRONMENTS								
OSTRACODA	AUTOCHTHONOUS			ALLOCHTHONOUS				
	<i>Paranotacythere pustulata</i> , <i>Galliaecytheridea postrotunda</i> , <i>Schuleridea</i> sp.1, <i>Cytheropteron aquitanum</i>			<i>Cytherella fullonica</i> , <i>Darwinula leguminella</i> , <i>Cypridea</i> , <i>Cetacella armata</i>				
FORAMINIFERA	<i>Choffatella</i> , <i>Rectocyclammina</i> , <i>Eoguttulina</i> , <i>Haplophragmoides</i>							
	Sample A10		Sample A3		Sample A2		Sample A5	
	Morphogroup	%	Morphogroup	%	Morphogroup	%	Morphogroup	%
	iv	99	iv	75	iv	65	iv	50
		ii	20	iii	20	i	30	
		iii	5	ii	10	ii	12	
				i	5	iii	8	
INTERPRETATION	Ostracods dominated by <i>Paranotacythere</i> and <i>Schuleridea</i> , interpreted as epifaunal opportunists (Whatley 1983) Lack of flora, high current activity. High stress (salinity changes)		Ostracods dominated by <i>Paranotacythere</i> . Some <i>Schuleridea</i> and <i>Galliaecytheridea</i> . Freshwater influence (reworked <i>Cypridea</i>) Sparse flora, high stress (salinity changes)		Ostracods dominated by <i>Paranotacythere</i> . Foraminiferal epifauna suggests moderate flora.		<i>Galliaecytheridea</i> - <i>Paranotacythere</i> ostracod assemblage with freshwater influence (<i>Cetacella</i> - <i>Darwinula</i>) Large proportion of foraminiferal epifauna suggests well developed floral community.	

Table 2.10: Subenvironments interpreted from foraminiferal morphogroups within brackish (polyhaline) Ostracodal biofacies. See Figure 2.15.

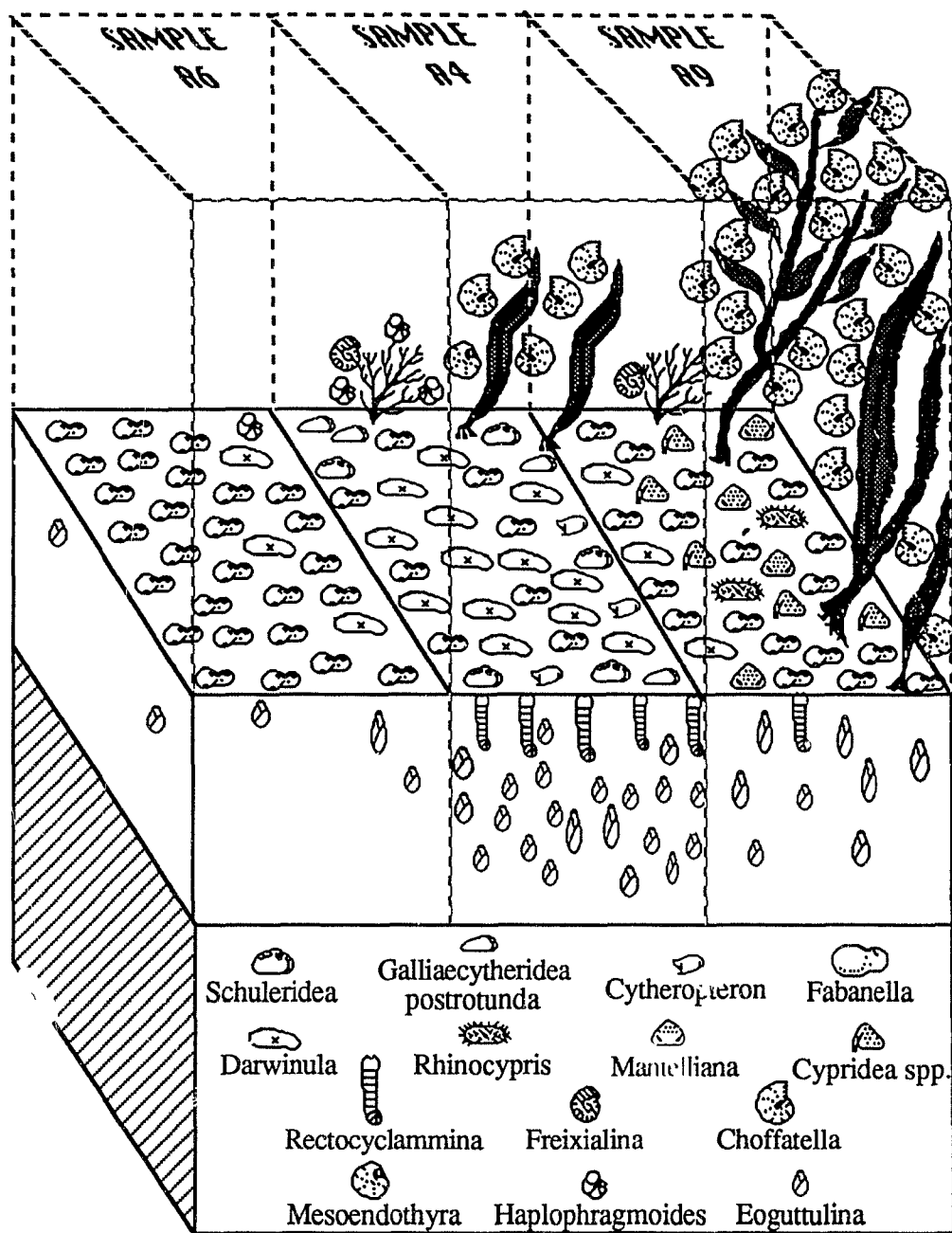


Figure 2.16: Distribution of samples in lower brackish (mesohaline to oligohaline) paleosalinities in the Praia Azul section. Sample A6 represents an unstable substrate, sample A9 a stable one supporting a 'climax' community. See Table 2.11 for additional remarks.

LOWER BRACKISH PALEOENVIRONMENTS				
OSTRACODA	AUTOCHTHONOUS		ALLOCHTHONOUS	
	<i>Fabanella boloniensis</i> , <i>Darwinula leguminella</i> , <i>Mantelliana cyrton</i> , <i>Galliaecytheridea postrotunda</i> , <i>Cytheropteron aquitanum</i> , <i>Rhinocypris jurassica</i>		<i>Schuleridea</i> sp.1, <i>Cytheropteron aquitanun</i> , <i>Paracypris</i> sp.	
FORAMINIFERA	<i>Eoguttulina</i> , <i>Choffatella</i> , <i>Freixialina</i> , <i>Haplophragmoides</i> , <i>Mesoendothyra</i> , <i>Rectocyclammina</i>			
	Sample A6	Sample A4		Sample A9
	Very rare	Morphogroup	%	Morphogroup %
		iv	60	i 67
		i	20	iv 25
		iii	15	iii 5
		ii	15	ii 2
INTERPRETATION	Virtual absence of foraminifera and abundant <i>Fabanella</i> plus <i>Darwinula</i> suggests salinity was $\leq 10\text{‰}$. Salinity rather than lack of habitat, may account for the lack of foraminifera. Flora may or may not have been present.	<i>Darwinula</i> and charaphyte sporangia indicate low salinity. Sparse Foraminiferal association hard to interpret, although epifauna suggests presence of flora.		Abundant <i>Fabanella</i> and <i>Darwinula</i> indicate salinity $\leq 10\text{‰}$. Sparse Foraminiferal association hard to interpret, although high relative abundance of <i>Choffatella</i> suggests phytal habitats.

Table 2.11: Subenvironments interpreted from Foraminiferal morphogroups within lower brackish to freshwater Ostracodal biofacies. See Figure 2.16.

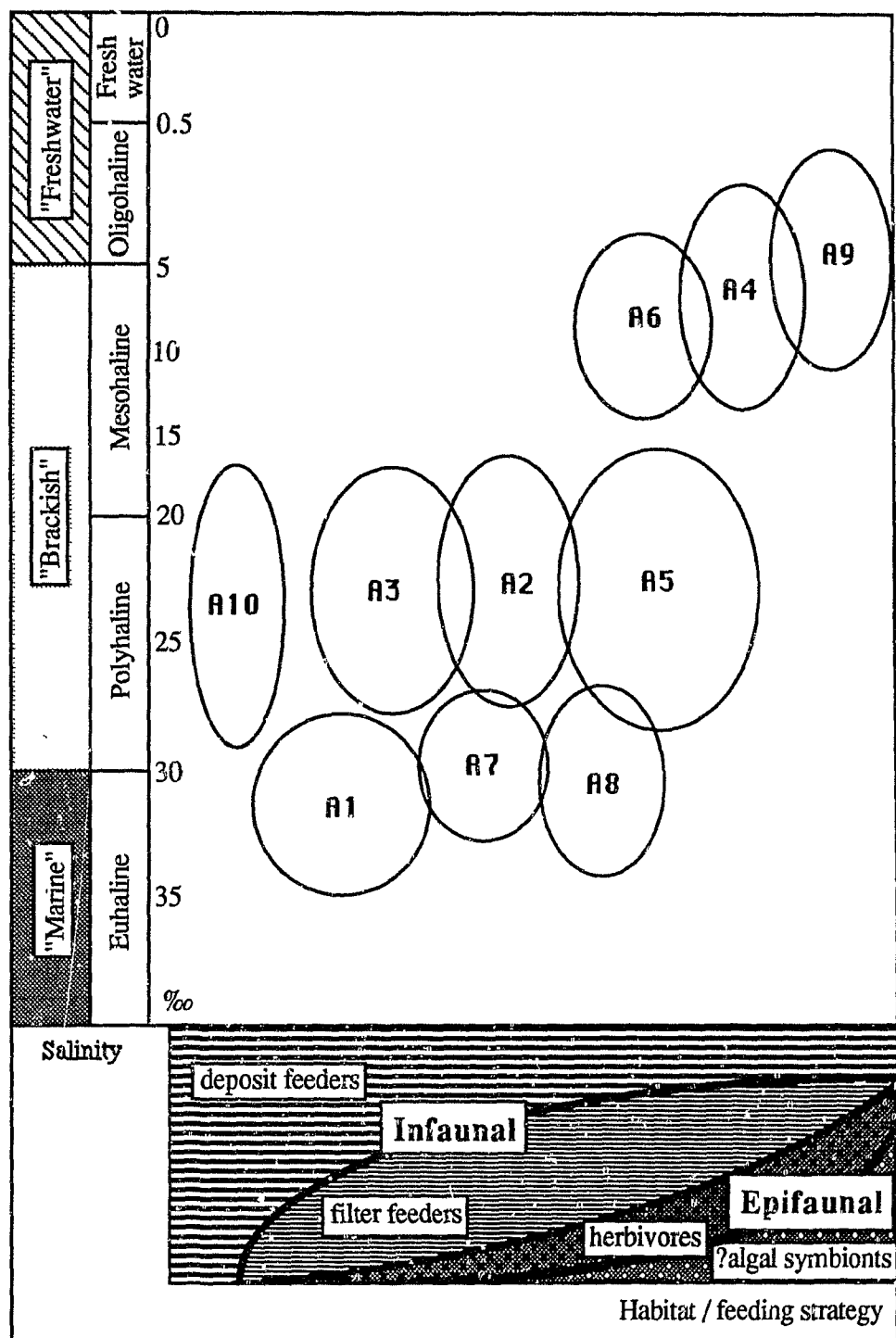


Figure 2.17: Distribution of Praia Azul samples as a function of salinity and habitat. Salinity as defined by the autochthonous Ostracodal assemblages, habitat/feeding strategy as typified by Foraminiferal morphogroups. Infaunal: deposit feeders = morphogroup iv; filter feeders = morphogroup iii. Epifaunal: herbivores = morphogroup ii; algal symbionts = morphogroup i (planispiral 'larger' Foraminifera).

Lithology	relative sea level	Bivalve association (Fursich 1981)	Ostracod salinity association	Foraminiferal morphogroup association	Interpretation
A10		<i>M. dammariensis</i> - <i>C. suprejurensis</i>	polyhaline- <i>Paranotacythere</i> , <i>Schuleridea</i>	infaunal group iv	brackish lagoon
					delta channels (Fursich, 1981)
A9			lower mesohaline <i>Fabanella</i> - <i>Darwinula</i>	i > iv > iii > ii <i>Choffatella</i>	back-reef lagoon
A8			upper polyhaline <i>cytherella</i> - <i>cytherelloidea</i> - <i>schuleridea</i>	mixed, group iv > iii > i > ii	brackish lagoon, subject to saline influx.
A7		<i>P. pustulosa</i> - <i>N. nana</i>	lwr mesohaline <i>Fabanella</i>	rare	back-reef lagoon
A6			polyhal. <i>Galliaecytheridea</i>	iv > i > ii > iii	brackish lagoon
A5			<i>Paranotacythere</i>	iv > i > iii = ii	back-reef lagoon
A4			lwr mesohaline <i>Fabanella</i> - <i>Darwinula</i>		fluvial channel
					floodplain (Fursich, 1981)
A3			polyhaline <i>cytherella</i> - <i>Schuleridea</i> - <i>Galliaecytherid.</i>	iv > ii > iii	brackish bay
A2		<i>J. edwardi</i>	<i>Paranotacythere</i>	iv > iii > ii > i	
A1				iv > iii > ii	floodplain with levees (Fursich, 1981)
10m					
0					

Figure 2.18: Summary of lithofacies, bivalve associations (after Fursich, 1981), microfossil assemblages and paleoenvironmental interpretations through the Praia Azul section.

CHAPTER 3

ERICEIRA SECTION

3.1: Introduction and previous work.

Four sections were examined north of Ericeira. These commence immediately south of the volcanic plug seen in the cliffs at Assenta, approximately 9km north of Ericeira, and continue to Praia do Coxo, the first bay south of the Safarujó river at Ribamar (Figure 3.1).

The sections were studied by Rey (1972), who assigned informal names to the units recognised. Hiscott *et al.* (1990b) examined the sections and assigned sedimentary units to formal lithostratigraphic formations and members. The emphasis of work by Hiscott *et al.* (1990b) was on the sandstone members of the Torres Vedras Formation, which are assigned to the Berriasian to Barremian interval. The terminology of Rey (1972) and the stratigraphic nomenclature and interpretations of Hiscott *et al.* (1990b) are summarized in Table 3.1.

Fieldwork was based on lithostratigraphic logs provided by R.N. Hiscott. Rey's (1972) main lithologic units are also recognised in the field, although his estimated thicknesses do not agree with Hiscott. The lithostratigraphic log (Figure 3.2) is based on Hiscott's work, whereas the unit names (in French) in the centre column are the informal names given to the lithologic units by Rey (1972). Eight sedimentary units are recognised in this study, referred to as units 1 to 8 in Figure 3.2.

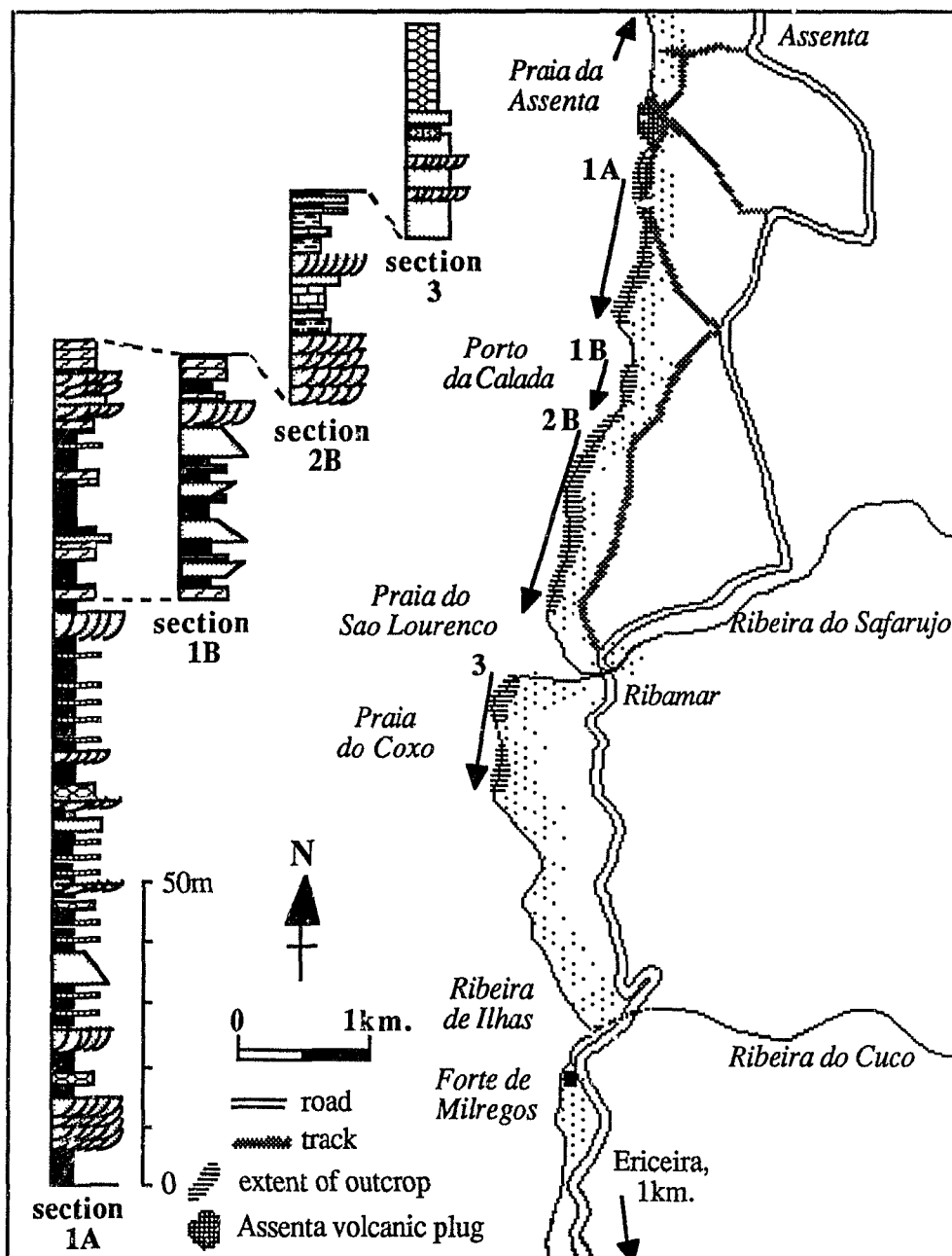






















Figure 3.1: Location map showing the cliff sections examined north of Ericeira, based on field logs compiled by Dr. R.N. Hiscott, Memorial University. A more detailed log of lithostratigraphy and sample distribution, and the key to the above sections is in Figure 3.2.

GROUP	FORMATION		LITHOLOGY	INTERPRETATION (Hiscott <i>et al.</i> 1990)	
	MEMBER				
ERICEIRA GROUP	TORRES VEDRAS FORMATION	CASCAIS FORMATION	interbedded limestone & dolostones, with intervals of fine & coarse sandstone	river dominated delta	
			fine sst., single crossbed 10° foreset dip	spit	
			limestone with corals		
			med-thick bedded fine sst. in <2m tabular beds, with <i>Thalassinoides</i>	mid-lower shoreface	low energy microtidal
			fine-gr., well sorted parallel-laminated sst	beach	beach deposit with migrating tidal inlets
			fine-gr. trough x-bedded sst.	megaripples	
			shales	marine tidal inlet	
		cross-bedded sandstones and pebbly sandstones with <i>Cruziana</i> and <i>Skolithos</i> ichnofacies	river mouth estuaries or low energy sand flats adjacent to these		
ESTRAMADURA	LOURINHA	Assenta	sandstones, caliches and ferroan dolomites	interdistributary bays and fluvial channels	

Table 3.1: Summary of sedimentary facies and interpretations for the Early Cretaceous sequences in the Ericeira section, outlined in Hiscott *et al.* (1990). Refer to Figure 1.4 for the position of the above Groups, Formations and Members within the general stratigraphic scheme for the Lusitanian Basin.

LEGEND	
Lithology	Structures/fossils
 shale	 lignite, plant debris
 siltstone	 larger Foraminifera
 coral limestons	 bivalves
 sandy limestone	 gastropods
 dolomitic limestone	 <i>Diplocraterion</i>
 nodular limestone	 <i>Thalassinoides</i>
 sandstone	 bioturbation
 red marly siltstone	 septarian nodules
	 caliche nodules
	 current ripples
	 laminations
B1 sample location	 dessication cracks

Key to lithostratigraphic sections north of Ericeira (Figure 3.1 and 3.2). Figure 3.2 is on the next page.

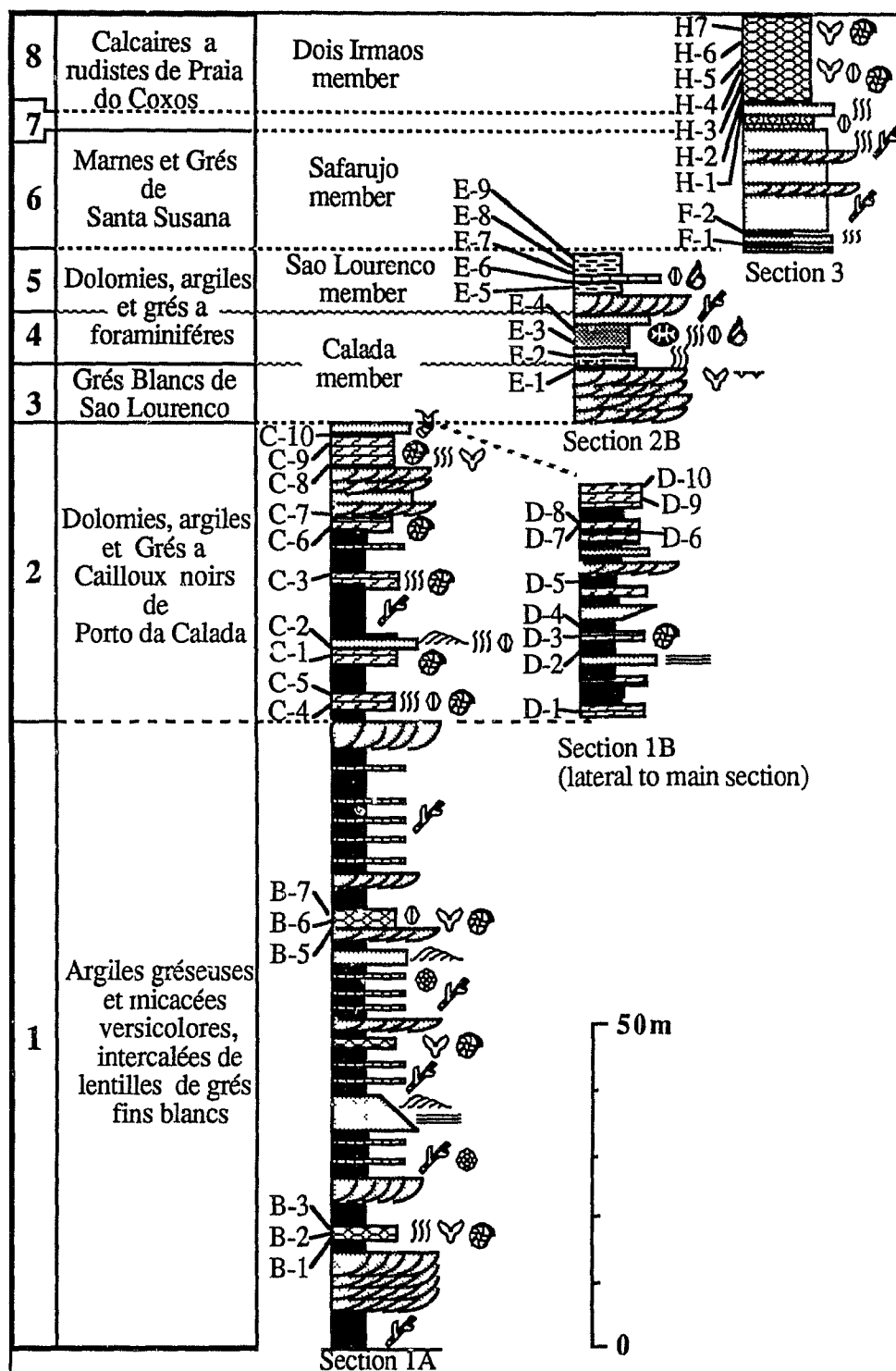


Figure 3.2: Lithostratigraphic log and sample distribution in the sections north of Ericeira. Numbers in the far left column refer to the unit described in the text. Names (in French) in the centre column after Rey (1972). Members after Hiscott *et al.* (1990). Location of sections shown in Figure 3.1.

3.2: Lithostratigraphy.

Section 1B (Figures 3.1 and 3.2) is a lateral continuation of the top 40m of section 1A, brought up to its current position in the cliffs on the south side of Porto da Calada by faulting. Field observations and subsequent microfossil determinations for these intervals confirm this lateral relationship.

The 200m thick succession consists of alternating coarse-to fine-grained siliciclastic and carbonate strata. The carbonate and finer siliciclastic strata were sampled. The siliciclastics in the basal 110m are predominantly fine grained, consisting of interbedded siltstones and claystones (red beds) with fine laminated sandstones and local coarser lenticular sandstone bodies. In the overlying 30m the siliciclastics are particularly coarse grained, conglomeratic, and show numerous channel deposits. Grain size is much reduced in the remainder of the section, and the siliciclastics consist of siltstones, claystones and fine sandstones with local coarser intervals.

Carbonate beds, up to 5m thick, are present locally. In the basal 90m, the carbonates are nodular bioclastic limestones, whereas in the 100-145m interval they are dolomitic limestone. The upper 50m of the sequence includes partially dolomitized and sandy bioclastic limestone, coral limestone, and at the top, nodular bioclastic limestones with thin marlstone intercalations.

Unit 1 is found in the cliff section between the Assenta volcanic plug and the north side of the bay at Porto da Calada. It consists of a predominantly siliciclastic sequence of micaceous to sandy siltstone and claystone with interbedded fine laminated sandstones, local beds of medium grained sandstone and three units of bioclastic limestone. The siltstone and claystone are green to red, commonly with caliche nodules and woody fragments. Interbedded with these are laminated fine micaceous sandstones in beds up to 10cm thick. The medium grained sandstone bodies are up to 3m thick, and are more

common in the lower part of the unit. The medium sandstones in the lowest part of the unit have concave-upward basal surfaces and show trough cross-bedding. Slightly higher, the medium sandstones tend to occur in fining upwards sequences, and commonly show ripple cross-laminations. Many of these sequences are bioturbated. The bioclastic limestones, up to 3m thick, contain nodular beds 15-20cm thick, separated by shaley partings, and are heavily bioturbated, frequently containing *Thalassinoides* and burrows toward the top. On exposed surfaces abundant larger Foraminifera and smooth shelled Ostracoda are weathered out, and on fresh surfaces a high concentration of fragmented bioclasts may be seen.

Unit 2 is seen in two cliff sections at the north and south sides of the bay at Porto da Calada. The unit consists of another series of predominantly siliciclastic sediments, containing several dolomitic limestones.

The siliciclastics are generally coarser grained than in the underlying unit, made up of coarse-to medium-grained cross-bedded sandstones. The finer siliciclastics are less abundant than in Unit 1, but are similarly red to green coloured. Coarsening upward sequences are apparent in the lower part of the unit. Section 1B appears to have a greater proportion of fine-grained sediments.

The carbonates are dark brown dolomitic limestones, sandy at the top, with interbedded sandy shales containing woody fragments. They are up to 2m thick, with individual planar beds 10-25cm thick. Primary depositional structures were not observed. Biogenic structures are limited to *Thalassinoides* on the underside of the lowest bed in section 1B. Abundant discoid specimens of the larger Foraminifera *Anchispirocyclina lusitanica* occur on the upper bedding planes along with the bivalve *Myophorella lusitanicum*. The latter is also found in local bands within the dolomitic beds. Bioclastic debris locally is seen in the lower few centimetres of certain beds. The dolomitic limestones have a saccharoidal texture on fresh surfaces. The brown colour of the beds appears to be

a weathering (oxidation) phenomenon: newly fractured surfaces are grey. The clastic interbeds are generally 10-40cm thick and are of shale and laminated, cross-bedded fine sandstones with woody fragments.

The carbonate sequence at the top of the unit becomes increasingly sandy. The upper dolomitic beds in section 1A contains abundant mollusc steinkerns toward the top, are overlain by a thin (25cm) bed of claystone and then a 30cm bed of bioturbated medium-grained sandstone containing the trace fossil *Diplocraterion yoyo*. In section 1B the upper dolomitic beds alternate with thin (5cm) laminated silty sandstones.

The carbonate strata are continuous laterally within each cliff profile and can be correlated between sections 1A and 1B, however, the number of beds in each set of strata varies between the sections. In section 1B the carbonate strata tend to be thicker but contain a greater number of shale interbeds.

Unit 3 commences about 300m south of Porto da Calada and continues southward to a point roughly mid-way between Porto da Calada and Sao Lourenco where it is faulted against Unit 4. The exact thickness of the unit is uncertain, although 12m is exposed up to the fault. The unit consists of cross-bedded coarse sandstones and conglomerates commonly with concave-upward basal surfaces. Locally, some of these deposits contain woody fragments.

Unit 4 commences mid-way between Porto da Calada and Sao Lourenco, continuing south along the cliffs to the start of the sandy beach north of the Safarujó river mouth. The unit commences with a bed of shale containing coarse quartz grains, a thin bed of carbonaceous shale, a bed of coarse sandstone, a massive medium-grained sandstone bed, and bioturbated (*Thalassinoides*) sandstone. Overlying this is 5m of sandy dolomitic limestone and a bed of siltstone that coarsens up into sandstone.

The lower clastic strata contain woody fragments and are bioturbated, more so at

the top. The dolomitic limestone strata occur in five massive undulose beds, each about 1m thick, which are weathered to a light grey colour and are distinctively nodular in appearance. Compositionally, these beds are locally sandy and rich in bioclastic (mollusc) debris. Eroded septarian nodules (malikaria) are found throughout, but are particularly abundant in the second and fourth beds, with higher concentrations of bioclastic debris and gastropods. Ostracoda are weathered out on the surface of the dolomitic limestones.

Unit 5, carbonaceous siltstone with thin sandy carbonate interbeds, is found at the top of section 2B, in the cliffs immediately above the sandy beach on the north side of the Safarujó river mouth. From the sections described in Rey (1972), this unit appears to correspond to the "Marnes et grés de Santa Susana". However, according to Rey (1972, p.173) the latter is located "...immédiatement au S de l'embouchure du Rio Safarujó, dans les falaisés couronnés par le fort de Santa Susana.". Inspection of the sequences below the fortress on the south side of the Safarujó river failed to show any similar sequence. The alternative is that the unit belongs to the "Dolomies, argiles et grés á foraminifères", however, Rey (1972) does not recognise such a sequence north of the Safarujó river mouth. Possibly this is due to a typographic error in Rey (1971).

The unit comprises a series of dark grey carbonaceous siltstone with several beds of sandy dolomitic limestone up to 40cm thick. The siltstones appear homogeneous and lack macrofossils or biogenic structures. The sandy dolomitic limestone bands are lighter grey and locally contain gastropods and bivalves.

Unit 6 forms the cliffs on the south side of the Safarujó river, continuing south into the next bay, Praia do Coxo. The sequence is composed of thin to medium bedded (15-45cm) fine sandstones, locally bioturbated, cross-bedded and with woody fragments, but lacking macrofossils. Two thin (15-25cm) claystone beds occur in the lower part of this unit, one at the base and the other 3m above.

Unit 7 is located in the cliff section in the southern part of Praia do Coxo. The unit is composed of a series of sandy bioclastic limestones with local coral build-ups. The biomicrites are thickly bedded, highly indurated, and locally sandy. At the base of the unit, quartz pebbles are seen. Coral debris occurs throughout, and on the underside of one of the lower beds undercut by the sea immediately below the dirt access road, large colonial corals in growth position were observed. The beds at this locale form a knoll that thins laterally. The upper beds are less sandy but more shaley. The top of the unit contains a bed of fine calcareous cross-bedded sandstone.

Unit 8 is located in the south part of Praia do Coxo and consists of interbedded nodular limestone and marlstone. The limestones are medium grey, thin to medium bedded (5-15cm), heavily bioturbated and rich in bioclastic debris. The larger Foraminifera *Choffatella decipiens* is locally abundant, weathered out on exposed surfaces. The marlstone is dark grey and occurs both as thin partings between the nodular limestones and as thicker sequences (up to 30cm). The thicker marlstone beds are more common in the upper part of the unit.

3.3: Microfossil analysis and interpretations.

Sampling was restricted to marine intervals (carbonate and shale beds), rather than the intervening clastic beds. The marine beds were preliminarily identified as such by R.N. Hiscott (personal communication, 1987). Forty-one of the 42 samples collected contain microfossils, although these were sparse in many samples. Forty-two species of Foraminifera and 21 species of Ostracoda were recognised. The specimen abundance and number of species of Ostracoda and Foraminifera recovered from the samples are shown in Figures 3.3 and 3.4. The Ostracoda are most abundant in the nodular carbonates in Unit 1, and the number of species is also highest in this unit. The sandy limestone at the top of

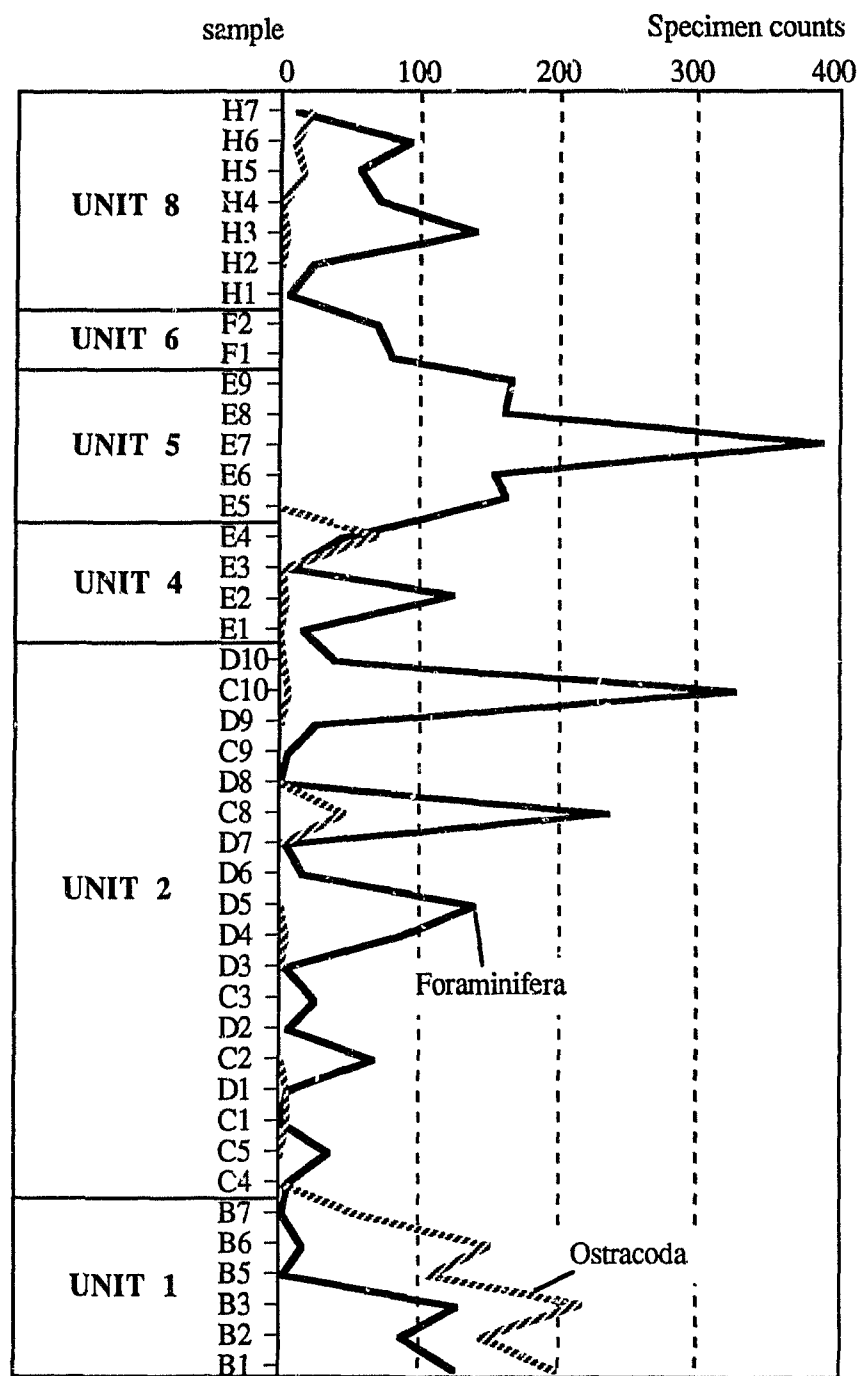


Figure 3.3: Number of Foraminiferal and Ostracodal specimens in the Ericeira samples (>125 μ m size fraction).

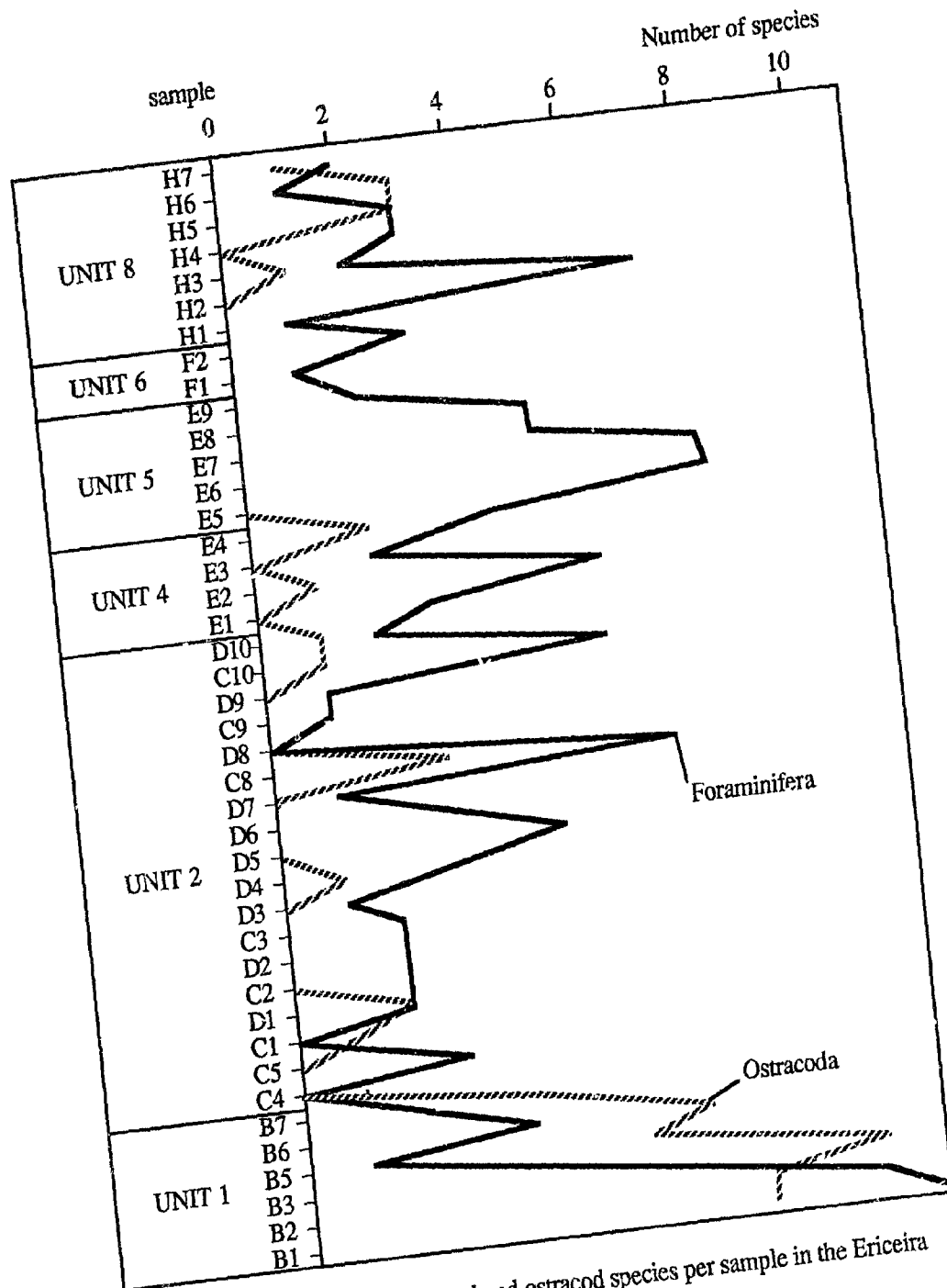


Figure 3.4: Number of foraminiferal and ostracod species per sample in the Ericeira sections ($>125\mu\text{m}$ size fraction).

Unit 2 and the sandy bioclastic limestone in Unit 4 also contain a few dozen Ostracoda specimens, only two species. The nodular limestones in Unit 8 contain sparse Ostracoda represented by only four species. Samples from the other units have sparse Ostracoda represented by two species. Foraminiferal abundance and number of species fluctuates markedly within and between the units. The number of species is low, rarely exceeding six and at most eleven, even in samples with higher numbers of specimens.

3.3.1: Ostracoda.

3.3.1.a: Distribution of Families.

The Ericeira Ostracoda are represented by the same suborders as in Praia Azul. The Podocopina are represented by the Families Cytheruridae, Cytherideidae, Cytheridae and Paracyprididae, and also include three families (and four genera) not seen in the Praia Azul section. These are: Family Brachycytheridae (genus *Amphicythere*); Family Progonocytheridae (genus *Protocythere*); Family Trachyleberididae (genera *Cythereis* and *Platycythereis*). Families Cytherideidae and Cytheruridae also contain two genera not seen in Praia Azul, *Asciocythere* and *Cytheropterina* respectively.

3.3.1.b: Distribution of species and salinity indicators.

The distribution of the Ostracoda species (Table 3.2) shows marked variability between the units. As mentioned above, maximum Ostracodal diversity and abundance is seen in Unit 1. Several longer ranging taxa have significant gaps in their ranges that may be due to ecological exclusion from particular facies. Absence of many species found in Unit 1 from younger units may also be due to ecologic control, or could be due to extinction events.

Using the framework established above for the Ostracoda as salinity indicators at Praia Azul, the distribution of the Ostracoda in the Ericeira section will be discussed for

H7		Amphicythere confundens
H6		Asciocythere sp.1
H5	3	Asciocythere sp.2
H4	4	Cythereis ericeirensis
H3	8	Cytherella fullonica
H2		Cytherella suprajurassica
H1		Cytherella pyriformis
F2		Cytherelloidea weberi
F1		Cytheropteron aquitarum
E9		Cytheropterina triebeli
E8		Darwinula sp.
E7		Fabanella boloniensis
E6		G. postrectunda
E5		Galliaecytheridea sp.2
E4	6	Paracypris sp.
E3		Paranotacythere pustulata
E2		Platycythereis crisminaensis
E1		Protocythere sp.
D10		Schuleridea sp.1
C10		Schuleridea triebeli
D9		Schuleridea thoerenensis
C9		
D8		
C8		
D7	21	
D6		
D5		
D4	1	
D3		
C3		
D2		
C2		
D1		
C1		
C5		
C4		
B7	24	
B6	3	
B5	4	
B3	25	
B2	13	
B1		

Table 3.2: Distribution of ostracoda in the Ericeira section.

each unit. This will assist in identification of ecological controls affecting the ranges of species.

Unit 1 nodular limestone beds contain assemblages dominated by, and *Schuleridea triebeli*, *Cytheropteron aquitanum*, *Amphicythere confundens*, *Cytherella fullonica*, *C. suprajurassica*, *G. postrotunda*, *Cytherelloidea weberi*, *Schuleridea* sp.1, *Asciocythere* sp.1, and *Galliaecytheridea* sp.2. *Fabanella boloniensis* is locally abundant in samples from the upper nodular bed. Less common or rare are *Paranotacythere pustulata*, *Paracypris*, *Darwinula leguminella*, *Cytheroptera triebeli* and *Protocythere* sp. With the exception of *Paranotacythere pustulata*, *Paracypris* and *Darwinula leguminella*, all species have late stage instars which include carapaces, and implies high infant mortality. The latter three species are interpreted as allochthonous, while all others are part of the biocoenosis. The majority of species are euryhaline although some are perhaps stenohaline (*Cytheropteron*, *Cytherelloidea* and *Cytherella*), suggesting upper polyhaline to euhaline salinity. Appearance of *Fabanella boloniensis* in sample B6 and absence of the latter three stenohaline forms indicates increased brackishness (lower polyhaline to mesohaline).

Unit 2 contains sparse, poorly preserved specimens of *Schuleridea*, *Asciocythere*, and *Galliaecytheridea* from shaley partings between the dolomitic beds. Absence of Ostracoda from the dolomitic limestones may be an artefact of re-crystallization. The sandy limestone at the top of section 1A, on the other hand, yielded low numbers of *Fabanella boloniensis* and *Cytherella*, both as adults and late juveniles, plus rare *Cytheroptera triebeli*. All specimens were poorly preserved. The Ostracoda indicate brackish salinity at the time of deposition.

Unit 3 contained coarse clastics and was not sampled.

Unit 4 contains rare *Fabanella boloniensis* in the lower strata. The sandy, bioclastic dolomitic limestone contained abundant adult and juvenile carapaces of *Fabanella boloniensis*, and rare *Asciocythere*. Articulation of all specimens of *Fabanella* indicates premature mortality. Many of the carapaces contain small round holes indicating predation, possibly by gastropods found in these strata. Maddocks (1988) examined predation in Mesozoic Ostracoda, and determined that small circular holes are the result of predation by naticid gastropods. The mortality of the *Fabanella* population is probably indirectly related to salinity as a change in the latter may have caused the introduction of the predatory gastropods. The salinity at the time of deposition of these units is interpreted to have been in the lower brackish (mesohaline) spectrum, based on the *Fabanella* association.

Units 5 and 6 were barren of Ostracoda; Unit 7 was not sampled since it was an indurated limestone.

Unit 8 contains sparse Ostracoda including *Cythereis ericeirensis*, *Platycythereis crisminaensis*, *Schuleridea thoerenensis*, and *Asciocythere* sp.2. The latter is slightly more abundant (20 specimens) at the top of the section. Trachyleberid Ostracoda (represented by *Cythereis* and *Platycythereis*) are reported as typical of marine shelf environments in the Early Cretaceous (Neale, 1978) although the other two species are thought to be euryhaline.

3.3.2: Foraminifera.

3.3.2.a: Superfamily distribution.

The Foraminiferal superfamilies in the Ericeira sections are represented by the Lituolacea, the Nodosariacea and the Miliolacea. The latter group is numerically unimportant (three specimens of *Quinqueloculina*) and will not be considered further. The

distribution of the Lituolacea and the Nodosariacea are shown in Figure 3.5, in which the Lituolacea are separated into their "larger" and "smaller" components. "Larger" lituolids dominate in Units 1 and 8, and also at the top of Unit 2. The "smaller" lituolids constitute most of the specimens in the other units, although are represented by only a few specimens in many samples. The Nodosariacea are important in Units 1 and at the top of Unit 4 only.

3.3.2.b: Distribution of species and morphogroups.

The distribution of Foraminiferal species in the Ericeira sections (Table 3.3) is variable and appears influenced by lithology. As indicated above, the calcareous taxa *Eoguttulina* and *Lenticulina muensteri* are virtually restricted to the nodular limestones of Unit 1 and the sandy dolomitic limestone in Unit 4. The 'larger' lituolids have a wider distribution. In Unit 1 they include abundant *Pseudocyclammina muluchensis*, *Everticyclammina virguliana*, and low numbers of *Choffatella tingitana*, *Rectocyclammina chouberti*, *Anchispirocyclina lusitanica* and *Mesoendothyra* sp.A occur in the dolomitic limestones of Unit 2 and is abundant in the sandy limestones at the top of Unit 2 in section 1A, with rare *Pseudocyclammina lituus*. Abundant *Choffatella decipiens* occur in the Unit 8. The "smaller" lituolids include several species of *Ammobaculites* and *Haplophragmoides* that are locally abundant in Units 2, 4 and 5, and abundant trochamminids in Unit 4. Species of *Ammomarginulina*, *Dorothia*, *Freixialina*, *Haplophragmium*, *Reophax* and *Spiroplectammina* are locally common through the units.

Using the framework established above for Foraminiferal morphogroups as indicators of habitats in the Praia Azul section, the distribution of Foraminiferal species will be related to morphogroups in an attempt to assess the role of substrate as an ecological control. The generic composition of Foraminifera at Ericeira differs from Praia Azul by the presence of *Ammobaculites*, *Anchispirocyclina*, *Dorothia*, *Feurtillia*, *Flamellammina*, *Haplophragmium*, *Lenticulina*, *Pseudocyclammina*, *Reophax* and the trochamminids. The latter genera may be assigned to the morphogroups established for the Praia Azul

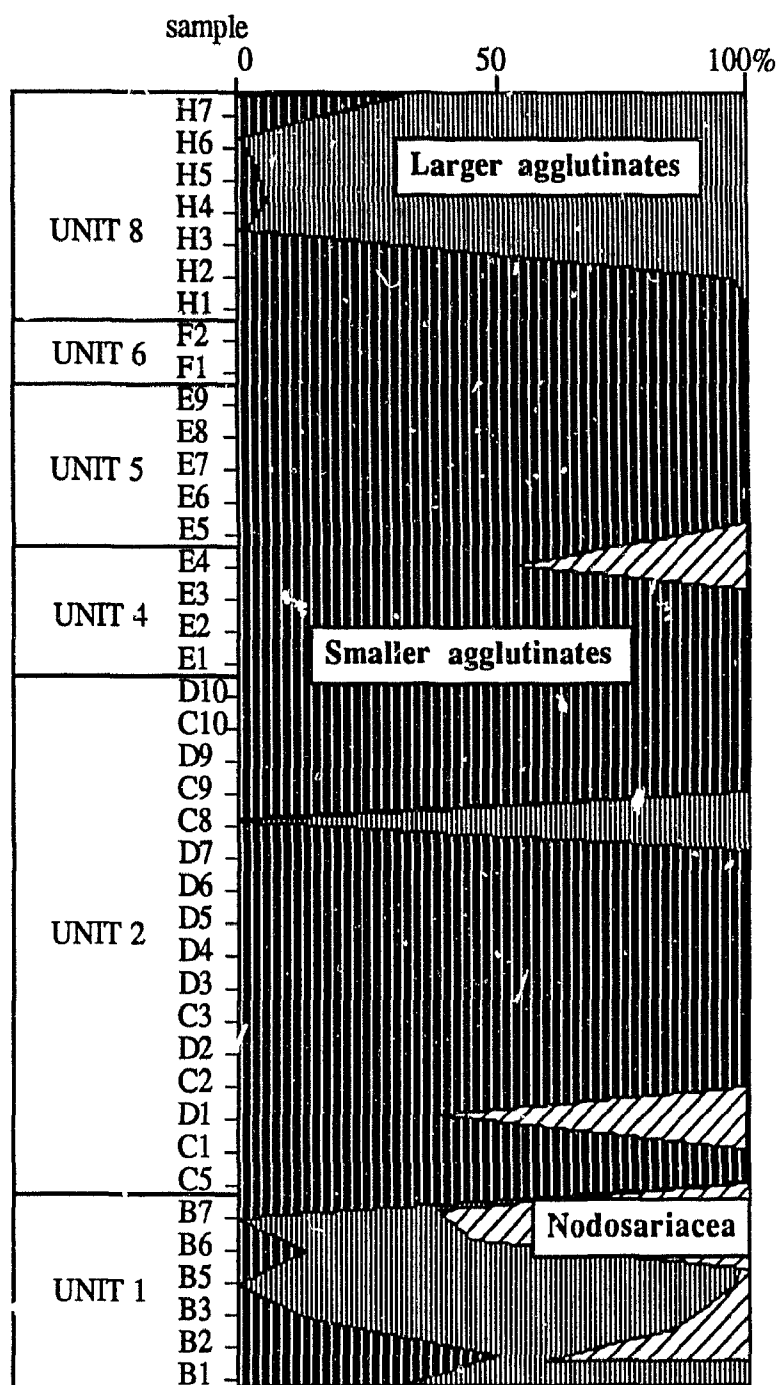


Figure 3.5: Distribution of the foraminiferal superfamilies in the Ericeira sections. The Lituolacea have been split into the 'larger' and 'smaller' components.

H7		Ammobaculites agglutinans	
H6		A. coprilithiformis	
H5	7	A. euides	
H4	3	A. godmani	
H3	5	A. sp.1	
H2	2	A. obliquus	
H1		A. reophacoides	
F2		A. subcretaceus	
F1		Ammomarginulina sp.	
E9	162	Anchispirocyclina lusitanica	
E8		Choffatella decipiens	
E7		C. tingitana	
E6		Dorothia kummi	
E5	88	Eoguttulina bilocularis	
E4	36	E. inovroclaviensis	
E3		E. liassica	
E2	1	E. metensis	
E1	3	E. oolithica	
D10	2	Everticyclammina virguliana	
D9		Feurtillia frequens	
D8	4	Flabellaminina vitrea	
D7	1	Freixialina planispiralis	
D6		Haplophragmium inconstans	
D5	40		
D4			
D3			
D2			
D1			
C1			
C5			
C4			
B7			
B6			
B5			
B3	8		
B2	26		
B1	19		

Table 3.3: Distribution of foraminifera in the Ericeira section

H7		Haplophragmiodes minor	
H6		H. concavus	
H5		H. nonionoides	3
H4		Lenticulina muensteri	
H3		Mesoendothyra sp.A	
H2	2	Ps. muluchensis	
H1	3	Quinqueloculina sp.	
F2	4	Rectocyclammina chouberti	
F1		R. arrabidensis	
E9		Reophax horridus	12
E8		R. aff. scorpiurus	6
E7		R. sp.	3
E6		Spiroplectammina sp.	10/23/12
E5	4	T. aff. quinqueloba	25
E4	2	T. globigeriniformis	67
E3	5	T. ragatti	25
E2	38	T. sp.	20
E1	7	Tiphotrocha spp.	25
D10	18	Verneuilinoides minuta	
D9	20		
D8			
D7			
D6	7		
D5	2		
D4	66		
D3	2		
D2	5		
D1	16		
C2	1		
C1	3		
C5	8		
C4	60		
B7	2		
B6	3		
B5	22		
B4			
B3			
B2			
B1			

Table 3.3 continued.

Foraminifera: *Anchispirocyclus* and *Pseudocyclammina* are "larger" planispiral litiolids with complex endoskeletons, and are assigned to morphogroup i; Planispiral *Lenticulina* and the low trochospiral trochamminids ("smaller" litiolids) are assigned to morphogroup ii; *Ammobaculites*, *feurillia*, *Flabellammina*, *Haplophragmium* and *Reophax* are assigned to morphogroup iii; *Dorothia* is assigned to morphogroup iv. Although the trochamminids are not planispiral, their present day mode of life is generally phytal within shallow marine environments. (D. Scott, pers. comm. 1989). The percentage distribution of the four Foraminiferal morphogroups is shown in Figure 3.6.

Unit 1: Samples from the lower limestone bed contained more specimens and consequently more species than those from the upper bed. The "larger" Foraminifera *Everticyclammina virguliana* and *Pseudocyclammina muluchensis* are the dominant species in samples B3 and B5 respectively. In other samples the latter species are represented by a few specimens only. *Ammobaculites* is abundant in sample B2, where *A. agglutinans* and *A. euides* comprise over half the specimens. *Freixialina planispiralis* and species of *Eoguttulina* are well represented in sample B1 in the lower limestone bed, but are found in low numbers in other samples. Other species found in low numbers of *Choffatella tingitana*, *Feurillia frequens*, *Mesoendothyra* sp.A, *Rectocyclammina chouberti*, *Reophax horridus*, *Trochammina* sp. and *Verneuilinoides minuta* are seen in some samples. All Foraminiferal morphogroups are seen in the lower limestone bed, although the infauna is more abundant. Morphogroup i is slightly more abundant in the upper part of the bed. The upper nodular bed has a sparse assemblage that is difficult to evaluate, although morphogroup i clearly dominates the lower part of the bed.

Unit 2: The dolomitic limestones in the unit contain generally impoverished Foraminiferal assemblages. Although poor preservation made identification difficult, the specimens examined are placed in the two common species *Haplophragmoides concavus* and *H.*

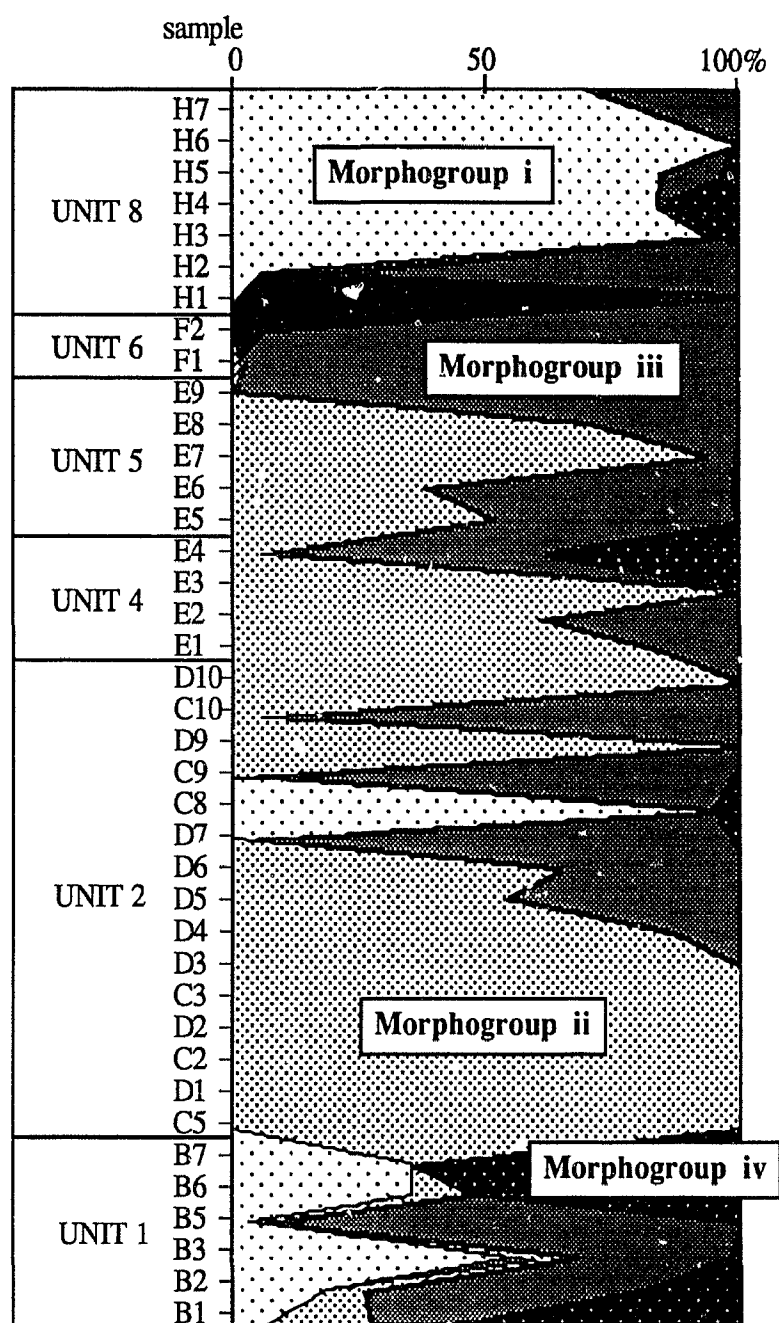


Figure 3.6: Distribution of the Foraminiferal morphogroups in the Ericeira samples.

nonionoides.

Shales interbedded with the dolomitic limestone contain locally numerous *Ammobaculites* including *A. agglutinans*, *A. godmani* and *A. subcretaceus*, and *Haplophragmoides concavus*, low numbers of *H. minor* and *H. nonionoides*. The larger foraminiferid *Anchispirocyclus lusitanica* is abundant in the sandy dolomitic limestone (sample C-8) near the top of section 1A, and occurs with *Pseudocyclammina* and rare *Eoguttulina*, *Everticyclammina*, *Freixialina*, *Rectocyclammina* and *Quinqueloculina* sp. The shelly dolomitic sandstone (sample C-9) contains a sparse assemblage with a few specimens of *Ammobaculites agglutinans*, whereas the overlying thin claystone bed (sample C-10) beneath the upper-most sandstone contains a rich assemblage of *Ammobaculites subcretaceus*. Other smaller agglutinated species are also present in low numbers at this level including *Ammobaculites agglutinans*, *Reophax* spp., *Spiroplectammina* sp. and *Haplophragmium inconstans*.

Morphogroups in the dolomitic beds are limited to the epifaunal morphogroup ii. Shaley strata contains morphogroups ii and iii, whereas the sandy limestone in the upper part of the unit is dominantly morphogroup i with a low abundance of infauna.

Unit 4: The thin claystone in the lower part of section 2B contains a sparse Foraminiferal assemblage with a few specimens of *Ammobaculites euides*, *Haplophragmoides concavus* and more numerous *Trochammina depressa*. The shale at the base of the shelly dolomitic sequence contains a more abundant assemblage with *Ammobaculites euides*, *A. obliquus*, *A. reophacoides*, *Haplophragmoides concavus*, *Reophax horridus* and *Trochammina depressa*. The genera *Ammobaculites*, *Haplophragmoides* and *Trochammina* are represented by roughly equal numbers of specimens. Foraminifera in the shelly dolomitic strata are sparse, represented by *Trochammina depressa* and a few specimens of *Reophax* sp. and *Haplophragmoides concavus*. The highest sample in the unit has the only calcareous Foraminifera seen in these sections: *Eoguttulina metensis* and rare *Lenticulina*

muensteri. Morphogroup distribution shows a dominance of morphogroup ii. Morphogroups iii and iv occur in moderate proportions in samples E2 and E4 respectively.

Unit 5 contains abundant "smaller" litiolids dominated by trochamminids and species of *Ammobaculites*. Four species groups of *Trochammina* are recognised: *T. depressa*, *T. aff. quinqueloba*, *T. globigeriniformis* and *T. aff. ragatti*. In addition to *Trochammina*, another species group is assigned to *Tiphotrocha* on the basis of apparent supplementary apertures. The species of *Ammobaculites* are *Ammobaculites coprolithiformis*, *A. obliquus*, *A. reophacoides* and *Ammobaculites* sp.A. Other species belonging to *Haplophragmoides*, *Haplophragmium*, *Reophax*, *Flabellamina* and *Spiroplectammina* are present, but generally in low numbers. The distribution of the agglutinated genera in this unit show interesting trends. Sample E-5 contains about twice as many trochamminid specimens as *Ammobaculites*, whereas the opposite situation is seen in E-6. In sample E-7 the trochamminids are abundant. Sample E8 has similar proportions of *Ammobaculites* and trochamminids as in sample E-5, with over twice as many trochamminids as specimens of *Ammobaculites*. Sample E-9 has virtually monospecific *Ammobaculites coprolithiformis*, rare *Reophax*, but no trochamminids.

With the exception of a small proportion of morphogroup iv in sample E6, the assemblage in this unit are composed of Morphogroups ii) or iii) or a combination of both, reflecting the alternating dominances of the trochamminids and species of *Ammobaculites*.

Unit 6 contains a monospecific assemblage of *Ammobaculites subcretaceus* in sample F1. Sample F2 has an almost monospecific assemblage of *Ammobaculites obliquus*. Other species in this sample are represented by rare *Haplophragmoides concavus* and *Trochammina depressa*. Foraminiferal morphogroup iii dominates the unit.

Unit 8: Foraminifera are sparse in the first three samples which contain low numbers of

Choffatella decipiens, *Reophax* sp. and rare *Ammobaculites*, *Haplophragmoides*, *Spiroplectammina* and *Trochammina*. *Choffatella decipiens* is more numerous in the higher samples and occurs with rare specimens of *Dorothia*, *Ammobaculites* and *Haplophragmoides*. Morphogroup distribution shows overall dominance of epifauna, reflecting the high relative abundance of *Choffatella*.

3.4: Paleoecology and paleoenvironments of the Ericeira sections.

3.4.1: Microfossil assemblages of nodular limestones in Unit 1.

The predominance of euryhaline Ostracoda in this assemblage indicate deposition of the nodular limestones in a marine to slightly brackish environment. Presence of larger Foraminifera indicate shallow (photic zone) water depths and the trace fossil *Thalassinoides* indicates intertidal to shallow subtidal environments. Bioturbation has homogenised the strata in both limestone beds, however the abundance of Foraminiferal morphogroup i in the lower part of the highest nodular bed suggests the flora was well developed.

3.4.2: Foraminiferal assemblages of dolomitic limestones in Unit 2.

Well preserved *Anchispirocyclus lusitanica* on dolomitic limestone bedding planes is a problem as there is no evidence of the species in samples taken from within the dolomitic beds. Compositional differences between the tests of *Haplophragmoides* and *Anchispirocyclus lusitanica* (the latter composed of agglutinated calcareous grains) may have resulted in obliteration of *Anchispirocyclus* during re-crystallization (dolomitization) and selective preservation of *Haplophragmoides*; specimens of *Anchispirocyclus lusitanica* on bedding planes at an interface with non-carbonate could have retained their original form. Examination of thin sections from the dolomitic limestone beds did not show up any relict textures. Preservation of *Myophorella* within the dolomitic beds would have depended on the original composition of the valves. The latter species indicates a

marine environment (Fursich, 1977). Presence of larger Foraminifera indicate shallow water (photic zone), and the trace fossils *Thalassinoides* and *Diplocraterion yoyo*, indicate a nearshore environment.

3.4.3: *Anchispirocyclus* assemblage.

Association of *Anchispirocyclus lusitanica* with the Ostracoda *Fabanella* in sandy limestone (sample C8) in the upper part of Unit 2 suggests the former species had a preference for brackish marine environments. Presence of *Quinqueloculina* spp. in the sample, however, argues against brackish conditions based on modern distributions of the genus in sandy sediments of the inner shelf and hypersaline lagoons (Murray, 1973). The salinity tolerance of *Fabanella* is uncertain and it has been suggested that it may have also been tolerant of hypersalinity (Kilenyi and Neale, 1978). *Fabanella* probably tolerated a broad range of salinity from mesohaline through to hypersaline, but was only successful in environments of high stress where there was little competition, i.e. it was an opportunistic species (Levinton, 1970). The abundance of *Anchispirocyclus* in this sample suggests the larger lituolid was an opportunist. The larger Foraminifera indicate shallow water (photic zone). Deposition of the sandy limestone was probably in a lagoon (i.e. a shallow body of water partially isolated from open sea) with well developed meadows of sea-plants and calcareous algae as indicated by the epifauna.

3.4.4: Mixed *Ammobaculites*-*Trochammina*-*Haplophragmoides* assemblages.

The genera *Ammobaculites*, *Trochammina* and *Haplophragmoides* are well represented in the argillaceous facies sampled in Units 2 and 4 and 5. The varying relative abundances of the three genera, however, suggest lithology is not the only paleoecological factor controlling their distribution. The modern distribution of *Ammobaculites* and trochamminid associations is typical of lower to upper marsh facies (Murray, 1973; Scott and Medioli, 1980), and a general marsh paleoenvironment is interpreted for these

associations seen in the Ericeira section. Marsh faunas are notably conservative in nature, and have changed very little since the Mesozoic, as demonstrated in Wall, (1976) and Scott *et al.*, (1983). Fluctuating trochamminid-dominated (*Trochammina* and *Tiphotrecha*) and *Ammobaculites*-dominated assemblages in the silts of Unit 5 may reflect fluctuating high marsh and lower marsh paleoenvironments, as observed by Scott *et al.* (1983) in modern environments. The Ericeira assemblages, however, lack representatives of *Miliammina*, *Eggerella* and *Ammotium* that are typical of marsh environments today (e.g. Scott and Medioli, 1980) and have also been reported from similar environments in the Late Cretaceous of Alberta (Wall, 1976). Absence of calcareous Foraminifera and Ostracoda from Unit 5 supports interpretation of these strata as marsh deposits, since decay of plant debris within a marsh results in the production of humic acids which causes the pH to decline and the calcareous fauna to dissolve.

The paleoecology of *Haplophragmoides* in Unit 4 is not easy to determine since they are not well represented. However, the association of *Haplophragmoides* with *Trochammina* and *Ammobaculites* in samples E-1 and E-2 suggests the genus could survive in lower marsh environments as it does today (Scott *et al.*, 1983). The association of *Haplophragmoides* with the Ostracoda *Fabanella boloniensis* in samples E-3 and E-4 is further indication that the genus inhabited restricted environments. Interestingly, this assemblage occurs in sandy dolomitic limestone beds containing eroded septarian nodules (malikaria), which are known from vadose zones.

3.4.5: *Ammobaculites* assemblages.

Virtual absence of the presumed epiphytal Foraminifera (*Trochammina*, *Haplophragmoides*) from the otherwise monospecific *Ammobaculites* assemblages in samples C-10, E-9, F-1 and F-2 suggests that suspended particulate matter (SPM) was the principal source of nutrients. The most likely paleoenvironmental setting for these assemblages is estuarine based the present-day distribution of agglutinated Foraminifera in

estuarine and estuarine transition zones that are characterized by high ambient SPM concentrations due to ponding by flood and ebb tides (Scott *et al.*, 1980). Species of *Ammobaculites* are reported from infaunal habitats in estuaries by Ellison (1972). Buzas (1974) reported species of *Ammobaculites* from estuaries at depths 10-15 cm below the sediment surface, and suggested the taxon had relatively stringent oxygen requirements. The monospecific nature of the *Ammobaculites* assemblages suggests that *Ammobaculites subcretaceus*, *A. coprolithiformis* and *A. obliquus* were 'opportunistic' species that flourished in the absence of competition in environments subjected to extreme daily or seasonal fluctuations in ecological factors (e.g. salinity and temperature), normally observed in estuarine paleoenvironments. Such assemblages are strongly conservative in nature and have changed little since the Mesozoic (Scott *et al.*, 1983)

3.4.5.a: Grain size selectivity in species of *Ammobaculites*:

Although the three species of *Ammobaculites* discussed above are interpreted as opportunists from estuarine environments, a further question arises as to the ecological factors controlling the distribution of these species. *Ammobaculites subcretaceus*, *A. coprolithiformis* and *A. obliquus* are morphologically distinct and each appears to have been highly successful in similar environments, yet they rarely co-occur in any abundance. The assemblage in sample E9, for example consists of 98% *A. coprolithiformis*, whereas in the *Ammobaculites* assemblages from adjacent samples, this species is absent. Why should this be so? The nature of the substrate and the availability and quality of test-building material may be the reason for this. The test of *Ammobaculites subcretaceus* is constructed from a wide grain size range. It used smaller grains in the planispiral portion of the test, and larger grains in the uncoiled portion. *Ammobaculites coprolithiformis* appears to be more selective in this respect and used grains in the 30-100 μm size range throughout ontogeny. The test of *Ammobaculites obliquus* is agglutinated from silt-sized grains, generally less than 50 μm across. The obvious implication of the grain-size

preferences of the *Ammobaculites* species is that each proliferated in a particular sedimentary environment determined by grain size.

The relationship between the size of the agglutinated grains in the Foraminiferal wall and the substrate implied for the species of *Ammobaculites* may seem simplistic. This phenomena has not been reported in Recent species of *Ammobaculites*. In a study of a number of transects across the Scotian Slope, Schroeder (1985) observed that many living species of *Ammobaculites* were not grain selective, and would modify their test form (and appearance) according to availability and quality of sedimentary grains. On the assumption that the three forms of *Ammobaculites* seen in the Ericeira section are not different morphological expressions of one taxon, then grain selectivity appears to have been a characteristic of each species.

The apparent grain selectivity of each species of *Ammobaculites* may be related to grain size distribution within estuarine facies. Although difficult to determine the type of estuary represented by the facies in the Ericeira section, it is possible to relate sediment grain size to estuarine facies using a modern analogue. Examining grain size distribution in the macrotidal estuary of the Minas Basin, Bay of Fundy, Yeo and Risk (1981) recognized five different facies and subfacies: salt marsh; upper mudflat; lower mudflat; mixed mudflat; sandflat, lag and sandbar. From the latter, *Ammobaculites obliquus* possibly inhabited fine grained upper mudflat subfacies, while the *A. coprilithiformis* lived in coarser lower mudflat subfacies. *Ammobaculites subcretaceus* may have inhabited mixed mudflat subfacies (Figure 3.7). The monospecific nature of the *Ammobaculites* assemblages suggests the three species were 'opportunistic' within each subfacies. Detailed sedimentary grain size analysis would be necessary to confirm the above relationships.

Although the species of *Ammobaculites* found in the Ericeira section probably inhabited estuarine paleoenvironments, all the species have been previously reported from open marine sediments. Barnard *et al.* (1981) reported abundant *Ammobaculites*

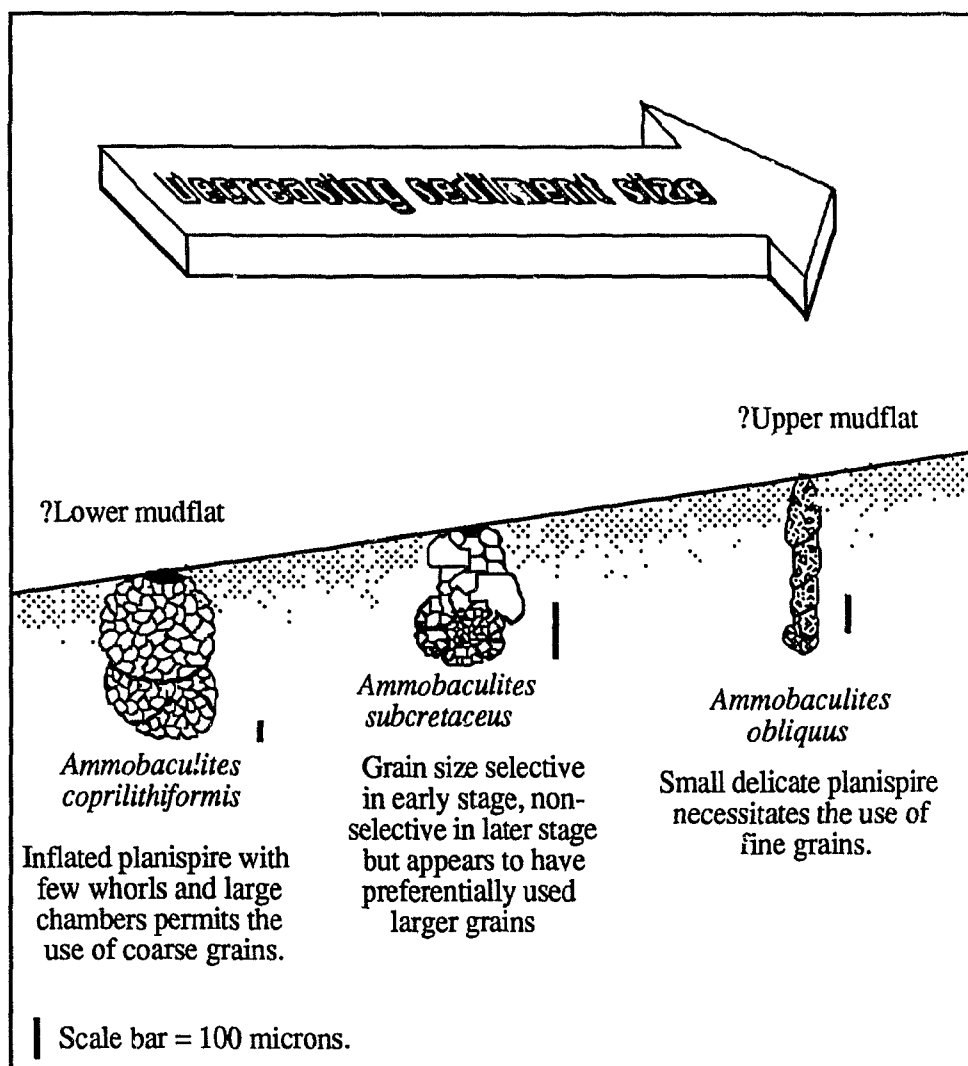


Figure 3.7: Interpretive model for the distribution of *Ammobaculites* assemblages in estuarine facies of the Lower Cretaceous of western Portugal.

coprolithiformis from the Oxford Clay, Crittenden (1981) listed *Ammobaculites obliquus* from the Atherfield Clay of southern England, and Loeblich and Tappan (1946) reported *Ammobaculites subcretaceus* and *A. obliquus* from the Walnut Clay of Texas. Despite the possibility that the monospecific *Ammobaculites* assemblages in the Ericeira section indicate euryhaline tolerances for the three species, salinity was probably secondary to substrate as an ecologic control.

3.4.5.b: Architectural constraints of grain size in test construction.

Grain selectivity of *Ammobaculites subcretaceus* through ontogeny has another possible paleoecologic implication. It appears the species was architecturally constrained into using only fine grains to build the coiled portion of the test, but was not so limited in construction of the uncoiled part. The requirement of possessing up to nine regular chambers in the final whorl of the test may have prevented the species from using grains larger than a certain diameter (Figure 3.8). Use of larger grains in the uncoiled portion of the test is difficult to explain, but may be a reflection of a need to conserve energy or to use less cement. Architectural constraints in agglutinated Foraminiferal test construction have also been suggested for trochamminids from the Recent (Bronnimann and Whittaker, 1988).

The test of *Ammobaculites coprolithiformis*, in contrast to *A. subcretaceus*, has a relatively large, but simple planispire with three to five chambers in the final whorl. It seems unlikely that the design of the test would have limited this species to using only fine grains in the planispire, and on this basis it is not unreasonable to expect that *Ammobaculites coprolithiformis* could have inhabited either fine or coarse grained substrates. The species' use of relatively coarse grains, however, may indicate preference for coarser substrates. The preference for coarser substrates is hard to explain. One possibility is that test construction may have been achieved more rapidly using coarser material, which would seem to be a successful strategy for an opportunistic species,

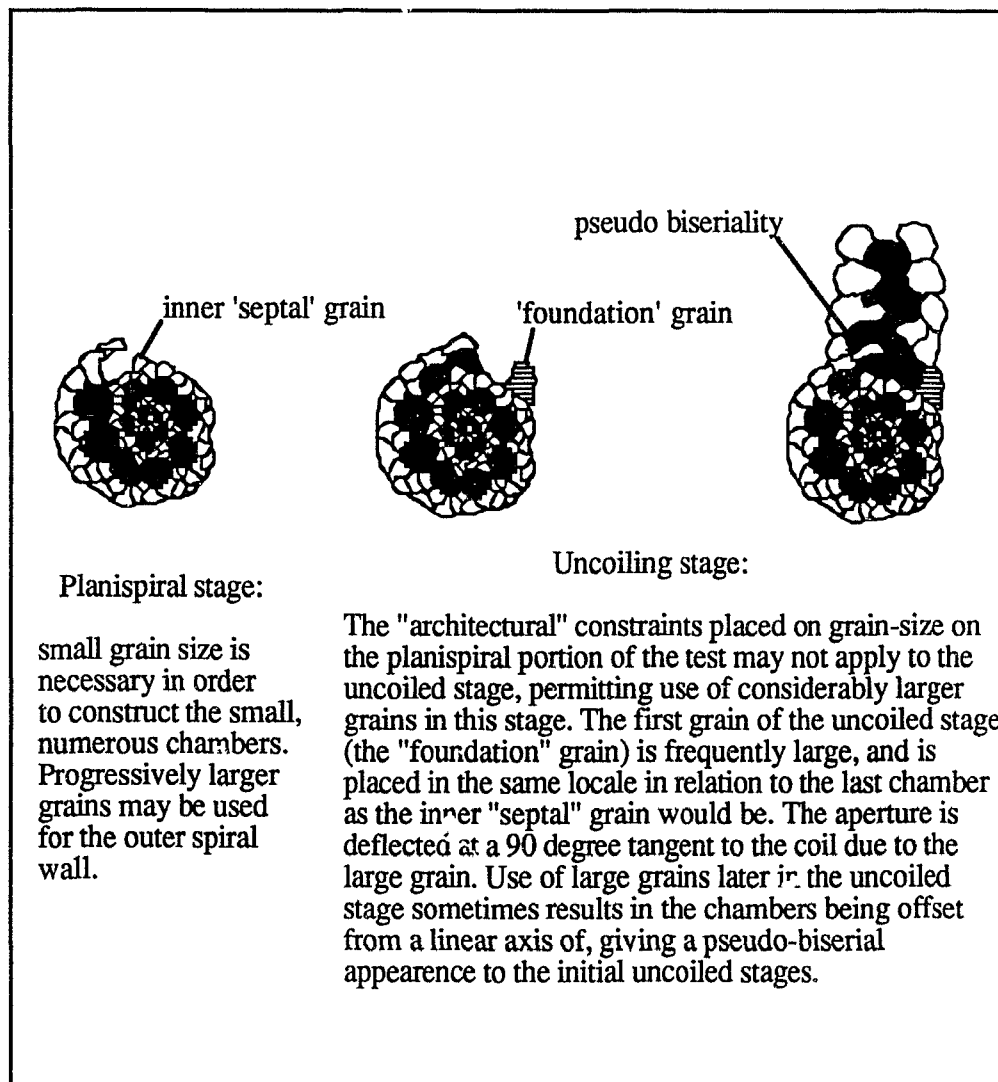


Figure 3.8: *Ammobaculites subcretaceus* in the Ericeira sections of Portugal, showing the inverted planispire, pseudo-biseriality, and the interpretation of the novel method of growth. Specimens were immersed in glycerine.

although such a relationship is not apparent among agglutinated Foraminifera inhabiting these types of environment today (D. Scott, pers.comm. 1989).

3.4.5.c: Development of uncoiled portion of *Ammobaculites* test.

It is of interest that finely agglutinated forms of *Ammobaculites* display variability with respect to the development of the uncoiled portion of the test. *Ammobaculites* sp.A has a short uncoiled portion of only one chamber, whereas *A. obliquus* and *A. euoides* frequently have long uncoiled portions of up to four chambers. Little is known of relationships between test morphology and substrate in modern *Ammobaculites*. It is suggested here that the development of the uncoiled stage of the test may be related to the nature of the sediment-water interface, in particular, the depth of the nephroid layer. Assuming *Ammobaculites* lives infaunally with its aperture at the sediment-water interface, the presence of a 'soupy' layer of sediment may act as a partial barrier to communication between the living Foraminifera and the aqueous environment. In such a situation, a longer uncoiled portion may be an advantage as it would allow the Foraminiferal test to penetrate through the nephroid layer. Alternatively, a well developed uncoiled portion may enable the Foraminifera to anchor itself more deeply within the sediment in relatively higher energy conditions. In the former situation, the uncoiled portion is analagous to a "chimney", whereas in the latter, the coiled stage may function as an "anchor".

3.4.6: *Choffatella* assemblage of Unit 6.

Sparse Ostracoda make determination of paleosalinity difficult. Absence of Ostracoda recognised as euryhaline suggest that salinity was near normal marine, however the abundance of *Choffatella* may indicate marginal marine conditions based on the paleoecology of the Kimmeridgian form at Praia Azul. Trace fossils (*skolithos*) indicate a possible intertidal environment dominated by infaunal suspension feeders, whereas the Foraminifera are represented by an abundance of the epifaunal morphogroup i. The

epifaunal Foraminifera may indicate local stabilization of high energy intertidal areas by sea plants. Although the low number of Foraminifera species seen in this assemblage is partly a reflection of the low number of specimens, it may also reflect the reduced faunas in the Early Cretaceous (Basov *et al.*, 1978).

3.4.7: Relationship of micropaleontological results to sedimentological interpretations in Hiscott *et al.*, (1990b).

A nearshore intertidal to estuarine (river mouth) environment based on ichnofacies and larger Foraminifera in the carbonate beds and the *Ammobaculites* associations in the interbedded shales in Unit 2 accords with Hiscott *et al.* (1990b) who interpret Unit 2 as a sequence of fluvial channel sands, caliches and dolomites of inter-distributory bays.

Interpretation of Unit 4 as lower marsh and lagoonal deposits also accords with Hiscott *et al.* (1990b) who interpret the upper part of the Calada member to have been deposited within river-mouth estuaries, or on low-energy sand flats flanking river mouths. Interpretation of most strata in Unit 5 as having been deposited in fluctuating high marsh and low marsh environments is not in agreement with Hiscott *et al.* (1990b), who regard this unit as marine shale. Interpretation of the *Ammobaculites coprilithiformis* assemblage in the upper part of the siltstone of Unit 5 as a lower mudflat facies indicator of estuarine environments, supports the interpretation of the sharp contact at the base of the overlying sandstones (Unit 6; Safarajo member) as the erosional surface of a migrating tidal inlet (Hiscott *et al.*, 1990b).

The samples taken from the lower part of Unit 6 contained *Ammobaculites* assemblages (*A. subcretaceus* and *A. obliquus*), thought to indicate mixed and upper mudflat estuarine facies respectively, which also supports interpretation in Hiscott *et al.* (1990b). Unit 8 comprises the basal 15m of the Dois Irmãos sandstone member examined by Hiscott *et al.*, (1990b). The carbonate facies in Unit 8 are interpreted to indicate a shallow marine intertidal environment, however, Hiscott *et al.* (1990b) regarded the whole

member as a river-dominated deltaic sequence, but did not elaborate on the carbonate facies within the sequence. A shallow marine intertidal environment would fit within the deltaic interpretation offered by Hiscott *et al.* (1990b).

3.4.8: Implications of Foraminiferal morphogroups.

Observations on the gross test morphology of Foraminifera in the shallow marine facies at Ericeira reveal a general trend in which the morphogroups in Foraminiferal assemblages in the more marginal environments are reduced to one or perhaps two dominant types. In upper marsh facies the epifaunal morphogroup ii is dominant. In lower marsh facies, morphogroups ii and iii may be present in equal amounts. Estuaries are dominated by morphogroup iii.

The forgoing morphogroup trends in Ericeira are misleading since they are not seen in the distribution of Foraminifera in modern marsh and estuarine environments, and are the likely result of selective preservation of the agglutinated taxa in marshes and estuaries (calcareous taxa having dissolved post mortem). Murray (1973) indicated modern marshes contain many infaunal taxa, both calcareous and agglutinated, that are not seen in the Ericeira section. Similarly, Scott *et al.* (1977) reported infaunal estuarine faunas from the Miramichi estuary that included coiled forms assignable to morphogroup ii, for example *Criboelphidium* and *Protelphidium*.

The occurrence of morphogroups in certain lagoonal environments in Ericeira however, is thought to reflect what would be seen in modern lagoonal environments. Few studies, however, have dealt with feeding strategies or microhabitats of living Foraminifera. Murray (1973) indicated that a number of Foraminifera are closely associated with plants, for example, the larger Foraminifera *Peneroplis* is associated with *Jania* and similar algae, *Sorites* clings to the blades of sea-grass, *Elphidium* and *Amphistegina* are associated with seaweed. In a study of Foraminifera from the Bassin d'Arachon lagoon on the west coast of France, Le Campion (1970) recognised two intertidal and six subtidal

subenvironments each with its own characteristic Foraminifera. The intertidal subenvironments and their Foraminifera were: 1) *Zostera nana* meadows, containing *Protoelphidium*, *Elphidium* and *Ammoscalaria*; 2) *Scrobicularia* mudflats, mainly with *Ammoscalaria*. The subtidal subenvironments were: 1) Channels with shell lag deposits, containing *Cibicides*; 2) Mussel-beds, containing *Fissurina*, *Planorbulina*, *Asterigerinata* and *Textularia*; 3) *Amphioxus* sands (barren); 4) Calcareous algae with *Discorbis* and rare miliolids; 5) *Zostera marina* meadows with clinging *Planorbulina* and *Cibicides*; 6) Infralittoral sands with the plants *Venus* or *Abra*, containing *Crithrionina* and *Nonionella*. Le Champion's data (in Murray, (1973)), although not quantitative, serves to illustrate that study of Foraminiferal morphogroups may help delineate microhabitats, such as seaweed meadows and zones of calcareous algae within broader environments.

Absence of one or more morphogroups from particular units in Ericeira does not necessarily imply absence of suitable habitat. The apparent absence of infaunal groups in the dolomites of Unit 1, for example, is most likely related to preservational bias in favour of agglutinated taxa. The absence of all but morphogroup ii in the upper marsh facies, and morphogroup iii in the estuarine facies is probably related to other ecological controls such as salinity and perhaps temperature. The only species able to survive in such environments are those that are highly euryhaline and eurythermic. Such forms (for example, *Trochammina* and *Ammobaculites*) are usually extremely conservative in nature and have changed little since the Mesozoic (Scott *et al.*, 1983). Hence, Foraminiferal morphogroups cannot be used to determine specific environments, but may be used to identify sub-environments.

3.4.9: Summary of paleoenvironments.

A number of paleoenvironments are recognised in the Ericeira sections ranging from subtidal through lagoonal, estuarine to marsh, based on Foraminiferal and Ostracodal assemblages. The paleoenvironmental successions through the sections indicate a number of fluctuations in relative sea level, with a regressive peak in Unit 5, as indicated by the

development of a marsh sequence. The latter marsh sequence may have been as much as 1-3m above sea level at the time, based on present day distribution of upper marsh facies. The distributions of the Foraminiferal and Ostracodal assemblage and paleoenvironments are summarized in Figure 3.9.

Lithology	Ostracodal assemblage	Foraminiferal assemblage	Interpretation	
			Paleoenvironment	relative sea level
8	<i>Schuleridea</i> poly/euhaline	monotypic <i>Choffatella decipiens</i>	shallow marine intertidal spit (Hiscott <i>et al.</i> 1990)	-
7			coral reef	
6		<i>A. obliquus</i> <i>A. subcretaceus</i> <i>A. coprolithiformis</i>	beach deposit with migrating tidal inlet (Hiscott <i>et al.</i> 1990)	
5	Ostracoda absent	<i>Trochammina-Tiphotrecha</i>	estuarine upper marsh	
4	bored <i>Fabanella</i>	<i>Trochammina</i> - <i>Ammobaculites</i>	estuarine to lower-middle marsh	
3			estuary/ low energy sand flat (Hiscott <i>et al.</i> 1990)	
	rare <i>Fabanella</i> <i>Cytherella</i>	monotypic <i>A. subcretaceus</i> monotypic <i>Anchispirocyclina</i>	estuarine ?lagoon	
2	Ostracods absent from dolomites (?recrystallized), rare in shale interstices	<i>Haplophragmoides</i> and <i>Anchispirocyclina</i>	interdistributary bays and fluvial channels (Hiscott <i>et al.</i> 1990)	
1	(nodular limestones) euhaline- polyhaline; <i>Asciocythere</i> , <i>Schuleridea</i> , <i>Cytherella</i> , <i>Cytherelloidea</i> , <i>Cytheropteron</i>	mixed 'larger' (<i>Everticyclammina</i> & <i>Pseudocyclammina</i>) & 'smaller' agglutinates, plus <i>Eoguttulina</i>	fluvial deposits with three marine bands (nodular limestones); limestones probably deposited in intertidal to shallow subtidal environment in open marine conditions.	

Figure 3.9: Summary of lithofacies, microfossil assemblages and paleoenvironmental interpretations through the Ericeira section.

CHAPTER 4

CABO ESPICHEL SECTION

4.1: Introduction and previous work.

Cabo Espichel forms a small headland 12 km west of Sesimbra and 30 km SW of Lisbon (Figure 4.1). The section forms a near complete succession of northward dipping beds forming the cliffs that extend from just south of Praia do Cavalo, northwards to the Areia do Mastro promontory.

The lower 503 m of the 800m section was studied by Ramalho (1971), who divided the sequence into 43 beds ("niveaux"), and erected a biostratigraphic framework based on calcareous algae, Foraminifera and Ostracoda identified largely from limestone thin sections. Ramalho (1971) dated the base of the section as Portlandian, based on isolated specimens of the ammonite *Lithacoceras sileceum*, and divided the stage into two biozones, referred to as Portlandian A and Portlandian B, based on the first occurrence of the foraminifer *Anchispirocyclina lusitanica*.

Fursich and Schmidt-Kittler (1980) examined the sedimentology, trace fossils, benthic assemblages and microfacies of the part of the section dealt with by Ramalho (1971), and recognised 8 major facies and paleoenvironments. The Fursich and Schmidt-Kittler (1980) work is summarized in Table 4.1.

The upper 300 meters of the 800m section was examined by Rey (1972), who divided it into a number of lithological units. Rey assigned these units to the Berriasian to Barremian stages of the Lower Cretaceous, based largely on echinoderm stratigraphy. There is no other biostratigraphic framework published for the upper part of the Cabo Espichel section.

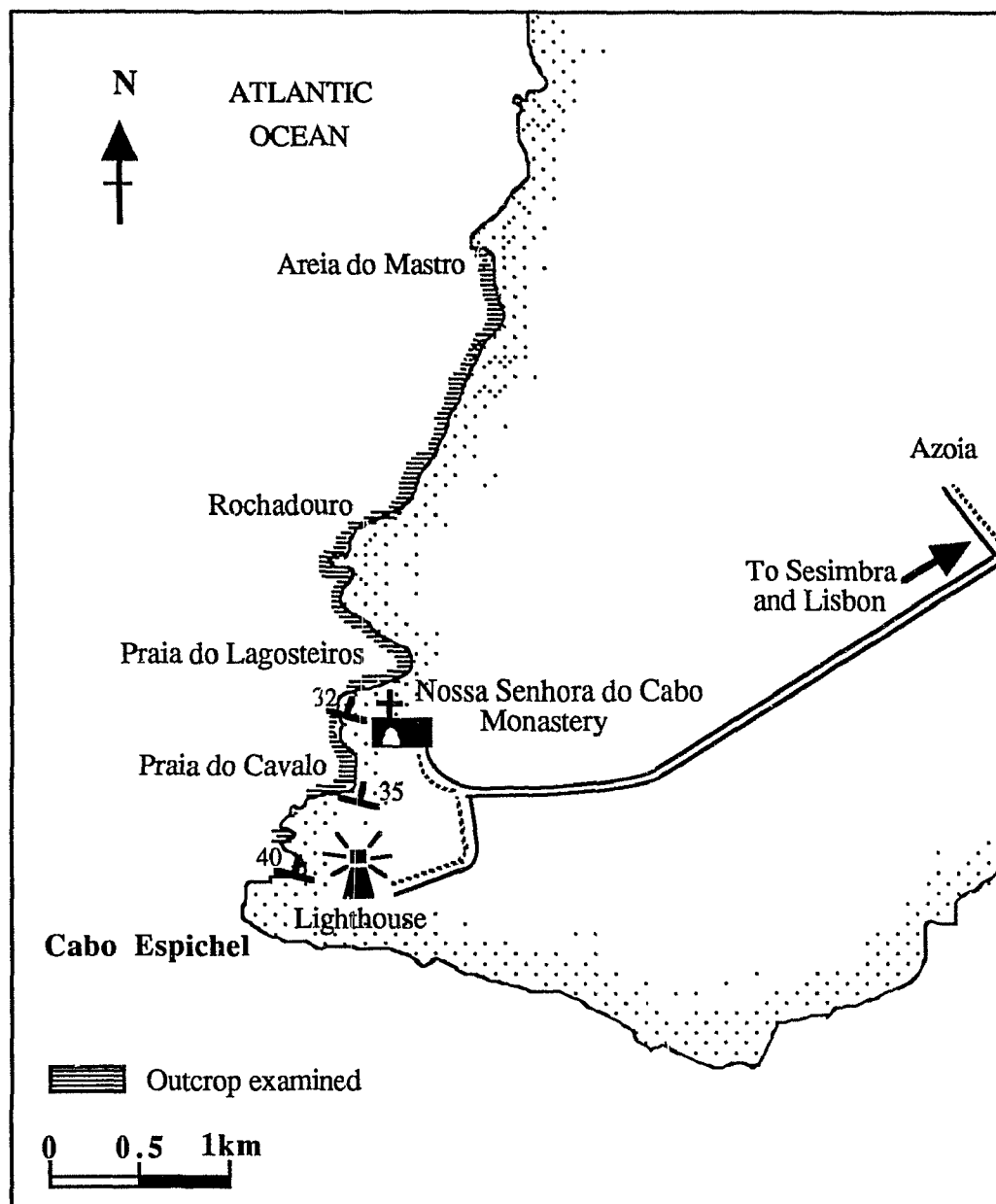


Figure 4.1: Location map of the Cabo Espichel section, SW. of Lisbon.

Facies, lithology and microfacies	Trace and characteristic invertebrate fossils T: trace, B: bivalve, G: gastropod, C: coral; r: rare, f: few, o: occasional, c: common, a: abundant.	Interpretation
<u>Nodular limestone</u> marly to fine sandy nodular limestone with thin marly interstices; bioclastic wackestone, packstone and grainstone	T: Planolites, f; Rhizocorallium, c; Thalassinoides, a B: Protocardia, Mactromya, Camptonectes, Arcomytilus, Trichites, Nanogyra, Ostrea; G: Pseudomaura, Neritoma, Cyphosolenus, nerineids	shallow <20m marine, low energy but local winnowing
<u>Massive biomicrites</u> bioclastic limestone; similar to nodular limestone; bioclastic wackestone prevails	T: Planolites, r; Thalassinoides, r; Diplocraterion, r B, G: similar to nodular limestone, but Liostrea (B) in place of Nanogyra (B), plus Nerineid shell beds.	moderate energy, shallow area of bay or lagoon
<u>Laminated limestone</u> biomicrite, pelmicrite, fenestral micrite, algal laminite	T: Skolithos, c Invertebrate fossils absent	protected tidal flat in low energy lagoon
<u>Coral biostrome</u> mudstone & wackestone with angular clasts & peloids	T: Lithophaga, r B: Arcomytilus; Plagioecia (bryozoan); Pseudocidaris (echinoid); C: Actinastrea, Dermosmilia, Thecosmilia; Stromatopora (stromatopora)	very shallow, fully marine, normal salinity
<u>Marls and silty marls</u>	T: Planolites, r; Thalassinoides, c; Rhizocorallium, c; Cylindrichnus, r <i>Invertebrate fossils very dense, but mainly B: Corbulomima, Mesosacella, Protocardia, Nicaniella, Placunopsis, Modiolus</i>	shallow, low energy, slightly brackish
<u>Fine- to medium-grained marly sandstone</u> poorly sorted with coarse quartz & wood fragments	T: Thalassinoides, o; Planolites, c. B: Eomiodon, Liostrea. G: Multiptyxis, Valanginella	very shallow marginal marine, moderate energy
<u>Medium to coarse pebbly sandstone</u> coarse quartz & feldspar at base, wood & mud clasts	T: Skolithos, r; Ophiomorpha, r; Diplocraterion, r. Invertebrate fossils absent.	fluvial and submarine channels
<u>Poorly sorted fine sandstone & siltstone</u> locally, much feldspar wood & plant debris	T: Planolites, o. Invertebrate fossils absent.	alluvial plain & crevasse splay

Table 4.1 : Principal facies, fossils and their interpretation at Cabo Espichel (after Fursich and Schmidt-Kittler, 1980).

4.2: Lithostratigraphy.






















The lithostratigraphy at Cabo Espichel is summarized in Figure 4.2. The lower 503m of the section, studied by Ramalho (1971), is composed of a carbonate succession of alternating nodular (bioturbated) and massive limestones. Intercalated within the carbonates are numerous siliciclastic intervals characterised by marlstones, siltstones, sandstones and conglomerates. The 43 beds ("niveaux") recognised by Ramalho (1971) are shown in the column on the left side of the lithologic log.

The topmost 300m of the section was examined in detail by Rey (1972), who identified ten main units based on facies associations. These units are recognisable in the field by their main lithological features, and are shown by their informal names (in French) in the left-hand column of the lithologic log (Figure 4.2).

A detailed bed-by-bed examination and lithostratigraphic log of the lower 503 m of the section in the field was made, and all the principle facies types recognised correspond to those described by Fursich and Schmidt-Kittler (1980). Recognition of particular "niveaux" described in Ramalho's (1971) was difficult because of the repetitive nature of the facies, although certain key "niveaux" stand out, allowing the intervening strata to be placed within the section. In overview, the lower 503m of the section reveals a number of distinctive facies associations which have been grouped into larger units (numbers 1-5, Figure 4.2). Units 6-15 correspond with those recognised by Rey (1972). The geographic location of Units 1-5 are shown in Figure 4.3, and Units 6-15 in Figure 4.4.

Unit 1 corresponds to Ramalho's (1971) beds 6-8, and is composed of grey and red marly siltstone, with an 0.7m thick intercalation of limestone and a 1.5m thick interbed of fine cross-bedded sandstone.

Unit 2 includes Ramalho's (1971) beds 9-18, and consists of alternating nodular-weathered

legend	
carbonates	
	sandy marlstone
	marlstone
	dolomitic limestone
	coral limestone
	sandy limestone
	shaley limestone
	laminated (algal) limestone
	bedded limestone
	nodular (bioturbated) limestone
macrofossils	
	gastropods
	<i>Natica</i>
	bivalves
	oysters
	echinoderm spines
	<i>Terrebratula</i>
siliciclastics	
	claystone / shale
	sandy siltstone
	fine sandstone
	medium - coarse sandstone
	gravelly sandstone
	pebbly sandstone/conglomerate

Legend for Figure 4.2.

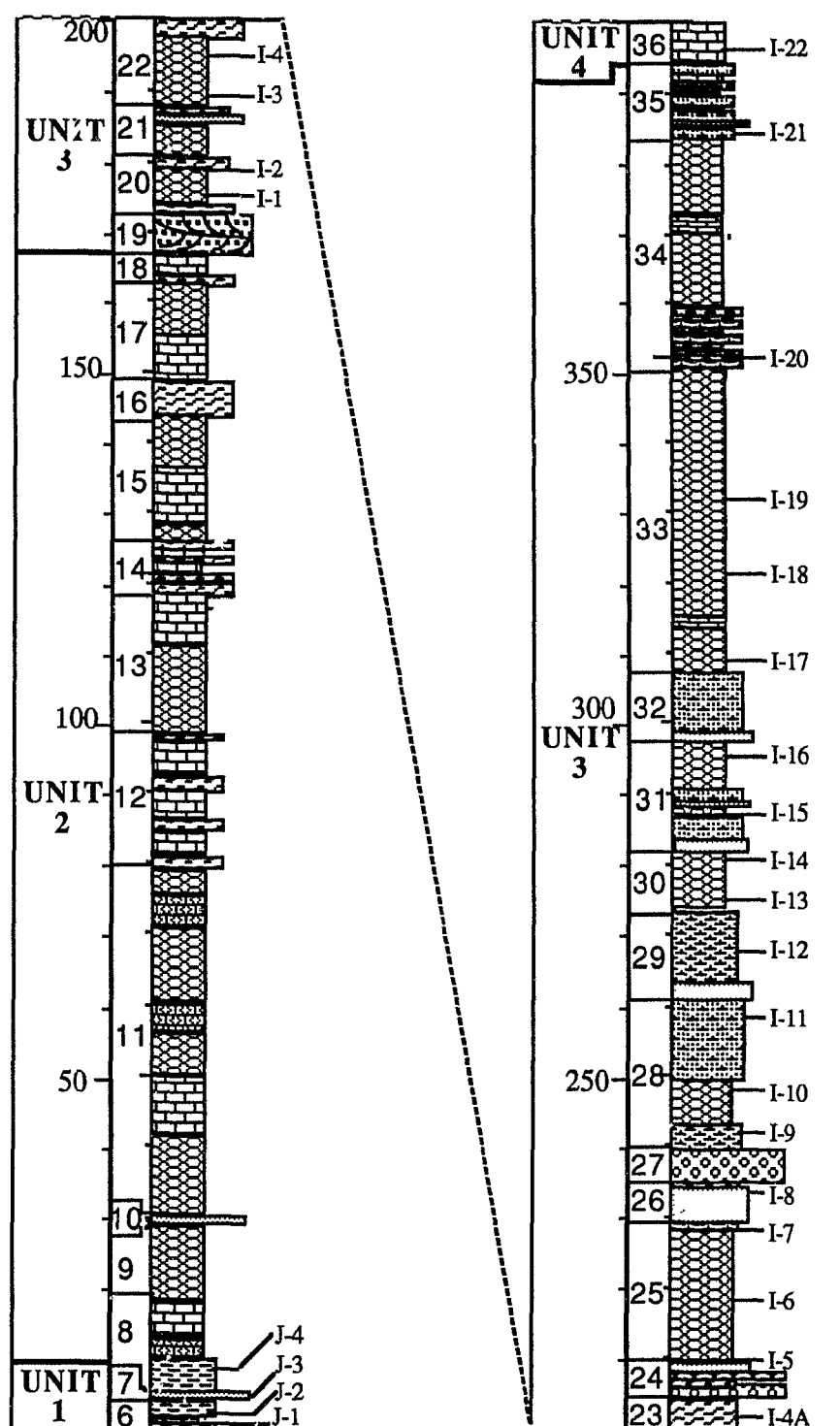


Figure 4.2: Lithologic and sample distribution in the Cabo Espichel section. Numbers 6-36 (centre column) refer to Ramalho's (1971) original division of the sequence. Units 1-4 (left column), this study. Sample locations indicated by the letters J -1 to I-22. 50 m intervals shown on left. Figure 4.2 is continued overleaf.

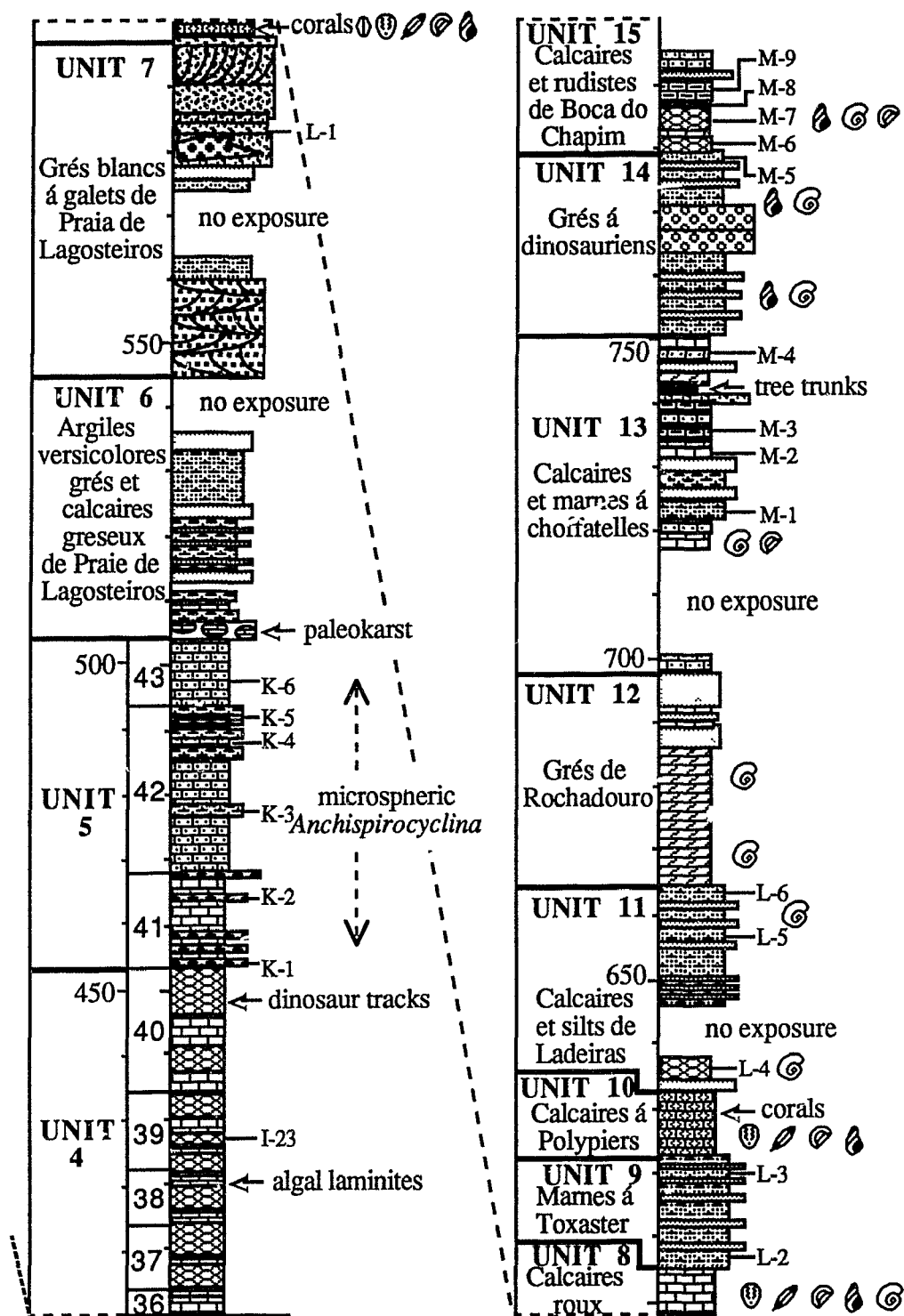


Figure 4.2 continued: Numbers 36-43 refer to Ramalho's (1971) division of the sequence; Upper unit names (in French) are the units described in Rey (1972). Sample locations indicated by the letters I-23 to M-9.

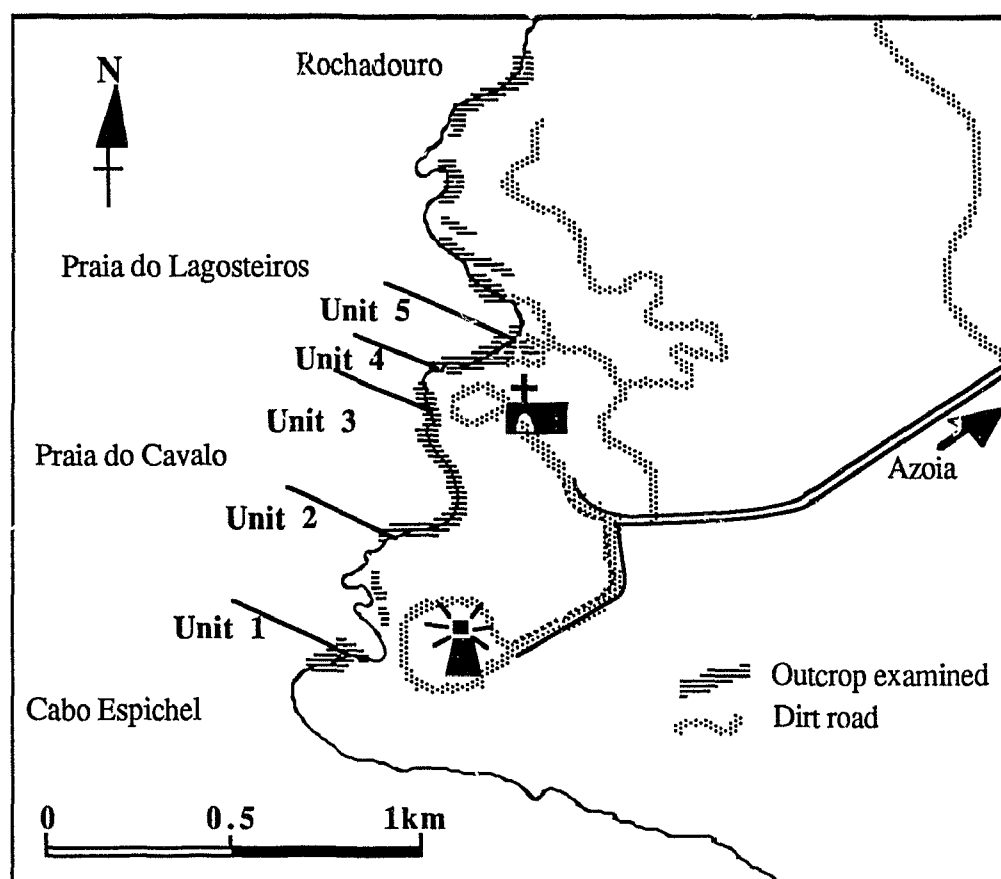


Figure 4.3: Location of lithological Units 1-5 in the lower part of the Cabo Espichel section.

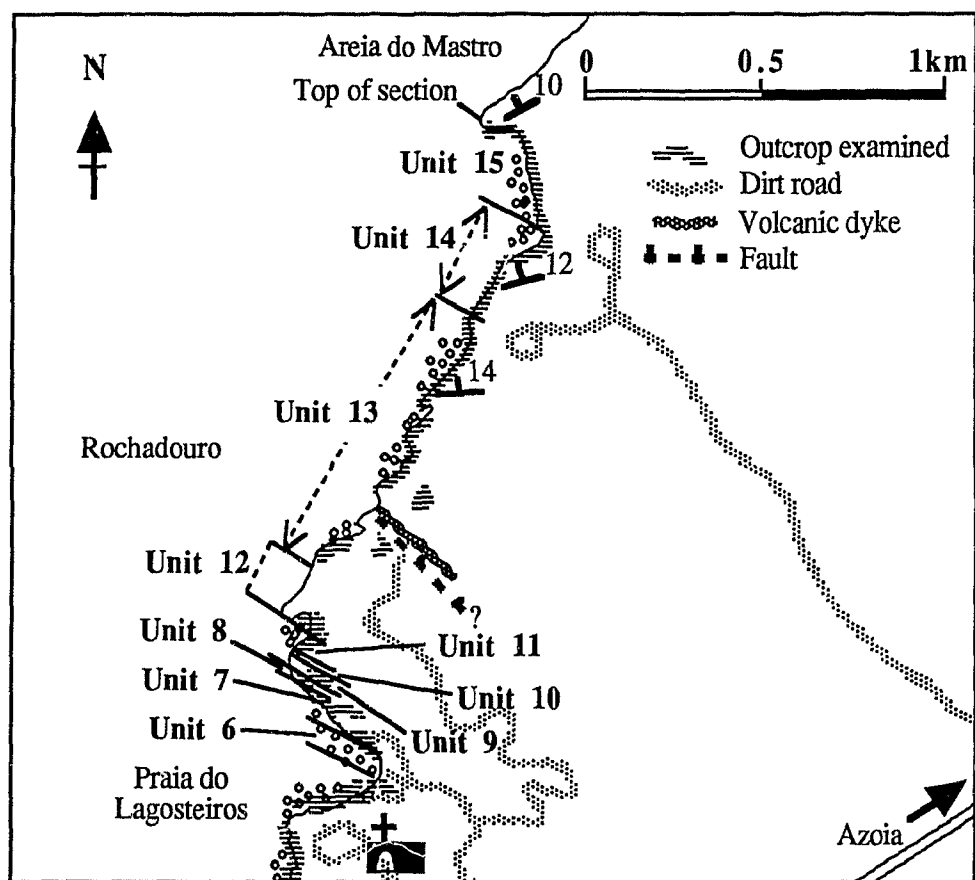


Figure 4.4: Location of lithological Units 6-15 in the upper part of the section at Cabo Espichel.

limestone, marlstone and massive limestone. The unit commences with a limestone rich in invertebrate fossil debris (*Pseudocidaris* spp., bivalves, gastropods, solitary and colonial corals in apparent growth position). Coral debris is also apparent within massive limestone beds at the top of the cliff, and bipedal dinosaur footprints are seen on the top of Ramalho's (1971) bed 11. The marlstone was deeply weathered into the cliff section. The beds within this unit were not accessible from the cliff top, and were not sampled.

Unit 3 corresponds to Ramalho's beds 19 to 35 and is characterized by a number of carbonate-siliciclastic alternations. All the major facies types recognized by Fursich and Schmidt-Kittler (1980) (Table 4.1), with the exception of the coral biostromes are seen here and are arranged in a series of coarsening up and fining up sequences.

The base of the unit is marked by a conglomerate, with a concave upward erosional base. Other conglomerates and coarse sandstones are seen in the lower part of the unit (up to bed 31). The nodular limestones are more abundant towards the top of the unit, where there is a corresponding decrease in the grain size and number siliciclastic beds. The upper part of the unit (Ramalho's bed 33 and 24) shows algal-laminated, micritic limestones. The highest siliciclastic bed in the unit is a sandy marlstone.

Unit 4 includes Ramalho's beds 36 to 40 and is composed of massive limestones, nodular limestones and algal-laminated limestones. Massive and laminated limestones are developed in the lower part of the unit, whereas nodular biomicrite predominates in the upper, inaccessible, part which forms the headland between Praia do Cavalo and Praia do Lagosterios. The uppermost beds in this unit have well-preserved bipedal dinosaur tracks on their bedding-planes, seen in the southern part of Praia do Lagosteiros.

Unit 5 corresponds to Ramalho's beds 41 to 43, and is found in the southern part of the section at Praia do Lagosterios. The unit is characterized by a series of alternating

marlstone and massive limestones with minor nodular limestones. The massive limestones become increasingly sandy towards the top of the unit and the marlstone is gypsiferous. The marlstone is particularly well developed and up to 1m thick in Ramalho's bed 41 where it contains abundant large *Anchispirocyclina lusitanica*. Miliolid Foraminifera (*Quinqueloculina* spp.) are also apparent throughout. The beds in the upper part of the unit (Ramalho's beds 42-43) contain abundant scattered grains of fine sand. Ramalho's bed 43 contains a rich assemblage of *Discorbis scituliformis*.

Unit 6 commences with a 1.5m bed described by Rey (1972) as a limestone-marlstone conglomerate, characterized by limestone blocks up to 15cm diameter floating in a marlstone matrix. The limestone blocks are similar in lithology to Ramalho's bed 43 immediately below. This suggests that the limestone 'clasts' may be *in situ* erosional remnants of the top bed of Ramalho's bed 43 that have been subsequently encased in a younger deposit, i.e. a paleokarstic feature.

The overlying beds commence with a sandy limestone containing abundant turritellid gastropods, overlain by alternations of siltstone and thinly-laminated sandstone. The lowermost sandstone (512m) has an erosive base.

Unit 7 consists predominantly of unsorted coarse pebbly sandstones with erosive bases and cross-bedding. The uppermost bed in this unit consists of thick, ochre-stained gravels with distinctive large-scale (5m) progradational foresets dipping about 35 degrees to the south, seen at the top of the cliffs on the north side of Praia de Lagosteiros.

Unit 8 commences with three beds of unsorted coarse pebbly sandstone, overlain by 8m of poorly bedded fossiliferous limestone containing scattered coarse sand grains. The limestone contains abundant and diverse invertebrate fossils including solitary hermatypic corals (*Montlivaultia*), bivalves ('oysters' including *Exogyra* and *Lopha*), brachiopods

(terebratulids including *Terebratula* and *Zeilleria*), echinoderms (including *Toxaster*, *Phymosoma*, *Holectypus*) and gastropods. The lowest bed of the limestone is undercut, revealing large *in-situ* colonial corals thickets, approximately 0.5 m in diameter and height.

Unit 9 is characterized by siltstone interbedded with laminated, fine-grained micaceous sandstones in thin (10cm) beds. The siltstone is red where weathered, grey on fresh surfaces. Upper and lower boundaries appear gradational. Rey (1972) reported a diverse invertebrate fossil assemblage in two calcareous beds in the lower 0.5m of the "Marnes á *Toxaster*". These beds were not recognised in the field; possibly they correspond to the top 0.5m of Unit 8. The siltstones and interbedded micaceous sandstones appeared unfossiliferous in the field, although Rey (1972) reported 'oyster' fossils and gastropods from these beds; two samples were taken for microfossil analysis.

Unit 10 commences with well-bedded coral bearing limestones containing abundant small colonial "brain" corals and numerous forms of solitary coral in aparent growth position. The upper part of the unit is less well bedded and the corals occur as fragmented debris.

Unit 11 commences with a series of heavily weathered, bioturbated, sandy, medium-bedded limestones. These frequently contain large naticid gastropods, and in the upper part of the limestone, the Foraminifera *Choffatella*. Above the limestones are a series of green-grey, locally sandy siltstones with abundant woody fragments. Thin (20-30cm) beds of poorly sorted, slightly calcareous sandstone are interbedded with the siltstone.

Unit 12 is characterized by a thick (20m) sequence of well-bedded dolomitic limestones overlain by fine to medium grained, poorly sorted sandstone and thin sandy limestone. The dolomitic limestones have a gradational contact with the underlying unit. *Thalassinoides* traces on the bedding surfaces of the dolomitic limestones result in

undulatory bedding contacts. Large naticid gastropods are seen locally on the bedding planes of the dolomitic limestone. The uppermost sandstone in the unit is orange to grey/green in colour, with quartz pebbles.

Unit 13 is characterized by a series of interbedded, heavily bioturbated bioclastic limestones, with marlstone and sandstone intercalations. The lower part of the unit shows a coarsening upward trend commencing with medium-bedded, bioclastic limestones that become increasingly sandy before passing into a marly siltstone with interbedded fine sandstone. The upper part of the unit consists of heavily bioturbated limestones that are locally sandy and shaley, overlain sharply by a 1m thick bed of unsorted, coarse arkosic sandstone. Immediately above the arkosic sandstone is a thick (2m) bed of sulphurous, heavily convoluted claystone, containing woody fragments and tree trunks.

The upper few meters of the unit contains a poorly sorted sandstone which passes into a thin sandy marlstone, overlain by a sandy limestone. The limestone in the top 2.5m of the unit is largely sand-free, and has an erosive contact with the underlying sandy limestone, indicated by an irregular contact and clasts of the latter within its lowermost bed. The top of the underlying sandy limestone is characterized by wavy lamination, possibly of algal origin.

Unit 14 consists of a series of interbedded grey-green sandy marlstone and finely laminated silty sandstones. The middle of the unit contains two conglomeratic sandstones, both with concave upward erosional bases. These beds show normal grading and are rich in quartz, feldspar and wood fragments. The marlstone contains abundant large naticid gastropods.

Unit 15 consists of a series of biomicritic limestones locally shaley or nodular with local shale interbeds. In the upper part the limestone becomes increasingly sandy before passing into sandy marlstone and fine sandstones. The sandy limestone commences with a 30cm

thick bed containing quartz and black chert pebbles at the base.

4.3: Microfossil analysis.

A total of 49 samples were collected for microfossil analysis of which 46 contained Foraminifera and 39 contained Ostracoda. Forty-four species of Foraminifera and 27 Ostracoda species are recognised. The number of Ostracoda and Foraminifera species occurring in each sample is shown in Figure 4.5, and the total number of Ostracoda and Foraminiferal specimens in each sample is shown in Figure 4.6. Both groups show extreme fluctuations in their abundance and diversity through the section. In general the Foraminifera are more abundant than the Ostracoda and are represented by a greater number of species in most samples. Both the Foraminifera and Ostracoda show fluctuations in the number of species through Units 3 and 4, whereas in Unit 5 the Foraminifera show a fall in the number of species. Ostracoda are absent from Units 6 to 12 and are represented by up to five species in Unit 15. Foraminifera show fluctuating but generally low diversity in Units 11 to 15.

4.3.1: Ostracoda.

4.3.1.a: Ostracoda Families.

The Ostracoda at Cabo Espichel are represented by many of the families seen in the Ericeira section (the podocopids Cytheruridae, Cytherideidae, Cytheridae and Paracyprididae, and the platycopine Cytherellidae). In addition, the Family Loxoconchiidae is also represented, although the Darwinulididae are not seen.

4.3.1.b: Distribution of species and salinity indicators.

Most species seen in Ericeira are also found at Cabo Espichel. Seven additional

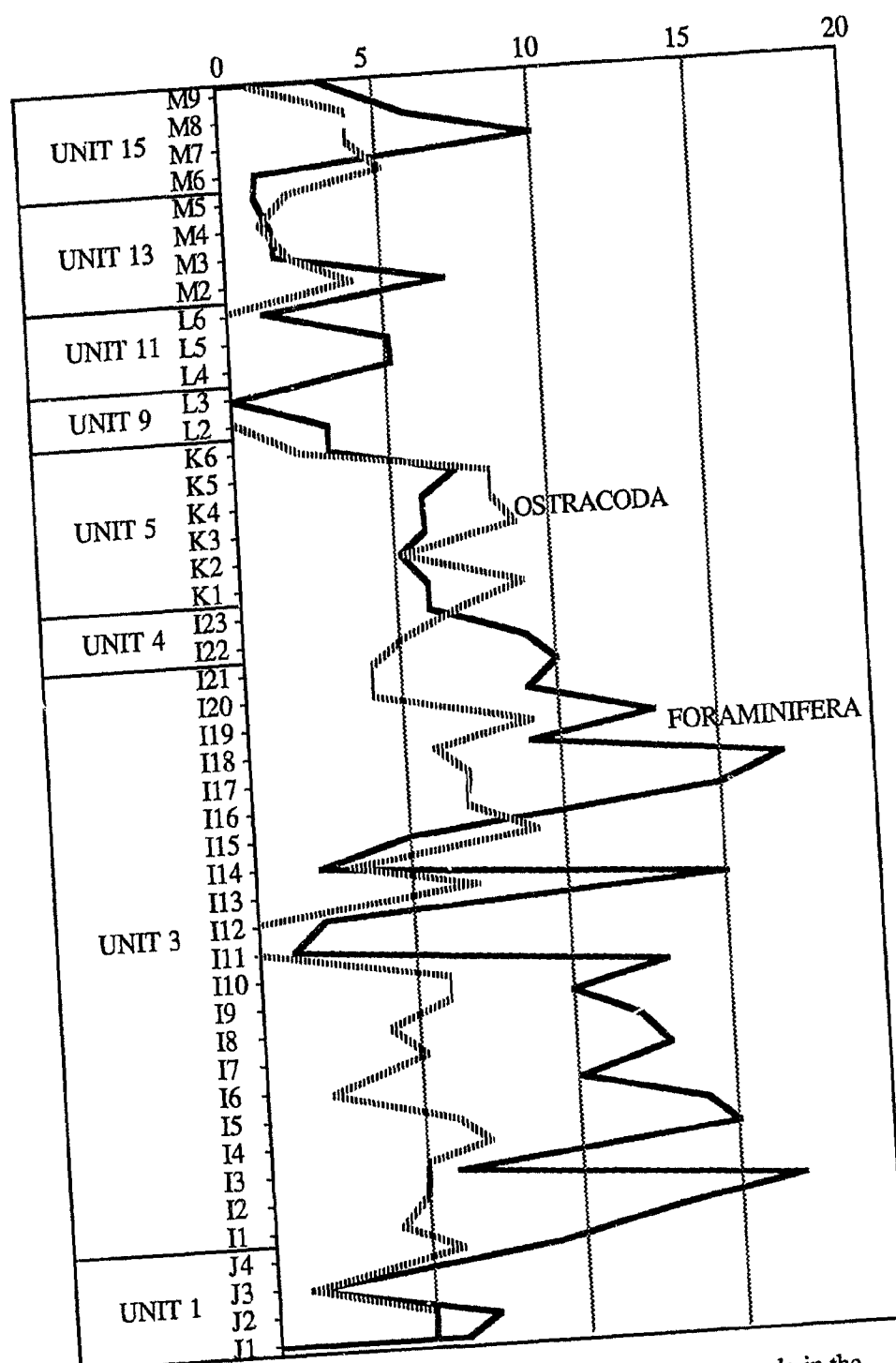


Figure 4.5: Number of foraminifera and ostracod species per sample in the Cabo Espichel section.

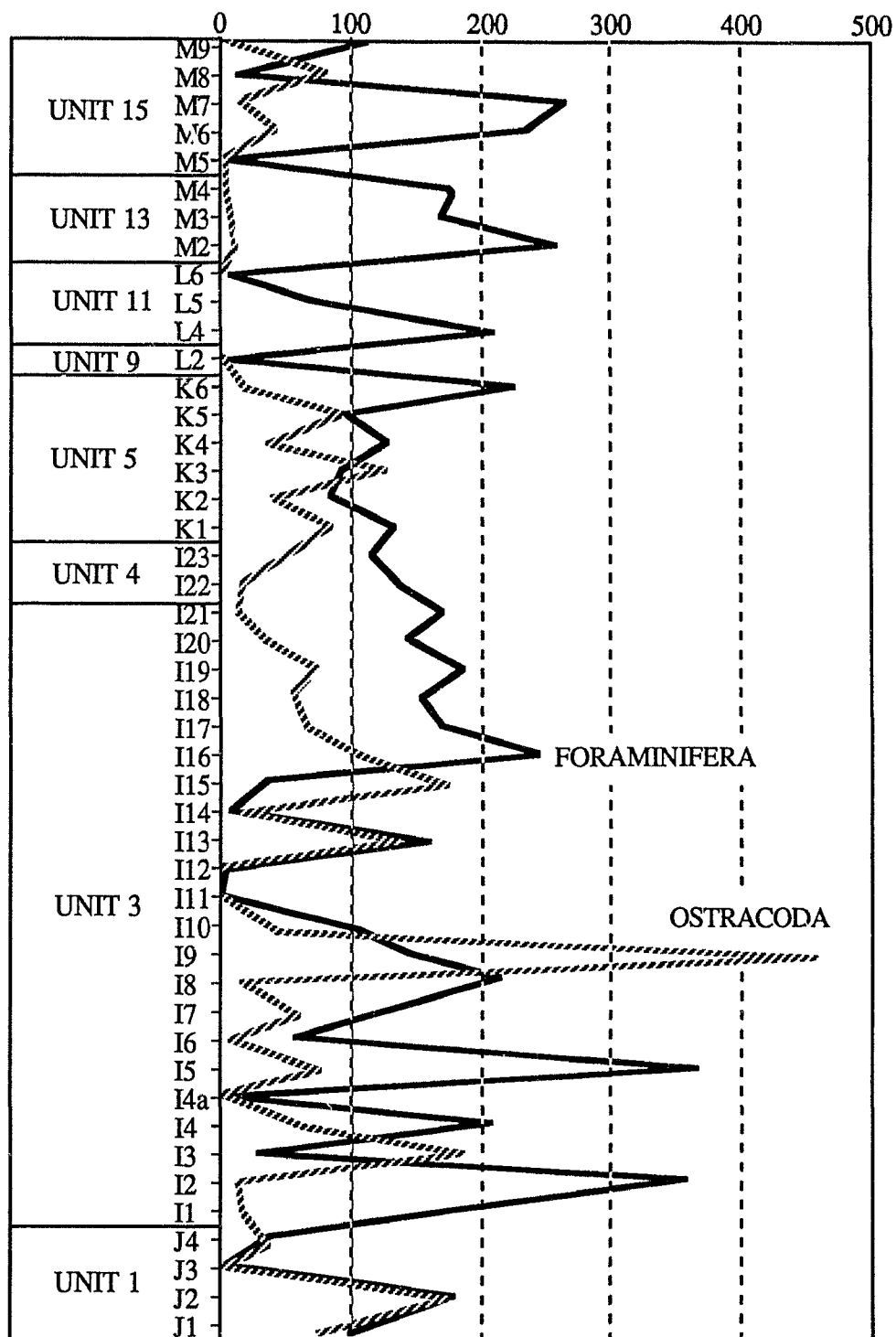


Figure 4.6: Number of foraminifera and ostracod specimens per sample in the Cabo Espichel section.

species are found, belonging to the genera *Cytheropteron*, *Mandelstamia*, *Exophthalmocythere*, *Protocythere* and *Rehacythereis*. All are short ranging and usually represented by a few specimens.

Distribution of the species (Table 4.2) shows that most have fragmented stratigraphic ranges, that may be partly due to facies variations. Comparison of species ranges with gross lithology, however, shows that lithology alone does not account for all the gaps seen. The lithologic descriptions, however, were generalised: there could be significant lithological variation that wasn't recorded in the field. Reduced salinity may have also been partly responsible for the local disappearance of a particular species. Absent from the assemblages are the fresh-water species seen at Praia Azul. All other forms are euryhaline or questionably stenohaline. Species of *Asciocythere* are thought to be stenohaline (Brenner, 1976). Since there is clearly no mixing of marine and non-marine species that needs to be resolved, (as there was at Praia Azul), detailed population studies are not called for. cursory examination of the Ostracoda populations, however, showed that all the common species contained late instars as both valves and carapaces. The distribution of the Ostracoda is therefore discussed in general terms of salinity for each unit, based on tolerances determined for the Praia Azul section.

Unit 1: *Cytherella fullonica* is the most abundant species, followed by *Galliaecytheridea* sp.2, *Schuleridea* sp.1 and low numbers of *Cytheropteron*, *Cytherelloidea* and *Paracypris*. Presence of *Cytherella*, *Cytheropteron*, *Cytherelloidea* and *Paracypris*, and the absence of *Fabanella* suggests near normal marine salinity.

Unit 2: Not sampled because of inaccessability.

Unit 3: The Ostracoda found in this unit are diverse compared with other units. *Schuleridea triebeli*, *Cytherella suprajurassica*, *Asciocythere* sp.1 and *Fabanella boloniensis* are

KEY TO SPECIES	SAMPLE	SPECIES CODE (See key)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Amphicythere aff. confundens	M-9			2											
	M-8			1											
2 Ascocythere sp.1	M-7			5			4					1			
3 Ascocythere sp.2	M-6			20								11			
	M-5			1			1								
4 Cytherella fullonica	M-4						1								
	M-3						2								
5 Cytherella suprajurassica	M-2			2			1								
6 Cytherella pyriformis	M-1														
	L-6														
7 Cytherelloidea weberi	L-5														
8 Cytheropteron sp.A	L-4														
	L-3														
9 Cytheropteron aquitanum	L-2														
	L-1														
10 Cytheropterina triebeli	K-6	4				14									
11 Metacytheropteron sp.59	K-5	2		33		5					5				4
12 Exophthalmocythere gigantea	K-4	3	22	2		21		3			2			3	
	K-3		4	21		16		19		5	8		3		
	K-2			18		15				5					9
13 Exophthalmocythere sp.A	K-1	6		24		6		4		4					1
	I-23		15	30		5				3					7
14 Fabanella boloniensis	I-22		2			4		2		2					
	I-21	2	6			4									
	I-20		3			31									
	I-19	4	2			6				7					2
	I-18		6			6		1		1					4
	I-17	4	16			1				8					1
	I-16		30			117				11					10
	I-15		40					1		10			1		4
	I-14		10			41									4
	I-13		2					6		12					5
	I-12		24												
	I-11					2									
	I-10	2				256				9					6
	I-9		6							27					13
	I-8		22			5									8
	I-7		5			9				8					14
	I-6		6			11									
	I-5		21					1		14					6
	I-4A					21									
	I-4		5			41				10					6
	I-3					2		1		1					
	I-2	4				8									
	I-1	2													
	J-4				11			1	4						
	J-3							1							
	J-2				101			1	5						
	J-1				51			1	1						

Table 4.2: Distribution of Ostracoda in the Cabo Espichel samples (continued on next page).

KEY TO SPECIES	SAMPLE	SPECIES CODE (See key)															
		15	16	17	18	19	20	21	22	23	24	25	26	27			
15 Galliaecytheridea	M-9																
postrotunda	M-8							70	1	2							
16 Galliaecytheridea sp.2	M-7													8			
17 Mandelstamia maculata	M-6							8	1	3							
18 Mandelstamia sexti	M-5																
19 Paracypris sp.	M-4																
20 Paranotacythere pustulata	M-3								3					2			
21 Platycythereis	M-2								1					2			
crisminaensis	M-1																
22 Protocythere hechti	L-6																
23 Protocythere triplicata	L-5																
24 Rehacythereis sp.1	L-4																
25 Schuleridea triebeli	L-3																
26 Schuleridea thoerenensis	L-2																
27 Schuleridea sp.1	L-1																
	K-6													10			
	K-5				8						3		3				
	K-4				2						7			10			
	K-3				27	2								7			
	K-2										9		4				
	K-1												12				
	I-23												12				
	I-22																
	I-21												5				
	I-20												26				
	I-19												31				
	I-18												25				
	I-17	15											4				
	I-16	81											19				
	I-15												20				
	I-14												10				
	I-13	8											37				
	I-12																
	I-11																
	I-10	4											15				
	I-9	21											118				
	I-8												6				
	I-7												12				
	I-6																
	I-5												19				
	I-4A																
	I-4					2	2						10				
	I-3	65											46				
	I-2	4	4									9					
	I-1	4										1					
	J-4	17				2											
	J-3																
	J-2	54										14					
	J-1	19										9					

Table 4.2 (continued): Distribution of Ostracoda in the Cabo Espichel samples.

important components of most samples; the former is generally the most abundant species, whereas the latter three are locally abundant. Other species frequently occurring in moderate abundances are *Galliaecytheridea postrotunda* and *Cytheropteron aquitanum*. *Amphicythere aff. confundens* is abundant in the base of the section, and like *Cytherelloidea weberi*, occurs infrequently in low numbers through the remainder of the section. Rare species include *Exophthalmocythere gigantea*, *Mandelstamia maculata*, *Paracypris* sp., and *Paranotacythere pustulata*. There are no trends apparent with lithology. In most samples, sample size is not sufficiently large to allow definite conclusions to be made, however it appears that increases in abundance of *Schuleridea* are coincident with increases in numbers of *Fabanella*, and reductions in *Cytherella*. Consideration of the common species indicates that the salinity at the time of deposition was probably upper brackish (polyhaline) to marine. Fluctuating salinity is suggested by changes in the proportions of brackish *Schuleridea* and *Fabanella*, and stenohaline *Cytherella*. The assemblage is similar to those from the nodular limestone facies of Unit 1 at Ericeira.

Unit 4: *Asciocythere* sp., *Cytherella suprajurassica*, *Cytherelloidea weberi*, *Cytheropteron aquitanum*, *Fabanella boloniensis* and *Schuleridea triebeli* are found in this unit, indicating an upper brackish to marine salinity.

Unit 5: *Cytherella suprajurassica*, *Asciocythere* sp.1 and A.sp.2 are the dominant taxa in this unit along with locally abundant *Schuleridea triebeli*, *S. thoerenensis*, *Cytherelloidea weberi* and *Mandelstamia sexti*. Many of the species seen in the underlying unit are also found in low abundances including *Amphicythere aff. confundens*, *Cytheropteron aquitanum*, and *Fabanella boloniensis*. *Cytheropteron triebeli* and *Rehacythereis* sp.A are seen in low numbers. Rare species include *Exophthalmocythere gigantea*, *E. sp.A* and *Paracypris* sp. Nine last occurrences and six first occurrences are seen in the upper beds of the unit. Species making their first appearance in the unit are *Asciocythere* sp.2, *C. triebeli*,

Exophthalmocythere sp.A, *M.sexti*, *Rehacythereis* sp.A and *S.thoerenensis*. Little is known about the salinity tolerances of the forms making their first appearance in the unit. Neale (1962) reported *C. triebeli* and *M. sexti* from marine beds at Speeton, England; *Rehacythereis* is typical of the 'Tethyan shelf' (R. Damotte, pers. comm., 1988), and has also been described from the Celtic Sea Basin (Colin *et al.*, 1981), Fastnet and Western Approaches Basins (Ainsworth, 1985a, 1985b; Ainsworth and Horton 1986). The Ostracoda fauna are much reduced in the upper part of the unit. The salinity of this unit was probably near normal marine or slightly brackish.

Units 6 to 12: Strata sampled within these units were barren of Ostracoda.

Unit 13: Ostracoda assemblages recovered from these bioturbated limestones, marlstones and sandstones were sparse, represented by a few specimens of *Schuleridea thoerenensis*, *Protocythere hechti*, *Cytherella pyriformis* and *Asciocythere* sp.2. *Protocythere* is reported from normal marine sediments (Neale, 1978). It is difficult to draw a conclusion from such a small sample size. Absence of non-marine forms suggests normal marine salinity.

Unit 14: Not sampled (clastic interval).

Unit 15: This unit contains sparse Ostracoda assemblages. *Platycythereis crisminaensis* is abundant in an almost monospecific assemblage in one sample near the top of the unit. Little is known of *Platycythereis* as it has only been reported from sections in west Portugal (Damotte and Rey, 1980). *Asciocythere* sp.2 and *Metacytheropteron* sp.59 are slightly more numerous than the other species in one sample. Low numbers of *Cytherella pyriformis*, *Metacytheropteron* sp., *Protocythere hechti*, *P. triebeli* and *Schuleridea thoerenensis* are also seen.

4.3.2: Foraminifera.

4.3.2.a: Distribution of superfamilies.

The Foraminiferal assemblages are more diverse at the Superfamily level than the previous sections. The dominant Superfamily represented in the Cabo Espichel section is the Lituolacea, as it was in the Ericeira section. Nodosariacea are also represented throughout most of the section but are less abundant. In the Praia Azul section, the nodosariids were the dominant group despite being represented by a single genus. The Miliolacea are represented in a few samples, and representatives of Discorbacea, Robertinacea and Cassidulinacea are seen only in one or two samples. Of the Lituolacea, the 'larger' agglutinants are the most abundant, whereas in the Ericeira section the smaller Foraminifera had greater abundance. The percentage distribution of the 'larger' and 'smaller' lituolids and the other super-families is shown in Figure 4.7. Planktonic Foraminifera are not seen.

Figure 4.7 shows distribution patterns that largely accord with lithology. Units 1 to 3, are characterized by mixed assemblages of 'larger' and 'smaller' lituolids and nodosarids. Robertinids and miliolids are seen at the top of Unit 1. In Unit 4, 'smaller' lituolids are absent, but miliolids are well represented. Unit 5 is dominated by 'larger' lituolids with local abundances of miliolids and low numbers of 'smaller' lituolids and nodosarids. At the top of Unit 5 the discorbids predominate.

In the upper part of the section, Units 9 and 11 contain assemblages of 'larger' and 'smaller' lituolids. Unit 13 has abundant 'larger' lituolids and rare 'smaller' lituolids and nodosarids. A mixed assemblage dominated by the 'larger' lituolids, with moderate local abundances of nodosarids, miliolids and smaller lituolids is seen in Unit 15.

4.3.2.b: Species and morphogroup distribution.

The variable distribution of species through the section (Table 4.3) is probably a

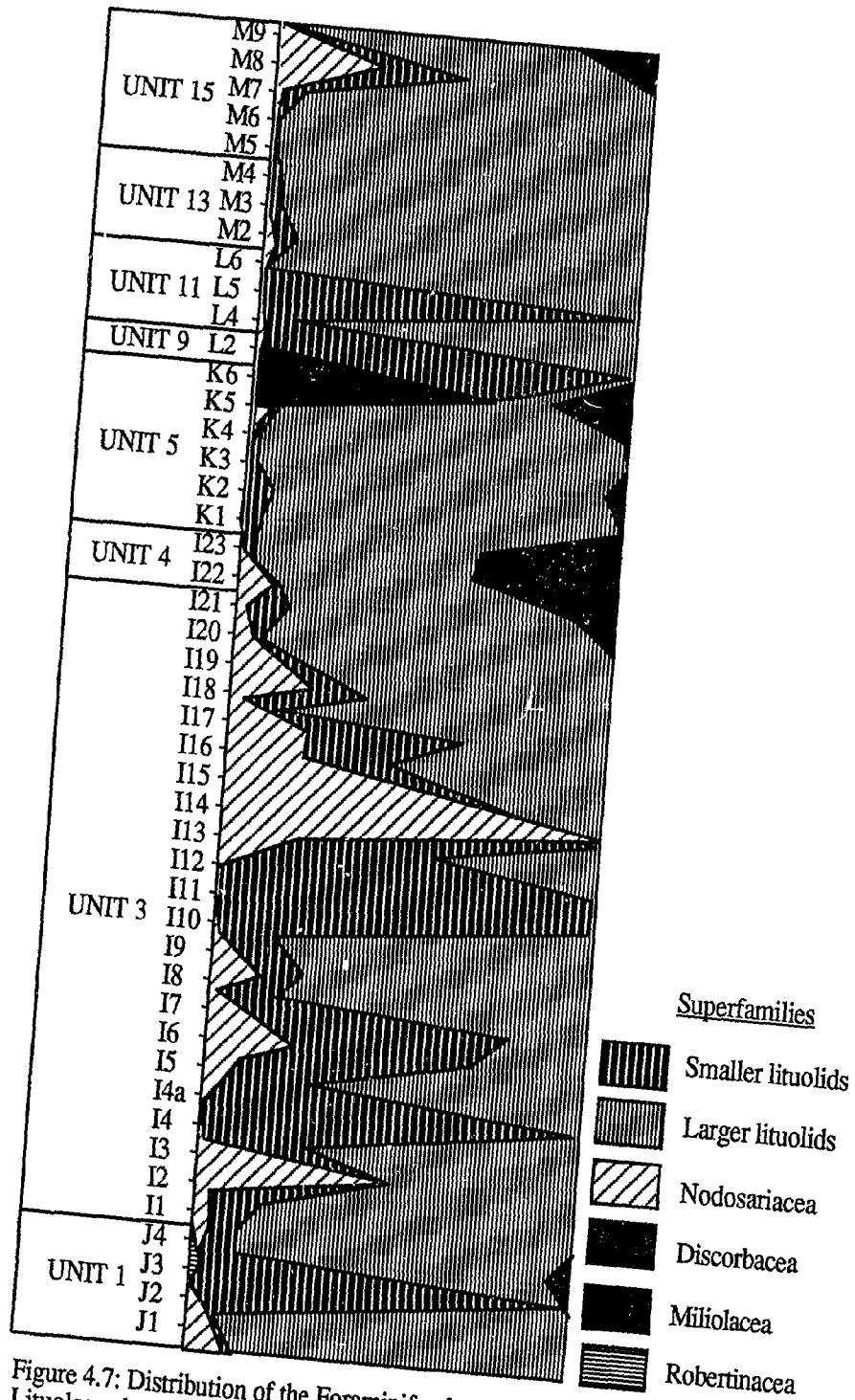


Figure 4.7: Distribution of the Foraminiferal superfamilies at Cabo Espichel. The Lituolacea have been separated into their 'larger' and 'smaller' components.

KEY TO SPECIES	SAMPLE	SPECIES CODE (See key)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Ammobaculites agglutinans	M-9										84					
	M-8										7					
2 Ammobaculites coprolithiformis	M-7		7								238					9
	M-6										231					
	M-5										1					
3 Ammobaculites euides	M-4										170					
4 Ammobaculites godmani	M-3		4								163					
	M-2										237					
	M-1															
5 Ammobaculites sp.A	L-6											7				
	L-5	26				2	10	24								
6 Ammobaculites obliquus	L-4											200				
	L-3															
	L-2		1					1								
7 Ammobaculites subcretaceus	L-1															
	K-6														156	
	K-5	3								54						
8 Ammomarginulina sp.	K-4	2								102						
9 Anchispirocyclina lusitanica	K-3				1					58						
	K-2				6					48						
	K-1		5							55						
10 Choffatella decipiens	I-23									10						
	I-22									26						
11 Choffatella sp.	I-21	17								33						
12 Choffatella tingitana	I-20									56						
	I-19	14								45						
13 Dentalina sp.	I-18	6														
14 Discorbis scituliformis	I-17	29	4	2									22			
	I-16	18		6	9								58			
	I-15													1		
15 Dorothia kummi	I-14															
	I-13	11		7					1				15			
	I-12															
	I-11	2														
	I-10	3											28			
	I-9	2					3						5			
	I-8	7			6								63			
	I-7	12			4								4			
	I-6												8			
	I-5	34											70			
	I-4A															
	I-4	24											75			
	I-3															
	I-2	18	7		6								106			
	I-1												53			
	J-4	2											10			
	J-3															
	J-2															
	J-1															

Table 4.3: Distribution of Foraminifera in the Cabo Espichel samples (continued next page).

KEY TO SPECIES	SAMPLE	SPECIES CODE (See key)														
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
16 Eoguttulina metensis	M-9				1											
17 Eoguttulina	M-8		1		1											
inovroclaviensis	M-7	1			2											
18 Eoguttulina liassica	M-6															
	M-5															
19 Eoguttulina oolithica	M-4											4				
	M-3															
20 Epistomina uhligi	M-2	6						3				2				
21 Everticyclammina	M-1															
virguliana	L-6															
	L-5													6		
22 Feurtilia frequens	L-4			2								1		4		
	L-3															
23 Flabellamina sp.	L-2													3		
24 Freixialina	L-1															
planispiralis	K-6															
	K-5		3		1		22		1	10	1					11
25 Frondicularia sp.	K-4		1	1			6	5								
26 Haplophragmium	K-3							1		14						
inconstans	K-2							6		10						
	K-1									1						
27 Haplophragmoides	I-23	2					5									
nonionoides	I-22	3	2		6			1		11						7
	I-21	3			1		2	5		74						5
28 Haplophragmoides	I-20	1		3			29	6		26						6
concavus	I-19	3	6	4	5		16	10		21						23
	I-18				1		12	19		6						5
29 Kurnubia	I-17	2	23	3	7		2	1		29				22		12
palastiniensis	I-16	22	12	10	2		22			37				3		16
	I-15													8		20
30 Lenticulina	I-14		1													2
muensteri	I-13	4	2	2	1		42	4		13			1	25		28
	I-12												1	1		
	I-11															
	I-10						5	4					4	3		3
	I-9		2	1			106						3	5		19
	I-8						4			78			7			4
	I-7		12	5	7								12	10		8
	I-6		2	2									7	25		2
	I-5		3	2						86			6	5		14
	I-4A												1	5		
	I-4			2			11	2		12			8			1
	I-3		4	10			12									1
	I-2			6	5	1	5	3		75			8	1		3
	I-1		2	3		2	56			14			8			5
	J-4						4			5						
	J-3															
	J-2			8			23			6					3	7
	J-1		2	6		2	19									5

Table 4.3 (continued next page): Distribution of Foraminifera in the Cabo Espichel samples.

KEY TO SPECIES	SAMPLE	SPECIES CODE (See key)														
		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
31 Marginulina sp.	M-9															
32 Mesoendothyra sp.A	M-8												2	1		
	M-7														1	
33 Quinqueloculina spp.	M-6															
	M-5															
34 Pseudocyclammina muluchensis	M-4															
	M-3															
	M-2						4							1		
	M-1															
35 Pseudoicyclammina lituus	L-6															
	L-5															
	L-4															
36 Pseudoglandulina sp.	L-3															
	L-2															
37 Rectocyclammina arrabidensis	L-1															
	K-6			52	18											
	K-5															
38 Rectocyclammina chouberti	K-4															
	K-3			8	8											
	K-2								10							
39 Reophax horridus	K-1			47	19				4							
40 Reophax aff. scoriurus	I-23			42	52	2										
	I-22			15	66											
	I-21				45				1							
	I-20				3				11							
41 Reophax sp.	I-19				14		2									
	I-18				81	22			3							
42 Spiroplectammina dorni	I-17				4					1						4
	I-16							10							1	4
	I-15				9											
43 Spiroplectinata sp.	I-14															
44 Trochammina sp.	I-13	3						1								
	I-12															
	I-11															
45 Verneuilinoides minuta	I-10				49	2		2								1
	I-9									2						
	I-8		9		32											3
	I-7		5		4			14						10	2	17
	I-6		1		6	2										1
	I-5		3		105	1		4			1					20
	I-4A															
	I-4		5			1		51		1	1	7				6
	I-3		1		1											
	I-2		30		64	1		4								14
	I-1		3		37							2				
	J-4		6	3	1										1	
	J-3															
	J-2		27					101								
	J-1		39					130								

Table 4.3 (continued): Distribution of Foraminifera in the Cabo Espichel samples.

function of lithology and more subtle ecological controls. As discussed previously, salinity, habitat and availability of test construction materials (in the case of the agglutinated Foraminifera) may have been three important ecological factors affecting the distribution of the Late Jurassic and Early Cretaceous Foraminifera.

Massive, non-bioturbated limestones and marlstone yielded the highest number of Foraminiferal species (twelve), followed by the nodular limestones (ten species). Fine siliciclastic facies (siltstones and fine sandstones) had the lowest number of species (three). The coarse siliciclastic facies were not sampled as it was unlikely that these would contain microfossils. The degree of induration of the sediment and the method of sample preparation likely affected the recovery of specimens. About a third of the samples contained fewer than 100 specimens. Since the number of species is related to the size of the sample, interpretations of small samples are of a somewhat tentative nature.

Foraminiferal test morphologies classify into the same groupings as in the previous sections. The calcareous form *Lenticulina*, although planispiral and lenticular, has a relatively well calcified test, and is thick in profile compared with the flattened planispiral and trochospiral forms in epifaunal morphogroup ii. Brasier (1979) regarded thicker-shelled, biconvex test morphology as typical of sediment dwellers from coarser substrates, although Blanc-Vernet (1969) reported *Lenticulina* from deeper water (>300m) argillaceous sediments. *Lenticulina muensteri* also displays various degrees of uncoiled growth, so it is tentatively placed in morphogroup iii. *Quinqueloculina* is placed in morphogroup iv on the basis of its coiling mode (following Jones and Charnock, 1985), although Murray (1973) reported that *Quinqueloculina* may also live on plants. *Discorbis* is placed in morphogroup ii on the basis of its planar to slightly concave ventral surface. Murray (1973) also indicated this taxon inhabits vegetation. The distribution of the morphogroups is shown in Figure 4.8. Distribution of species and morphogroups is discussed below for each unit.

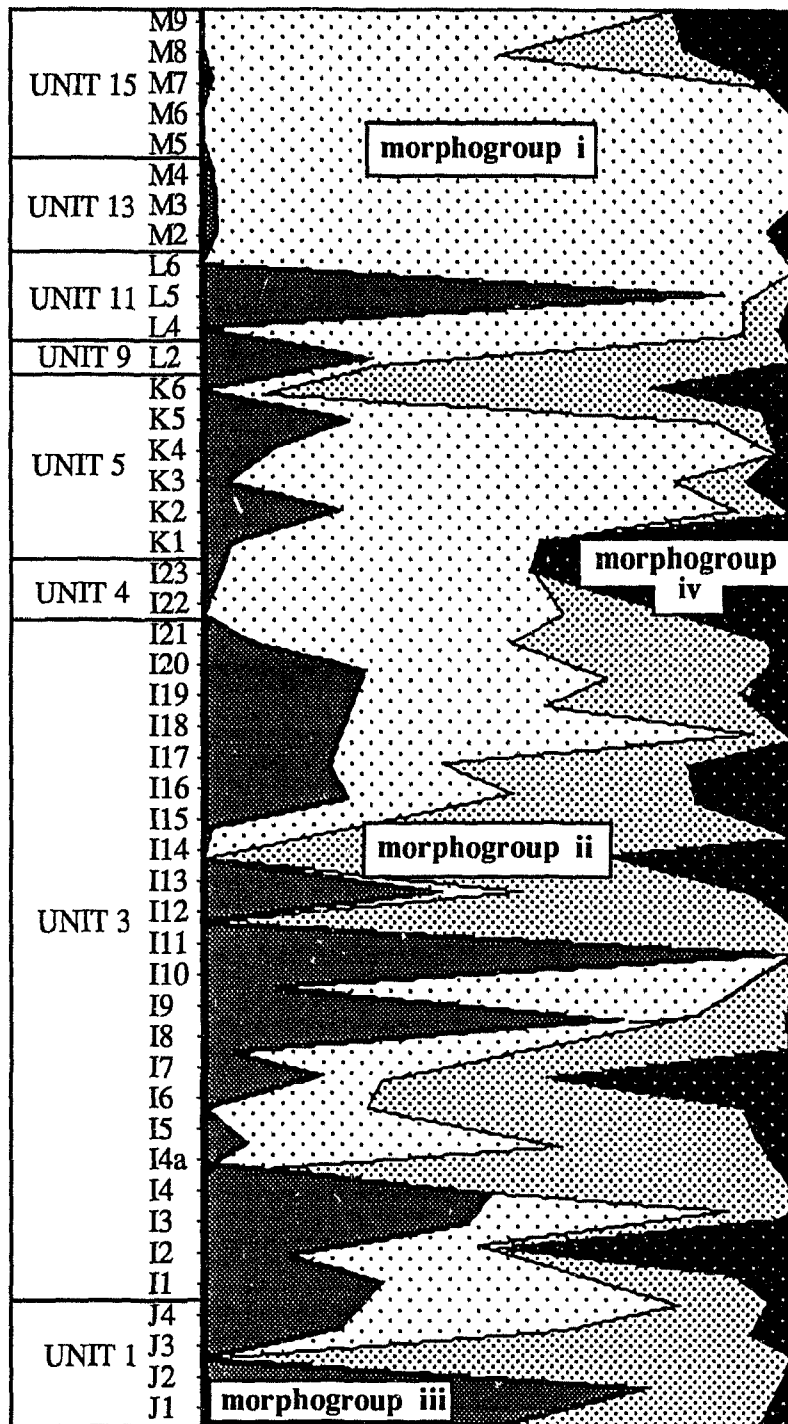


Figure 4.8: Distribution of Foraminiferal morphogroups in the Cabo Espichel section.

Unit 1: Siltstone in the lower part of this unit contains abundant *Rectocyclammina arrabidensis*, *Mesoendothyra* sp.A, and *Everticyclammina virguliana*. *Eoguttulina liassica*, *Lenticulina muensteri*, and *Freixialina planispiralis* occur in low numbers together with rare *E. metensis*, *Epistomina uhligi* and *Kurnubia palastinensis*. The siltstone at the top of the unit contains low numbers of *Choffatella tingitana*, *Mesoendothyra* sp.A, *F. planispiralis*, *E. virguliana*, *Ammobaculites agglutinans*, *Quinqueloculina* sp, rare *Pseudocyclammina muluchensis* and *Trocholina* sp. All morphogroups are seen in the unit although morphogroup iii is more abundant in the lower part, and morphogroup i in the upper part of the unit.

Unit 2: Not sampled (inaccessible)

Unit 3: The number of specimens and species recovered per sample varied considerably through this unit, depending partly on lithology as mentioned above. Common and locally abundant species in many of the samples include the 'larger' litiolids *Choffatella tingitana*, *Everticyclammina virguliana* and *Pseudocyclammina muluchensis* and the 'smaller' agglutinated Foraminifera *Freixialina planispiralis*. The 'larger' Foraminifera *Anchispirocyclina lusitanica* is found in abundance in samples in the upper part of the unit. *Rectocyclammina arrabidensis* and species of *Ammobaculites* and *Haplophragmoides* are common in many samples as are the calcareous forms *Lenticulina muensteri* and species of *Eoguttulina*. *Verneuilinoides minuta* and *Feurtillia frequens* have low to moderate numbers of specimens in the lower and upper parts of the unit respectively. Rare smaller agglutinated species are seen belonging to the genera *Reophax*, *Spiroplectinata*, *Trochammina* and *Trocholina*, in addition to rare nodosarids. Relationships between species are not particularly apparent, however, considering the more common species, *Pseudocyclammina muluchensis* is sometimes found in high numbers with *Choffatella tingitana* and *Freixialina planispiralis*. Regarding the less common taxa, species of

Eoguttulina appear to occur with species of *Ammobaculites*. All the Foraminiferal morphogroups are represented. In the lower siliciclastic-rich part of the unit, the morphogroup distribution appears to be cyclical, whereas in the upper carbonate-rich part of the unit there is a progressive increase in morphogroup i (epifaunal).

Unit 4: *Anchispirocyclus lusitanica* and *Pseudocyclammina muluchensis* dominate the two samples taken from this unit along with *Quinqueloculina* sp. *Freixialina planispiralis* is found in low numbers and is the only 'smaller' agglutinant seen. Rare species include *Feurtilia frequens*, *Everticyclammina virguliana*, *Pseudocyclammina lituus*, and *Lenticulina muensteri*. All morphogroups are seen although groups i and iv dominate.

Unit 5: *Anchispirocyclus lusitanica* is abundant through most the unit. The other larger lituolids, *Pseudocyclammina muluchensis*, *Everticyclammina virguliana* and *Rectocyclammina chouberti* are locally abundant together with *Freixialina planispiralis*, and *Quinqueloculina* sp. Nodosariids and 'smaller' lituolids are poorly represented. The highest sample in the unit contained abundant *Discorbis scituliformis*, moderate numbers of *Quinqueloculina* sp., and a few *Pseudocyclammina muluchensis*. Morphogroup i dominates the unit except for the top sample (mainly morphogroup ii). Local abundances of morphogroups iii and iv are also seen.

Unit 6: Sample L-1, taken from a thin claystone bed between conglomeratic beds, was barren.

Unit 9: This unit yielded sparse Foraminifera that included rare *Ammobaculites coprolithiformis*, *A. subcretaceous* and *Haplophragmoides concavus*. The three species correspond to morphogroups ii and iii.

Unit 10: Reconnaissance sampling of this unit in 1986 did not reveal any microfossils.

Unit 11: Bioturbated limestone in the lower part of the unit contains abundant *Choffatella*, plus rare *Haplophragmium inconstans*, *Haplophragmoides concavus*, *Lenticulina muensteri*, *Eoguttulina oolithica* and *Marginulina* sp. The siltstone contains an assemblage of smaller litiolids with moderate to low numbers of *Ammobaculites agglutinans*, *A. subcretaceus*, *A. obliquus*, *A. sp.A* and *Haplophragmoides concavus*. A few specimens of *Choffatella* are seen in the sample at the top of the unit. Tests of *Choffatella* in this unit are poorly preserved and could not be identified to a species in thin section, so are placed in open nomenclature. Rey (1972) suggested that they may be *Choffatella decipiens*. Morphogroups in this unit are dominated by groups i and iii.

Unit 13: The sandy bioclastic limestones contain abundant *Choffatella decipiens* (well preserved) and rare *Ammobaculites coprolithiformis*, *Feurtillia frequens*, *Haplophragmium inconstans*, *Textularia* spp., *Eoguttulina metensis* and *Pseudoglandulina* sp. The sandy siltstone in the middle of the unit is barren. Morphogroup i dominates the assemblage; morphogroups ii and iv are rare.

Unit 14: Reconnaissance sampling of this unit in 1986 did not reveal any microfossils.

Unit 15: *Choffatella decipiens* dominates this unit. A few specimens of *Ammobaculites coprolithiformis* and *Dorothia kummi* are also found, with rare *Spiroplectammia dorni*, *Eoguttulina oolithica*, *E. metensis*, *E. inovroclaviensis*, and *Trocholina* sp. in the upper beds.

4.4: Paleoecology and paleoenvironments of the Cabo Espichel section

A number of distinctive microfossil assemblages are seen in the Cabo Espichel section, some of these apparently reflecting the general facies changes between units. Paleoecological and paleoenvironmental interpretations and any further implications will be dealt with for each assemblage, and the results will be discussed in relation to previous interpretations for the section.

4.4.1: *Rectocyclammina-Mesoendothyra* assemblage.

Rectocyclammina arrabidensis and *Mesoendothyra* sp.A are well represented in Unit 1. The Ostracoda suggested salinity was near normal or slightly brackish. The larger Foraminifera indicate relatively shallow water (photic zone). Coral limestone immediately overlying the unit indicates salinity was normal marine some of the time. In the analysis of Praia Azul it was suggested that *Choffatella tingitana* may have been an opportunistic species in lowered salinity. Although presence of *C. tingitana* in the upper part of Unit 1 at Cabo Espichel might suggest onset of brackishness, the small sample size does not allow us to conclude that the form has adopted an 'opportunistic' strategy; hence, salinity could have been euhaline. Both *Choffatella* and *Mesoendothyra* have also been reported from coral reef facies by Septfontaine (1985). Foraminifera and Ostracoda in this assemblage may have been euryhaline to varying degrees, but that in itself is not evidence for lowered salinity. The assemblage in Unit 1 is similar in composition to that of the marine (euhaline) to slightly brackish (polyhaline) environment recognised at Praia Azul.

4.4.2: *Choffatella* assemblage of the siliciclastic-carbonate cycles.

Restriction of *Choffatella tingitana*, species of *Haplophragmoides*, *Trochammina*, *Verneuilinoides minuta* and most *Ammobaculites* (all of which are agglutinated) to the carbonate-siliciclastic alternations in the lower part of Unit 2 (corresponding to Ramalho's

(1971) beds 19-32, Figure 4.2) is clear, and may be related to the availability and quality of sediment for test construction. Relationships between species and lithology, however, are not evident. The Ostracoda suggest salinity fluctuated between marine and slightly brackish, but again, this is not clearly related to facies, and apparent trends in any one part of the succession may be reversed in others. Calcareous Foraminifera and the other larger Foraminifera are not restricted to this assemblage.

Cyclicality in the distribution of the Foraminiferal superfamilies (Figure 4.7) seems to accord with the sedimentological cycles; peak 'larger' lituolid abundance occurs in samples adjacent to the coarser siliciclastic intervals, and peak nodosarid abundance correspond with lower numbers of 'larger' lituolids. A similar pattern is seen in the distribution of the Foraminiferal morphogroups. Inferences from these patterns are tentative since sample size is small in many cases, however, these observations support the possibility that the availability of sediment was an important control. Rarity of morphogroup i in the marlstone at the base of bed 28 (sample I-9) and the base of the nodular limestone of bed 30 (sample I-13), however, may indicate a sub-environment with restricted flora, rather than absence of suitable material for test construction.

Higher abundances of nodosarids are not easily explained; Stam (1985) reported that *Lenticulina muensteri* was associated with water depths of 50-150m, but its presence with 'larger' lituolids in this assemblage indicates that it also occurred within the photic zone.

4.4.3: *Anchispirocyclina-Quinqueloculina* assemblage.

The 'larger' lituolid *Anchispirocyclina lusitanica* is restricted to the carbonate-dominated succession that commences in the upper part of Unit 3 and continues through to the top of Unit 5 (Ramalho's (1971) beds 33-43, Figure 4.2). *A. lusitanica* is abundant, sometimes almost monotypic in this assemblage. The Ostracoda associations suggest salinity fluctuated between marine and slightly brackish, however abundant

Quinqueloculina indicate salinity was probably higher than normal marine; Recent distributions of *Quinqueloculina* now it is typical of normal marine (inner shelf) and hyperhaline lagoonal environments (>32‰), where it is also associated with sandy sediments (Murray, 1973). Hence, depositional salinity of units containing the *Anchispirocyclina-Quinqueloculina* assemblage may have been only marginally brackish, but were more likely normal marine or hyperhaline. The latter interpretation differs from Fursich and Schmidt-Kittler (1982) who suggested deposition was under increasing brackishness through this interval. Ramalho (1971) reported a reduction in the mean size of miliolids, coincident with an increase in dasycladacean algae in the nodular limestones, and also suggested that it was due to reduction in salinity. Brazier (1975a), however, has demonstrated that miliolid Foraminifera are morphologically 'plastic' in hyperhaline environments, and that this phenomenon seems to be related to life habitat. Algal laminites and polygonal mudcracks in Unit 4 and bipedal dinosaur footprints at the top of the unit indicate local development of tidal flats.

The algae reported from the nodular limestone facies at Cabo Espichel belong to the dasycladacean and cyanophycean orders of the chlorophyta ("green" algae). Ramalho (1971) reported species of *Salpingoporella* and *Clypeina* from Cabo Espichel. Species of the calcareous algae are important stratigraphic markers for the Upper Jurassic and Lower Cretaceous strata of Portugal (Ramalho, 1971; Rey, 1972), but detailed thin section work would be necessary in order to use them. In a study of similar (nodular limestone) facies north of Lisbon, Ellis (1984) also reported the dasycladecans *Salpingoporella*, *Tripoporella* and *Campbelliella* in association with *Anchispirocyclina lusitanica* and miliolid Foraminifera. Based on Recent distributions of dasycladacean algae, Ellis (1984) determined that the depositional water depth for the nodular limestones was probably less than 5 metres.

The abundance of *Anchispirocyclina lusitanica* in Unit 5 (some samples are virtually monospecific) suggests that it was an opportunist. A similar interpretation for this

species was made in the analysis of Foraminifera in the Ericeira section. Opportunistic strategies amongst benthic organisms are typical found in restricted environments (Levinton, 1970), which supports the lagoonal environment interpreted for the *Anchispirocyclina-Quinqueloculina* assemblage.

4.4.3.a: Significance of microspheric *Anchispirocyclina lusitanica*:

A characteristic of *Anchispirocyclina lusitanica* in the upper part of Unit 5 (Ramalho's (1971) beds 41-43) is that in the marl beds it is represented almost entirely by the microspheric (asexual) form. The test of this form is large, frequently attaining 15mm or more in diameter. Elsewhere the microspheric form is less abundant and only 10-15mm in diameter, as is the case with specimens in the Ericeira section. The significance of the asexual reproductive strategy of *A. lusitanica* in the Cabo Espichel section is not fully understood, although such a strategy may prove successful in environments where normal sexual reproduction is not possible (F.T. Banner, pers. comm., 1986). Little is known about reproductive cycles of modern 'larger' Foraminifera, although Murray (1973) thought it probable that microspheric and megalospheric generations had different ecological requirements.

One possibility is that *Anchispirocyclina lusitanica* was a species that normally lived and reproduced sexually under hyposaline conditions, but could only regenerate asexually under normal marine salinities; the species reproduced asexually until such times that sexual reproduction could again take place. Murray (1973) indicated that the majority of living hyposaline species were confined to hyposaline environment, and rarely occurred under normal marine conditions.

An alternative possibility for the concentration of microspheric *Anchispirocyclina* is that the smaller (megalospheric) forms were winnowed away. Such a phenomena is seen in the nummulitic limestone (Eocene) at Fomm el Garia, central Tunisia (personal observation 1985; Moody, 1989) in which large (15mm) *Nummulites laevigatus* display

alignment of the tests, forming ripples. The possibility of winnowing is excluded in the Cabo Espichel section since Ostracoda are present in samples containing microspheric *Anchispirocyclina*; winnowing of the smaller megalospheric forms would also have removed the Ostracoda.

4.4.4: Significance of the high turnover of Ostracoda species in Unit 5.

Nine last and six first occurrences of Ostracoda are recorded in the upper part of Unit 5 (Ramalho's (1971) bed 42). This rapid turnover of species was unexpected in view of the restricted environment invoked by the Foraminifera. The 'opportunistic' strategy apparently displayed by *Anchispirocyclina lusitanica* is unseen in the species of Ostracoda, all of which are considered 'normal' marine forms. The 'turnover' of Ostracoda in this part of the section may be partly attributed to faunal extinction, however, Kilenyi (1978) reported that the disappearance of many species in the Late Jurassic was probably ecologically induced.

Van Harten and van Hinte (1984) and van Harten (1988) suggested a relationship between the longevity of Ostracoda species and change of relative sea level, based on the idea that Ostracoda would survive only as long as the environment continued to provide the original ecologic niche to which the species was adapted (unless the Ostracoda were able to change their niche requirements). The rate of environmental change may be critical, since the slower the rate of change, the more chance the species would have to adapt to new conditions. Conversely, van Harten and van Hinte (1984) and van Harten (1988) argued that rapid changes were reflected by short-lived species, and suggested that ecological changes in marine environments would be most rapid during transgressive and regressive peaks on continental margins, just after the passing of the shoreline during transgression and prior to departure of the sea during regression. On the basis of the foregoing, the rapid species turnover in Unit 5 may have been due to environmental changes brought about by marine regression.

4.4.5: *Discorbis* assemblage at the top of Unit 5.

Association of abundant *Discorbis scituliformis* with *Quinqueloculina* sp. and *Pseudocyclamina muluchensis* in Bed 43 in the upper part of Unit 5 indicates deposition in a lagoonal environment. Recent *Discorbis* is found in shallow (0-50m) water of normal marine salinity and is associated with vegetation (Murray, 1973). Le Campion (1970) reported an assemblage dominated by *Discorbis* associated with miliolids and the calcareous algae *Jania* in subtidal environments in the Bassin d'Arachon lagoon of west France. The Bassin d'Arachon is regarded as normal marine to slightly hyposaline, with salinity ranging from 29‰ to 35‰. The dominance of *Discorbis* in this assemblage suggests it may have been an opportunistic species. Ostracoda in the assemblage indicate slightly brackish to normal marine salinity. The assemblage probably inhabited a lagoon of normal marine salinity.

4.4.6: *Ammobaculites* assemblage.

The *Ammobaculites* assemblage seen in Units 11 is tentatively interpreted as indicative of estuarine facies, based on the earlier discussion of similar assemblages in the Ericeira section. Although a detailed sedimentological study of Unit 11 was not undertaken, the presence of abundant woody fragments within the siltstones indicates a nearshore environment of deposition. Rey (1972) interpreted the paleoenvironment of the unit simply as "restricted marine".

4.4.7: *Choffatella* assemblage.

Choffatella is the dominant Foraminifera in this assemblage, found in Units 11, 13 and 15. Sparse Ostracoda make determination of depositional salinity difficult, although the genera *Cytherella*, *Asciocythere*, *Schuleridea*, *Metacytheropteron* and *Protocythere* are generally regarded as marine (van Morkhoven, 1962). *Quinqueloculina* found at the top of Unit 15 suggests salinity was at, or slightly above, normal marine values. The high

abundance of *Choffatella decipiens*, and sparsity of other species in this assemblage suggests *C. decipiens* was an opportunist. Rey (1972) reported abundant Dasycladacean algae from the unit, including *Cylindroporella*, *Acicularia*, and *Actinoporella*. Present day distribution of the majority of Dasycladacean algae is in water depths less than 5 metres (Wray, 1977). The carbonate facies with which *C. decipiens* is associated is heavily bioturbated and frequently has a nodular texture. Inclined burrows are locally abundant, and these may be assigned to the *Skolithos* ichnogenus widely recognised in algal-rich limestones in Portugal. *Skolithos* trace fossils are interpreted to be of intertidal to very shallow subtidal origin (Fursich, 1981). A shallow water, restricted marine environment is likely.

The *Choffatella* assemblage in the Cabo Espichel section is similar to that seen in the Ericeira section. Both differ from the *Choffatella* assemblage of the siliciclastic-carbonate cycles in Unit 3 of Cabo Espichel in that they are dominated by *C. decipiens*, which seems to have been an opportunistic species. Although found in high numbers in the assemblage in Unit 3 and also at Praia Azul, *C. tingitana* does not numerically dominate the assemblages (Levinton 1970) regarded the numerical dominance of a species, making up 85-100% of a fossil assemblage, as a criteria for the recognition of opportunistic species in the fossil record). It is probable that *C. decipiens* and *C. tingitana* inhabited similar ecological niches, however, lack of evidence for lower brackish (mesohaline) environments in the upper parts of the Cabo Espichel and Ericeira sections limits determination of the salinity tolerance of *C. decipiens*.

4.4.8: *Platycythereis crisminaensis* assemblage in Unit 15.

A monotypic assemblage of *Platycythereis crisminaensis* occurs in sample M8, taken from a claystone rich in woody material. Although little is known of the paleoecology of this species, its high abundance suggests that it was an opportunist that proliferated in absence of competition in restricted environments. The high amount of woody material in

the claystone suggests a restricted nearshore, perhaps lagoonal paleoenvironment. Virtual absence of other Ostracoda species prohibit an estimate of the depositional salinity to be made.

4.4.9: Summary of paleoenvironments.

Lithofacies and biofacies trends and their paleoenvironmental interpretations for the Cabo Espichel section are shown in Figure 4.9. A number of shallow marine paleoenvironments are recognized on the basis of the Ostracodal and Foraminiferal assemblages.

Units 1-5 contain generally more diverse Foraminiferal and Ostracoda assemblages that are of a marine or only slightly brackish nature. A more open marine environment is suggested by the corals seen in the limestone at the base of Unit 2, and at several intervals through the unit. The lower part of Unit 3 is characterized by carbonate and siliciclastic facies alternations and contains predominantly agglutinated foraminiferal assemblages. The larger Foraminifera *Pseudocyclamina muluchensis* and *Choffatella tingitana* are well represented in the lower part of Unit 3, and the latter is stratigraphically confined to these beds. Ostracoda indicate salinity was generally slightly brackish, but may have fluctuated to normal marine values; this was likely due to the influence of rivers as indicated by the clastic intercalations.

The upper part of Unit 3, and strata in Units 4 and 5 are characterized by an absence of coarse siliciclastics, and dominance of carbonate. Foraminifera in this interval are characterized by an abundance of *Anchispirocyclina lusitanica*. The majority of the smaller agglutinated species are absent from these carbonate strata, and this is probably due to two equally important factors: 1) the lack of suitable substrates and sediment grains for test construction; 2) salinity. Depositional salinity of these strata was probably normal marine or hyperhaline; the underlying strata were more brackish. A restricted lagoonal environment is likely and is supported by the proliferation of *A. lusitanica* and *Discorbis scituliformis* in

unit #	Lithology	Ostracod assemblage/ salinity associations	Foraminiferal assemblage	Interpretation	
				paleoenvironment	relative sea level
15		?opportunistic <i>Platycythereis</i> no data	monospecific <i>Choffatella decipiens</i> no data	shallow inter/sub- tidal lagoon fluvialite	-
14	← dinosaurs ← paleokarst				
13		insufficient data	monospecific <i>Choffatella decipiens</i>	shallow inter/sub- tidal lagoon	
12		ostracods rare	no data	?lagoonal	
11		or absent;	<i>Ammoniaculites</i>	estuarine	
10	← corals	some units	<i>Choffatella</i>	lagoonal	
9		not suitable	no data	coral reef	
8	← corals	for sampling, or are inaccessible	rare agglutinates no data	?inner neritic coral reef	
7			no data	fluvialite (Rey, 1972)	
6					
5	← paleokarst	?euhaline; high 'turnover of species'	?opportunistic <i>Discobis</i> and microspheric <i>Anchispirocyclina</i>	'normal' marine to ?hypersaline lagoon	
4	← dinosaur tracks ← algal laminites ← mudcracks ← algal laminites ← mudcracks ← algal laminites	fluctuating euhaline and polyhaline; <i>Cytherella</i> , <i>Schuleridea</i> , <i>Fabanella</i>	'larger' foraminifera predominate, especially <i>Anchispirocyclina</i> & <i>Pseudocyclammina</i> , plus miliolids (<i>Quinqueloculina</i>)	shallow marine to intertidal; normal to restricted (slightly hypersaline) marine environ- ments, perhaps lagoonal.	
3	carbonate- siliciclastic cycles	fluctuating euhaline and polyhaline; <i>Cytherella</i> , <i>Schuleridea</i> , <i>Fabanella</i>	<i>Choffatella</i> <i>tingitana</i> and 'smaller' agglutinates; morphogroups occur in cycles	shallow inner neritic; coarse clastics represent submarine channels (Fursich & Schmidt- Kittler, 1982)	
2	50m ← corals ← dinosaur tracks ← corals	no data	no data	fluctuating ?mid-inner neritic shelf, at times intertidal	
1		poly-euhaline <i>Cytherella</i>	<i>Rectocyclammina</i> - <i>Mesoendothyra</i>	?mid-inner neritic shelf	

Figure 4.9: Cabo Espichel section: summary of litho- and biofacies and their interpretation.

the upper beds of Unit 3, a strategy associated with 'explosive opportunists' in marginal environments (Levinton, 1970). The Ostracoda in the upper beds of Unit 5 show considerable species turn-over of species, and on the basis of Ostracoda 'chronoecology' (van Harten 1988), this phenomenon may be related to marine regression in the upper beds of Unit 5. This possibility is supported by the development of a 'paleokarstic' surface at the top of the unit, and subsequent terrigenous facies in Units 6 and 7.

The *in-situ* corals and the rich macroinvertebrate fossil assemblage seen in Unit 8 indicates marine shelf deposition. The solitary hermatypic corals indicate deposition within the photic zone (a requirement of the symbiotic algae associated with hermatypic corals), probably within a depth of about 20-50 metres, and of normal marine salinity. The presence of echinoderms and brachiopods, generally regarded as stenohaline, supports this interpretation. Oysters, when found in abundance, may indicate hyposalinity, however this is not thought to be the situation in Unit 8 where the oysters are found as scattered individuals. The colonial corals at the base of the limestone are evidence of a biostrome; the overlying poorly bedded limestone is probably also part of the reef facies.

The 'Marnes a Toxaster' (Unit 9), according to Rey (1972) were deposited under open marine conditions. Assuming that the base of Rey's (1972) 'Marnes á Toxaster' is placed within the upper 0.5m of Unit 8, an open marine environment is likely for that portion of the section in view of the diverse 'reefal' invertebrate association recognised in the latter unit. The siltstones and interbedded fine micaceous sandstones that comprise the bulk of the remainder of the 'Marnes a Toxaster', however, may not have been deposited in an open marine setting. The invertebrate macrofossils are predominantly 'oysters' and gastropods (Rey, 1972), and typical stenohaline fossils (corals, brachiopods and echinoderms) are lacking. Microfossils are very sparse and consist of rare *Ammobaculites* and *Haplophragmoides*. A restricted (brackish) nearshore environment seems more likely for the unit.

The 'Calcaires a Polypiérs de Lagosteiros' (Unit 10) were deposited in an open

marine, but shallow water environment as indicated by the abundant hermatypic solitary and meandroid 'brain' corals, echinoderms and brachiopods. Rey (1972) interpreted the depositional environment of these limestones as 'peri-refal'. Unit 11 ('Calcairés et silts de Ladeiras') is regarded by Rey (1972) simply as having been deposited in a 'restricted sea'. The virtually monotypic *Choffatella* assemblage in the carbonates at the base of the sequence supports Rey's (1972) interpretation, although the coarse bioclasts (shell debris) and heavy bioturbation suggest a relatively high energy environment. The siltstone in the unit contains an *Ammobaculites* assemblage that may indicate an estuarine paleoenvironment. The 'Grés de Rochadouro' (Unit 12) is interpreted by Rey (1972) as a 'marine marsh' deposit. Fossils were not observed in the field, although Rey (1972) reported bivalves (trigonids and oysters), gastropods and the 'larger' Foraminifera *Choffatella decipiens* from most of the sequence. Although the fossil assemblages reported by Rey (1972) are of low diversity, it is unlikely that they represent a marsh paleoenvironment; oysters are found in brackish marine environments in the present day and in the ancient record, and *Trigonia* is an important component (frequently a rock-builder) in marine limestones of the Upper Jurassic. *Choffatella decipiens* has never been reported from marsh facies, and the 'smaller' agglutinated Foraminifera typical of modern marshes are not recorded from the unit.

The *Choffatella* assemblage seen in Units 13 and 15, associated with abundant dasycladacean algae indicates a shallow marine restricted, perhaps lagoonal, environment. The dominance of *Choffatella* in many samples suggests it was an opportunistic species. A similar strategy may account for the abundance of the Ostracoda *Platycythereis crisminaensis* in Unit 15. Opportunistic species are typical of very restricted, high stress environments. The ichnofacies and Dasycladacean algae in these units indicate intertidal to shallow subtidal deposition. Rey (1972) regarded Unit 13 ('Calcaires et marnes á choffatelles') as having been deposited at a water depth comparable to the 'Grés do Rochadouro'. From Rey's (1972) interpretation of the latter unit, Unit 13 would have been

deposited above mean sea level! Rey's (1972) interpretation of Unit 15 is supported by findings in this study.

The 'Grés a dinosauriens' (Unit 14) are reported as having macrofossils that include the dinosaurs *Megalosaurus superbus*, *Iguanodon mantelli* and *Astrodon valdensis*, bivalves (*Exogyra*) and gastropods. Samples examined for microfossils were barren, although Rey (1972) reported *Choffatella decipiens* the Ostracoda *Fabanella*, *Macrodentina*, *Asciocythere*, *Schuleridea* and *Cythereis* from the unit. The sequence was interpreted as a hypersaline lagoon deposit (Rey, 1972), which seems reasonable.

The succession of paleoenvironments through the section suggests a number of changes in relative sea level. It is not possible to determine absolute paleo-water depths for the deposition of the units at Cabo Espichel. The observed succession may have largely resulted from lateral facies changes and need not have involved changes in relative sea level, transgressions or regressions; the siliciclastic intercalations in Unit 3 serve as an example. Certain "more dramatic" features, however, suggest changes in relative sea level have taken place, one example being the (interpreted) paleokarstic surface at the top of Unit 5. Tentative changes in relative sealevel are shown by the curve in Figure 4.9.

CHAPTER 5

REGIONAL BIOZONATION AND CORRELATION

5.1: Introduction.

The previous analysis has shown that a number of species were strongly facies controlled. This presents a problem for biostratigraphic analysis, as observed ranges may be incomplete due to ecological exclusion.

The 'perfect' biostratigraphic marker, short ranging and cosmopolitan in distribution, is rare, if it exists at all. The majority of species in the Portuguese sections may have longer ranges than their local ranges suggest. Despite this problem local biozonation can be achieved on the basis of the paleoecologic knowledge gained through assemblage analysis. The schemes set out below are rather subjective, but I have attempted to keep open the option of being able to extend the scheme outside of the Lusitanian Basin and to the classic type localities of the Kimmeridge and Speeton Clays of England. Reference to the Portlandian stage is in the British sense, where the Lower Portlandian equates with the Upper Tithonian, and the Upper Portlandian (and the "Purbeck" facies) equates with the Berriasian in the French sense.

5.2: Foraminiferal biozonation of the Kimmeridgian-Barremian of the Lusitanian Basin.

The Foraminiferal zonation proposed for the three sections (Figure 5.1) is based on concurrent ranges of 19 Foraminiferal taxa and permits correlation of the sections. Seven zones of Kimmeridgian through Barremian age are recognised. Five of the zones may also be recognised by the highest occurrence of selected taxa, and these zones may potentially

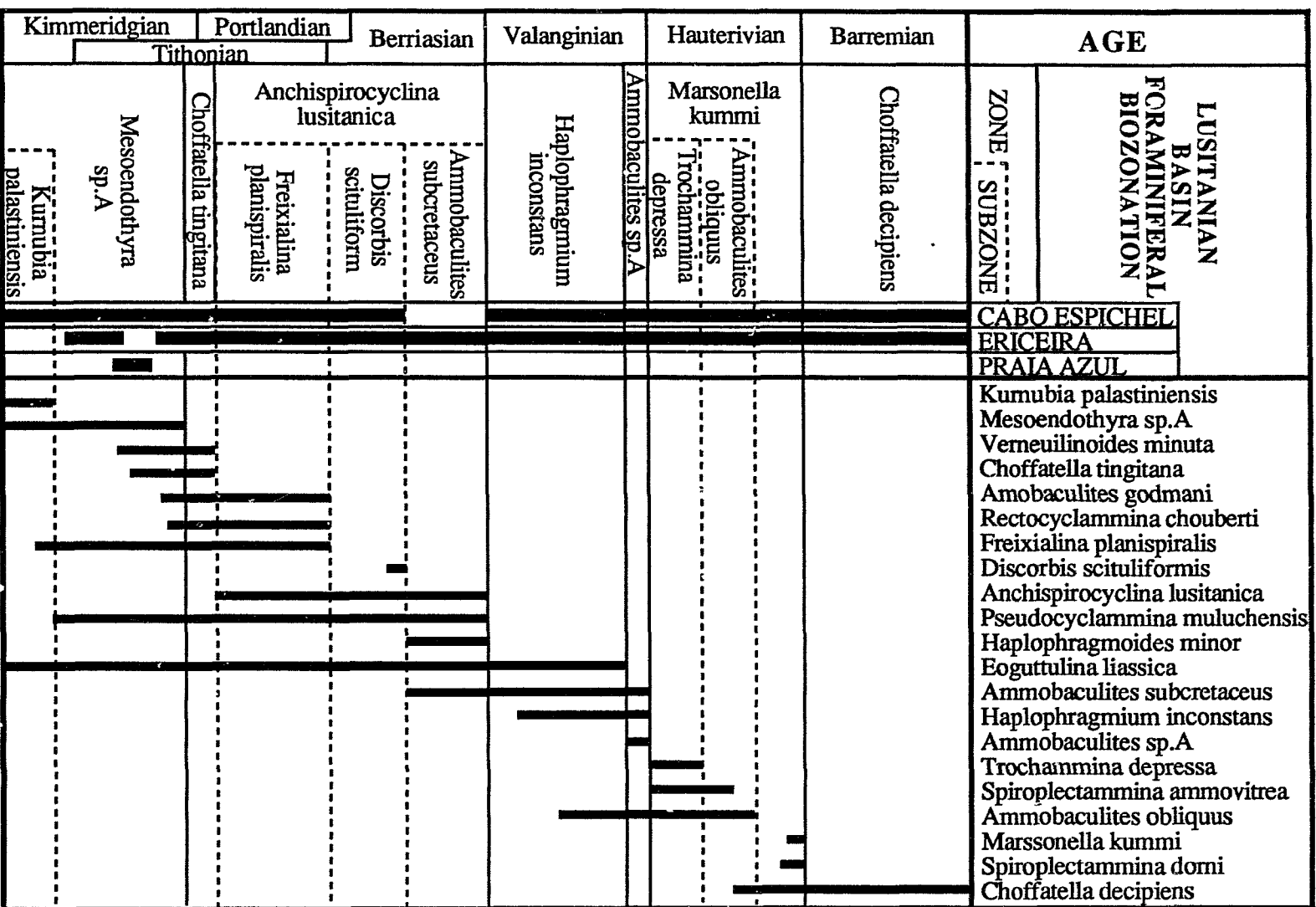


Figure 5.1: Foraminiferal biozonation for the Lusitanian Basin.

be used for sub-surface correlations in well sections. Six subzones are also apparent, although each is limited to a single section.

The ages of the zones are based on known ranges of selected taxa commonly reported from Europe, but often having a cosmopolitan distribution.

The 7 zones and 6 subzones are defined below, in stratigraphically descending order.

ZONE 1: *Choffatella decipiens* Partial Range Zone.

This partial range zone is based on the upper range of *Choffatella decipiens* in the studied sections. The upper limit of this zone is undefined, but extends into Rey's (1972) formations, "Calcaires á Rudistes de Praia dos Coxos" and "Calcaires á Rudistes de Boca do Chapim" in Ericeira and north Cabo Espichel respectively. The lower limit, based on the top of the underlying *Marsonella kummi* zone, is within the above formations.

Age: Early Barremian, based on the occurrence in the underlying zone of the Late Hauterivian species, *Spiroplectammina dorni* and *Marsonella kummi*. Also ranging up into this zone are the ostracods *Protocythere triplacata* and *P. hechti*, reported as having a Hauterivian to Early Barremian range (Neale, 1962, 1978). *Choffatella decipiens* is reported from Tethyan deposits of Early Barremian to Aptian age (Maync, 1950), and is also reported from Upper Hauterivian to Aptian strata in the Algarve region of Portugal (Rey, 1979).

Occurrence: Lusitanian Basin: Cabo Espichel, 785-798m, Calcaires á Rudistes de Boca do Chapim; Ericeira, 196-200m, Calcaires á Rudistes de Praia dos Coxos.

Discussion: This zone is recognized in shallow marine, inner neritic sediments of less than 50m water depth, based on the distribution of modern larger Foraminifera (Murray, 1973).

ZONE 2: *Marsonella kummi* -*Spiroplectammina dorni* Interval Zone.

The upper limit of this interval zone is defined by the highest stratigraphic occurrence of *Marsonella kummi* together with *Spiroplectammina dorni*. The lower limit is based on the top of the underlying *Ammobaculites* sp.A zone. The lowest occurrence of *Choffatella decipiens* is within this zone. Two subzones, based on distinctive Foraminifera assemblages, occur in the lower part of this zone.

Age: The top of this zone may coincide with the Hauterivian - Barremian boundary, based on finds of *Marsonella kummi* and *Spiroplectammina dorni* in the top few metres of the Portuguese sections. Bartenstein (1978) stated that *Spiroplectammina dorni* evolved from *Marsonella kummi* in the Early Hauterivian and continued into the Late Hauterivian. *Marsonella kummi* continued to the top of the Hauterivian, and is thought to have evolved into *M. subtrochus* in the Early Barremian (Bartenstein, 1978). The specimens of *M. kummi* examined in this study include forms transitional to *M. subtrochus*, probably indicating an Late Hauterivian age.

Occurrence: Lusitanian Basin: Cabo Espichel, 655-785m, Rey's (1972) formations: Calcaires et silts de Ladeiras (upper 10m); Grés á Rochadouro; Calcaires et marnes á Choffatelles; Grés á Dinosauriens; Calcaires á Rudistes de Boca do Chapim (lower 15m). Ericeira, 161-196m, Rey's (1972) formations: Calcaires á Rudistes de Praia do Coxos (lower 13m); Marnes et grés de Santa Susane (upper 22m).

2a: *Ammobaculites obliquus* subzone.

This concurrent range subzone is based on the overlap of the range of *Ammobaculites obliquus* with *Choffatella decipiens*. The upper boundary is based on the highest occurrence of the nominate species, whereas the lower boundary is defined by the top of the underlying *Trochammina depressa* subzone.

This zone also contains the local range of *Ammobaculites reophacoides*, along with the highest occurrences of the following species: *Reophax horridus*, *Ammobaculites coprolithiformis*, *Ammobaculites subcretaceus*, *Spiroplectammina ammovitrea*, *Trochammina globigeriniformis*, *Feurtillia frequens*, *Eoguttulina metensis*.

Age: The overlapping ranges of *Ammobaculites obliquus* and *Choffatella decipiens* below the first (Late Hauterivian) appearance of *Spiroplectammina dorni*, and within the lower range of the ostracods *Protocythere triplicata* and *P. hechti* (Hauterivian to Early Barremian), suggests a Middle to Late Hauterivian age for this subzone. The lower range of *Choffatella decipiens* is also reported from Upper Hauterivian strata (Rey, 1979).

Occurrence: This subzone is recognised in the section north of Cabo Espichel where it is represented by the Calcaires et marnes á Choffatelles formation (700-751m). In the Ericeira section this subzone is found in the upper 16m of the Marnes et grés de Santa Susane and the lower 9 m of the Calcaires á Rudistes de Praia dos Coxos, between 167m and 192m.

Discussion: Although in a strict sense this subzone is a partial range zone, it is also the product of two assemblages that represent facies transitions in each section. At Cabo Espichel the assemblage is composed of agglutinated Foraminifera with calcareous cement (dominantly *Choffatella decipiens* plus *Feurtillia frequens* and *Ammobaculites coprolithiformis*), together with the calcareous taxon *Eoguttulina metensis*. This assemblage reflects the sandy, shaley and heavily bioturbated inner neritic limestone facies seen here.

The assemblage in the Ericeira region, in comparison, lacks calcareous forms and is dominated by simple agglutinated Foraminifera with non - calcareous cement (*Ammobaculites obliquus*, *A. subcretaceus*, *A. reophacoides*, *A. coprolithiformis*,

Reophax horridus, *Spiroplectammina ammovitrea* and *Trochammina globigeriniformis*). The assemblage here reflects the transition from non - carbonate marsh, through estuarine to shallow marine, inner neritic facies (*Choffatella* abundant).

The top of this subzone in both sections represents an increase in availability of calcium carbonate and a reduction in clastic input that reflects the onset of more marine (transgressive) conditions at the top of the *Marsonella kummi* zone. This environmental shift is also mirrored in the Ostracoda assemblages.

2b: *Trochammina depressa* Interval Subzone.

The top of this Interval Subzone is defined by the highest occurrence of *Trochammina depressa*, and the lower range of *Spiroplectammina ammovitrea*. The base of the subzone is defined by the upper boundary of the *Ammobaculites* sp.A. zone. Other characteristic species include *Ammobaculites obliquus*, *Trochammina raggatti*, *T.* aff. *quineloba* and *Tiphotrecha* sp.

Age: A precise age determination is difficult for this subzone since it lacks age-diagnostic species. It lies above the highest occurrence of *Haplophragmium inconstans*, reported to range as high as the Valanginian (Bartenstein and Brandt, 1951), and is therefore presumed to be younger than Valanginian. The position of this subzone below the oldest finds of *Choffatella decipiens* suggests it is older than mid-Hauterivian. The relative position of this subzone suggests an Early Hauterivian age.

Occurrence: This subzone is recognised in the Ericeira section where it is found in the interval between 161-165 m represented by the lower part of the Marnes et grés de Santa Susana. The 665-698 m interval at Cabo Espichel was not sampled due to inaccessibility and poor exposure.

Discussion: This subzone is an assemblage subzone reflecting *Trochammina* -*Ammobaculites* dominated siltstone facies. It is unlikely that this subzone would be recognised in the Cabo Espichel section where the equivalent lithostratigraphic interval is represented by dolomitic sandstones and limestones.

ZONE 3: *Ammobaculites* sp.A Range Zone.

This zone is defined by the range of *Ammobaculites* sp.A. Also common in this zone are *Ammobaculites obliquus*, *A. subcretaceus* and *Haplophragmium inconstans*.

Age: The age of this zone is tentative since the only age diagnostic species is *Haplophragmium inconstans* which ranges from the Oxfordian (Gradstein, 1983) to the Valanginian (Bartenstein and Brandt, 1951). This zone is found below the first occurrence of the ostracods *Protocythere triplicata* and *P. hechti*, reported to have their oldest occurrences in the Hauterivian (Neale, 1962, 1978). The relative position of this zone suggests a Late Valanginian age.

Occurrence: North of Cabo Espichel, this zone is found in the 647 - 655m interval represented by the Calcaires et marnes de Ladeiras. In the Ericeira section this zone is found between 155m and 160m, within the Marnes et grés de Santa Susana.

Discussion: Although recognised in both the Ericeira and Cabo Espichel sections, this zone is strongly facies controlled and best developed in the marsh facies in the Ericeira section.

ZONE 4: *Haplophragmium inconstans* Partial Range Zone.

The top of this zone is defined by the base of the overlying *Ammobaculites* sp.A zone. The lower limit is coincident with the highest stratigraphic occurrence of *Anchispirocyclina lusitanica*. The lower range of *Haplophragmium inconstans* is within this

zone, and the highest stratigraphic occurrence of *Eoguttulina liassica* is at or near the top. Also common in this zone are *Ammobaculites subcretaceus* and *Haplophragmoides concavus*.

Age: The precise age of this zone is hard to determine since *Haplophragmium inconstans* ranges from the Oxfordian (Gradstein, 1983) to the Valanginian (Bartenstein and Brand, 1951). The position of the zone above the highest occurrence of the Berriasian ostracod *Cytheropteria treibeli* (Neale, 1978), and below the first appearance of the Hauterivian-Early Barremian ostracods *Protocythere triplicata* and *P. hechti*, suggests a Valanginian age for the zone.

Occurrence: North of Cabo Espichel this zone is found in the 608-646m interval, representing the Marnes á Toxaster, Calcaires á Polypiers de Lagosteiros and the lower portion of the Calcaires et silts de Ladeiras. In the Ericeira section this zone is found between 135m and 155m, represented by the Grés blancs de Sao Lourenco and the lower 9m of the Marnes et grés de Santa Susana.

Discussion: This zone is developed in marginal marine (estuarine-transitional) to shallow marine (inner neritic) facies

ZONE 5: *Anchispirocyclus lusitanica* Range Zone.

This zone is defined by the range of *Anchispirocyclus lusitanica*. *Pseudocyclamina muluchensis* is also present throughout the zone, which is divided into three subzones based on distinct Foraminiferal assemblages.

Age: Upper Tithonian-Berriasian. The ostracod *Paranotacythere pustulata* has its highest occurrence a short distance below the base of this zone. *P. pustulata* occurs in the latest

Kimmeridgian in the U.K., (Christensen and Kilenyi, 1970) which equates with the A Mid Tithonian in the French sense. Occurring with the upper range of *Anchispirocyclus lusitanica* are the ostracods *Cytheropteria triebeli* and *Mandelstamia sexti*, both of which are dated as Berriasian (Neale, 1978). The upper boundary of the zone may be as young as Early Valanginian, based on the occurrence of *Ammobaculites subcretaceus*, dated as Valanginian in the Speeton Clay section (Fletcher, 1973). Occurrence of *Haplophragmium inconstans*, which ranges as high as Valanginian (eg. Bartenstein and Brand, 1951; Sliter, 1981; Gradstein, 1983) immediately above this zone supports the age for the upper boundary of this zone.

Occurrence: At Cabo Espichel only the lower part of this zone is recognised where it is found in the 332-497m interval (Ramalho's (1971) beds 33-43) and is represented by the Foraminiferal assemblages of subzone 5b and 5c. In the Ericeira section, the complete zone is recognised between 17-135m, with the upper part (subzone 5a) being well represented between 95 -135m.

Discussion: *Anchispirocyclus lusitanica* has traditionally been regarded as Late Jurassic marker species (eg. Hottinger 1967). On the other hand, Rey (1972, 1979), extended the range of this species into the Berriasian, based on the typical "Purbeckian" ostracod *Mantelliana purbeckensis*, although the reliability of this non-marine ostracod as a stratigraphic marker is questionable. The occurrence of *Anchispirocyclus lusitanica* with the marine Berriasian Ostracoda *Cytheropteria triebeli* and *Mandelstamia sexti* represents the first strong evidence of a Berriasian highest occurrence of *A. lusitanica*.

5a: *Ammobaculites subcretaceus* Interval Subzone.

The top of this subzone is defined by the highest stratigraphic occurrence of the species *Anchispirocyclus lusitanica*. The lower boundary is based on the lower range of

Ammobaculites subcretaceus. Other species with their highest occurrence in this subzone are *Everticyclammina virguliana*, *Pseudocyclammina muluchensis* and *Eoguttulina oolithica*. *Haplophragmoides minor* is restricted to this subzone, whereas *H. concavus* and *H. nonionoides* are common throughout.

Age: The presence of abundant *Ammobaculites subcretaceus* slightly above *Anchispirocyclus lusitanica* is taken to indicate that this zone is of a Berriasian age.

Occurrence: This zone is only recognised in the Ericeira section where it is found at the 95-135m interval, represented by the Dolomies, argiles et grés a cailloux noirs de Porto da Calada.

Discussion: This subzone is an assemblage zone that reflects strong lithofacies control. The microfauna is dominated by three species of *Haplophragmoides* and 1 species of *Ammobaculites*. *Anchispirocyclus lusitanica*, in its large discoid A1 form, occurs in low numbers in the dolomitic intervals. At the top of the subzone, this species becomes abundant in its B form where it is associated with silty limestone.

The Foraminifera assemblage in this subzone reflect a restricted lagoonal environment. The top of the subzone marks a shift in salinity towards normal marine conditions.

5b: *Discorbis scituliformis* Interval Subzone.

This subzone is based on the occurrence and abundance of *Discorbis scituliformis* at the top of the Cabo Espichel section in Lagosteiros bay. The upper boundary of the subzone is defined by the base of the overlying subzone, the base by the top of the underlying subzone.

Age: The Foraminiferal species in this subzone are long ranging and offer no precise age determinations. However, the assemblage is associated with the Berriasian Ostracoda, *Cytheropteria triebeli* and *Mandelstamia sexti*. Dinoflagellate cysts from this interval have also been dated as Berriasian (Leereveld *et al.* 1989).

Occurrence: This subzone is recognised only in the Cabo Espichel section within the 493 - 503m interval, Ramalho's (1971) niveaux 43.

Discussion: This subzone is characterised by a low diversity assemblage of only three species in which *Discorbis scituliformis* predominates. The environmental conditions that likely controlled the diversity of microfauna here are difficult to assess, but appear to have been unfavorable to the majority of species in the underlying subzone. *Discorbis scituliformis*, on the other hand, appears to have been an opportunistic species that flourished through the lack of competition in an otherwise adverse environment. The ostracods in this interval are euryhaline, which suggests that salinity may have been one controlling factor.

5c: *Freixialina planispiralis* Interval Subzone.

This top of this subzone is based on the highest occurrence of *Freixialina planispiralis*. The base is defined by top of the underlying *Choffatella tingitana* zone. Other species that may be found in this subzone include *Ammobaculites godmani*, *Pseudocyclammina muluchensis*, *Rectocyclammina chouberti*, *Everticyclammina virguliana*, *Lenticulina muensteri*, *Eoguttulina oolithica*, *E. inovroclaviensis*, *E. liassica*, *E. metensis*, and *quinqueloculina* spp.

Age: It is difficult to assign a precise age to this subzone based on Foraminifera, however the dinoflagellates *Ctenidodinium culmulum* and *Senoniasphaera jurassica* reported from

332-460m in the Cabo Espichel section (P. Jahnke, Unocal, pers. comm. 1987), restrict the greater part of this subzone to the earliest Portlandian as defined in the type section in southern England. This age equates with the early part of the Late Tithonian in the French sense.

Occurrence: This subzone is better represented in the Cabo Espichel section where it is found in the 332-493m interval, Ramalho's (1971) beds 33-42. In the Ericeira section, this subzone is recognised on the basis of *Ammobaculites godmani*, and occurs between 17-63m.

Discussion: With the exception of *Anchispirocyclina lusitanica*, *Pseuacocyclamina muluchensis*, *Rectocyclamina chouberti* and the miliolids, the Foraminifera in this subzone show a decline in numbers towards the top. This trend is coincident with a facies change from nodular limestone to shales and sandy limestones.

ZONE 6: *Choffatella tingitana* Interval Zone.

The top of this interval zone is based on the highest occurrence of *Choffatella tingitana*, and is coincident with the base of the overlying *Anchispirocyclina lusitanica* zone. The lower boundary is defined by the top of the underlying *Mesoendothyra* sp.A zone. Common species in this zone include *Choffatella tingitana*, *Pseudocyclamina muluchensis*, *Lenticulina muensteri* and species of *Eoguttulina*.

Age: Middle to earliest Late Tithonian. The ostracod *Paranotacythere pustulata*, also found in this zone, is dated as latest Kimmeridgian *sensu Anglico* (Chrisiensen and Kilenyi, 1970). The dinoflagellates *Ctenidodinium culmulum* and *Senoniasphaera jurassica* are also reported from the upper part of this zone in the Cabo Espichel section (Phil Jahnke, Unocal, pers. comm. 1987). In the Type Section of the Portlandian in the U.K., these

dinoflagellates are found in the *albani* ammonite zone of earliest Portlandian age. The *Choffatella tingitana* zone therefore has a latest Kimmeridgian - earliest Portlandian age range in the English sense, which corresponds with the Middle to earliest Late Tithonian of the French terminology.

Occurrence: Cabo Espichel, 235-321m, Ramalho's beds 27 - 32; Ericeira, 16-17m, corresponding to the 'Argiles gresueuses et micacées, rouge, vertes ou bleues, intercalées de lentilles de grés fins blancs' of Rey (1972); Praia Azul, 70-100m.

Discussion: This zone is recognised in shallow, inner neritic siliciclastic facies of brackish salinity.

ZONE 7: *Mesoendothyra* sp.A Partial Range Zone.

This zone is defined by the upper range of *Mesoendothyra* sp.A. The lower boundary is undefined, but lies within Ramalho's (1971) bed 6. *Choffatella tingitana*, *Rectocyclammina arrabidensis*, *Everticyclammina virguliana*, *Verneuilinoides minuta* and *Eoguttulina liassica* are common species within this zone. *Kurnubia palastiniensis* is found in the lower part of this zone, which is separated into a subzone on its distinctive Foraminifera assemblage seen at Cabo Espichel.

Age: Kimmeridgian to Early Portlandian. The presence of *Kurnubia palastiniensis* dates the lower part of this zone as Early-Middle Kimmeridgian (Hottinger, 1967). The dinoflagellates *Ctenidodinium culmulum* and *Senoniasphaera jurassica*, reported from the top of this zone (P. Jankhe, pers. comm. 1987) indicate an Early Portlandian age for the top of the zone.

Occurrence: Cabo Espichel, 0-235m, Ramalho's (1971) beds 6 - 26; Ericeira, 0-16m,

Porto da Calada formation.

Discussion: This zone is present in shallow (middle neritic) carbonate and siliciclastic facies.

7a: *Kurnubia palastiniensis* Partial Range Subzone.

This subzone is based on the upper range of *Kurnubia palastiniensis* in the Cabo Espichel section. The top corresponds to the highest find of this species, and the base is defined by the lowest sample in this study, collected from Ramalho's (1971) bed 6. The Foraminifera assemblage in this subzone is characterised by large numbers of *Rectocyclammina arrabidensis*, *Mesoendothyra* sp.A and *Everticyclammina virguliana*.

Age: Early-Middle Kimmeridgian, based on the range of *Kurnubia palastiniensis* given by Hottinger (1967).

Occurrence: Cabo Espichel 0-10m, in the lower portion of Ramalho's (1971) bed 6.

Discussion: This subzone is associated with silty mud and a carbonate build-up, rich in corals, echinoderms (*Pseudocidaris* sp.) and bivalves.

5.3: ostracodal biozonation for the Kimmeridgian-Barremian of the Lustanian Basin.

The ostracodal biozonation proposed for the sections studied (Figure 5.2) is based on first and last occurrences of 21 taxa of Ostracoda, and permits correlation between the sections. Seven zones are recognised, of Kimmeridgian through Barremian age. Five of the zones may also be recognised by the highest occurrence of selected species, and these

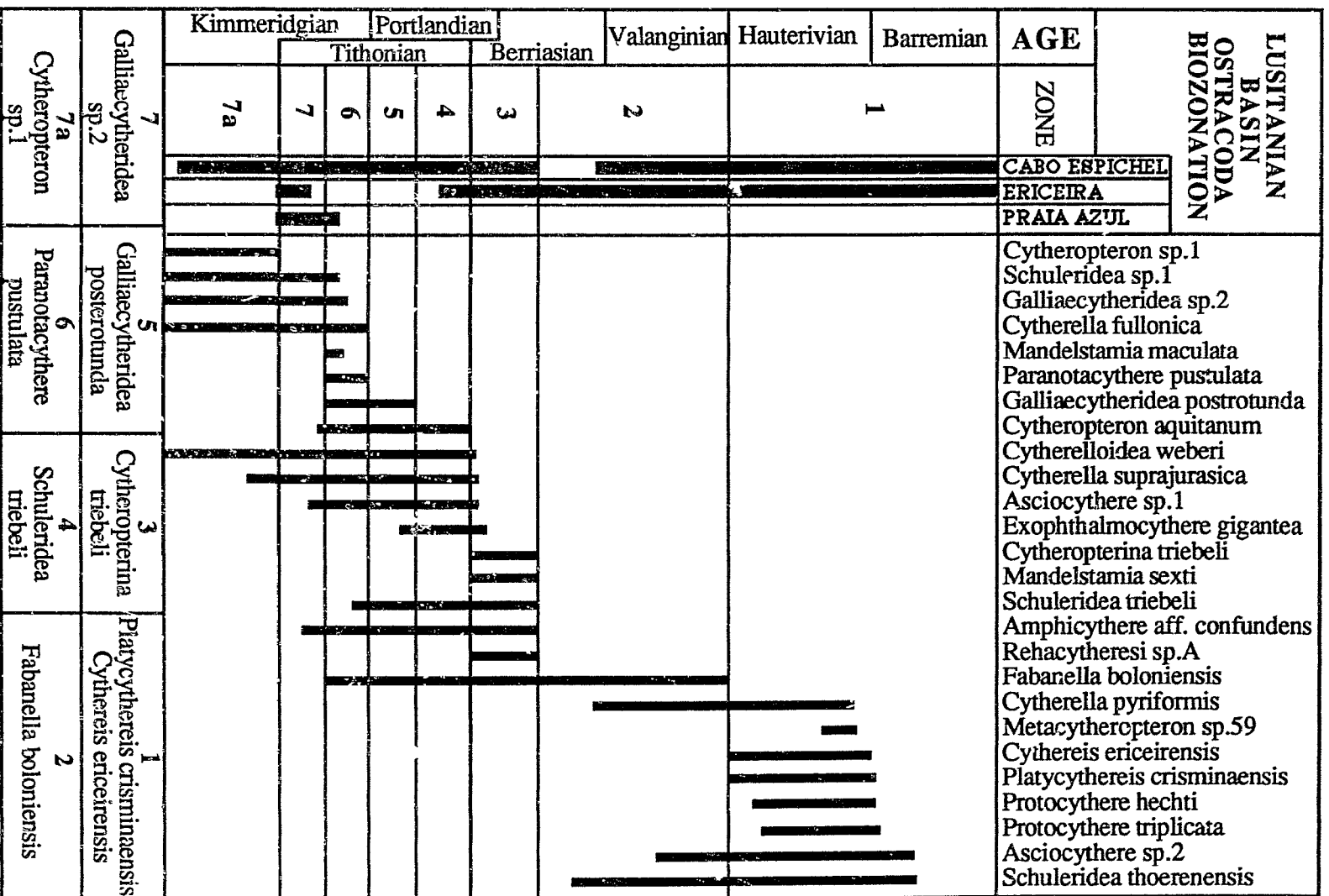


Figure 5.2: Ostracodal biozonation for the Lusitanian Basin.

zones may potentially be used for sub-surface correlation in well sections. A subzone is also recognised as seen in one of the sections only.

The ages of the zones have, where possible, been based on species previously reported from type sections that are dated by ammonites, for example the Kimmeridge Clay and Speeton Clay of England. The seven zones and the subzone are defined below.

ZONE 1: *Platycythereis crisminaensis* - *Cythereis ericeirensis* Concurrent Range Zone.

This zone is based on the lower ranges of *Platycythereis crisminaensis* and *Cythereis ericeirensis*. The upper limit is undefined, but extends into the 'Calcaires a Rudistes de Boca do Chapim' in the section north of Cabo Espichel, and into the 'Calcaires a Rudistes de Praia do Coxos' in the Ericeira section. Also restricted to this zone are *Protocythere triplicata* and *P. hechti*. In the lower part of this zone, extending from the underlying *Fabanella boloniensis* zone are *Schuleridea thoerenensis*, *Cytherella pyriformis*, *Fabanella boloniensis* and *Asciocythere* sp.2.

Age: Hauterivian- Early Barremian, based on the occurrence of *Protocythere triplicata* and *P. hechti*, reported as Hauterivian to Early Barremian in age in the U.K. (Neale, 1962, 1978).

Occurrence: This zone is found in the section north of Cabo Espichel in the 730-788m interval, represented by the 'Calcaires et marnes á Choffatelles' (upper 20m), 'Gres a dinosauriens' and the 'Calcaires á Rudistes de Boca do Chapim'. In the Ericeira section the zone is found in the 192 - 205 m interval, represented by the 'Calcaires á Rudistes de Praia do Coxos'.

Discussion: This zone is present in inner neritic environments.

ZONE 2: *Fabanella boloniensis* Interval Zone.

The boundaries of this interval zone are defined by the base of the overlying and top of the underlying zones. *Asciocythere* sp.2 has its lower range within this zone. *Fabanella boloniensis* has its highest occurrence at the top of this zone.

Age: Late Berriasian to Valanginian. The Foraminifera *Haplophragmium inconstans*, *Haplophragmoides concavus* and *Ammobaculites subcretaceus*, typical of Berriasian to Valanginian deposits of N.W. Europe (eg. Bartenstein and Brand, 1951), are common in the *Fabanella boloniensis* zone.

Occurrence: At Cabo Espichel this zone occurs in the 504-730m interval, representing the following formations: Argiles vérsicolores, grés et calcaires gréseux de Praia de Lagosteiros; Grés blancs á galets de Praia de Lagosteiros; Calcaires roux; Marnes á Toxaster; Calcaires á Polypiers de Lagosteiros; Calcaires et silts de Ladeiras. In the Ericeira section, this zone occurs in the 95-191m interval and corresponds to the following formations: Grés blancs de São Lourenco; Dolomies, argiles et grés á foraminifères; Marnes et grés de Santa susana; Calcaires á Rudistes de Praia do Coxos (lower 9m).

Discussion: In the strictest sense this is an ecozone that reflects a facies. It is not based on first or last occurrence of any particular species, rather it is based on the absence of the species found in the stratigraphically adjacent zones. *Fabanella boloniensis* is a long ranging species characteristic of the non-marine 'Purbeck-Wealden' facies of N.W. Europe, and is common in this zone. *Asciocythere* sp.2 is rare, but is a useful marker for this zone.

ZONE 3: *Cytheropteria triebeli* Range Zone.

This zone is based on the range of *Cytheropterina triebeli*. Also restricted to this zone are *Mandelstamia sexti*, *Exophthalmocythere* sp.A and *Rehacythereis* sp.A, although these are only found in the Cabo Espichel section. *Schuleridea triebeli* and *Asciocythere* sp.1 have their highest occurrence within this zone. Several species from underlying zones may also have their highest occurrence within this zone or immediately below it, including *Cytheropteron aquitanum*, *Amphicythere* aff. *confundens*, *Cytherella suprajurassica*, *Cytherelloidea weberi*, and *Exophthalmocythere gigantea*.

Age: Finds of *Cytheropterina triebeli* and *Mandelstamia sexti* indicate a Berriasian age for this zone. Both these species are reported from the Speeton Clay 'D' beds (Berriasian) of N.E. England (Neale 1962). The occurrence of *Schuleridea thoerenensis* in Cabo Espichel supports this age assignment. The species *Rehacythereis* sp.A, has morphological characters typical of Early Cretaceous (Berriasian) strata (R. Damotte, pers. comm. 1989). The dinoflagellates *Dichadogonyaulax culmula* and *Systematophora palmula* are reported from the interval represented by this zone in the Cabo Espichel section (Leereveld *et al.*, 1989), supporting a Berriasian age assignment.

Occurrence: This zone is found in Cabo Espichel between 480 and 504m, represented by niveaux 43 and the top half of niveaux 42 of Ramalho (1971). In the Ericeira section, this zone is represented by the 64-136m interval, corresponding to the 'Dolomies, argilles et grés a cailloux noirs de Porta da Calada' and the upper part of the 'Argiles gréseuses et micacées, rouge, vertes ou bleues, intercalées de lentilles de grés fins blancs' of Rey (1972).

Discussion: This zone is found in inner neritic carbonate facies.

ZONE 4: *Schuleridea triebeli* Interval Zone.

The top of this zone corresponds to the base of the overlying zone, and the base corresponds to the top of the underlying *Galliaecytheridea postrotunda* zone. The zone contains a number of long ranging taxa including, *Cytherelloidea weberi* var. *recticostata*, *Cytherella suprajurassica*, *Asciocythere* sp.1, *Amphicythere* aff. *confundens*, *Schuleridea triebeli* and *Fabanella boloniensis*. Most of these species disappear within the lower part of the overlying zone.

Age: Late Tithonian. The age of this zone difficult to define on Ostracoda alone. In the U.K., *Schuleridea triebeli* is reported from the Oxfordian to Early Kimmeridgian, (*mariae* to *mutabilis* zones, Kilenyi 1978), and *Cytheropteron aquitanum* from the Late Kimmeridgian (*wheatleyensis* zone (Kilenyi 1969) to *huddlestoni* zone (Wilkinson 1983). In N.W. Germany, *Exophthalmocythere gigantea* is reported from the 'Gigas Schichten' (Middle-Upper Kimmeridgian) (Klinger *et al.*, 1962). *Cytherelloidea weberi* var. *recticostata* is reported from the middle Kimmeridgian (*Gravesia* zone) of France (Donze 1960). The progressive loss of the mid-rib and increase in posterior tuberculation seen in the latter species (see taxonomy), however, is indicative of an Late Jurassic - Early Cretaceous age (Neale, 1966). The dinoflagellates *Ctenidodinium culmulum* and *Senoniasphaera jurassica* are found in all but the top 20m of the interval represented by this zone in the Cabo Espichel section (Phil Jahnke, Unocal, pers. comm. 1987), indicating a Early Portlandian age, equating with the Late Tithonian in mainland Europe.

Occurrence: In the Cabo Espichel section, this zone occurs between 334 and 480m, Ramalho beds 33 to 42 (lower part). In Ericeira this zone is found in the 63-64m interval representing the middle part of the top most nodular limestone bed in the 'Argiles gréseuses et micacées, rouge, vertes ou bleues, intercalées de lentilles de grés fins blancs' of Rey (1972).

ZONE 5: *Galliaecytheridea posterotunda* Partial Range Zone.

The top of this zone is based on the highest occurrence of *Galliaecytheridea posterotunda*. Also found in this zone are the species *Schuleridea triebeli*, *Cytheropteron aquitanum*, *Cytherella suprajurassica*, *Cytherelloidea weberi* var. *recticostata*, *Asciocythere* sp.1 and *Amphicythere confundens*. The lower limit of this zone coincides with the top of the underlying *Paranotacythere pustulata* zone.

Age: Late Tithonian. The dinoflagellates *Ctenidodinium culmulum* and *Senoniasphaera jurassica* are found in all but the lower 20m of the interval represented by this zone in the Cabo Espichel section (P. Jankhe, Unocal, pers. comm. 1987).

Occurrence: At Cabo Espichel this zone is found in the 210-333m interval, represented by Ramalho's (1971) beds 24 - 33. In the Ericeira section this zone is represented by the 17-63m interval in the Porto da Calada formation.

ZONE 6: *Paranotacythere pustulata* Range Zone.

This zone is defined by the range of *Paranotacythere pustulata*. *Cytherella fullonica*, *Schuleridea* sp.1 and *Galliaecytheridea* sp.2 have their highest stratigraphic occurrence in this zone. *Schuleridea triebeli*, *Galliaecytheridea posterotunda*, *Mandelstamia maculata* and *Asciocythere* sp.1 make their first appearance here.

Age: Latest Early - Middle Tithonian. *Paranotacythere pustulata* is widely reported from the Late Kimmeridgian (*Sensu Anglico*) of the U.K. and N.W. Europe, (*wheatleyensis* to *rotunda* zones, Kilenyi 1969; Kilenyi 1978; Christensen and Kilenyi 1970; Wilkinson 1983), where it is used for correlation with the Kimmeridge Clay type section. The *Paranotacythere pustulata* Zone of Portugal correlates with the *Mandelstamia maculata* and *Galliaecytheridea spinosa* ostracodal zones of Christensen and Kilenyi (1970), the

Mandelstamia maculata and *Galliaecytheridea spinosa* zones of Kilenyi (1978), and the *Mandelstamia maculata*, *Eocytheropteron aquitanum* and *Galliaecytheridea spinosa* zone of Wilkinson (1983).

The zone recognised in Portugal is assigned to the Late Kimmeridgian (*wheatleyensis* to *rotunda* Ammonite zones) which equates with the Middle Tithonian in the French sense. The ranges of *Cytherella fullonica* and *Schuleridea triebeli*, previously regarded as Early Kimmeridgian in age, are extended into the Late Kimmeridgian.

Occurrence: At Cabo Espichel this zone is represented by the 190-200m interval (beds 22-23 of Ramalho, 1971). In the Ericeira section, this zone occurs between 16 and 17m. The total section examined at Praia Azul lies within this zone.

Discussion: *Paranotacythere pustulata* appears strongly facies controlled, which may make recognition of this zone difficult. Although present in Cabo Espichel, *O. pustulata* is rare in that section, whereas in the Praia Azul section the species is abundant, possibly reflecting the opportunistic nature of the species as seen elsewhere (e.g. Kimmeridge Clay of the U.K.). Despite this limitation in using *Paranotacythere pustulata* in the Portuguese biozonation, the value of the species is seen in its use in correlation with the Kimmeridge Clay of the U.K. (*wheatleyensis* to *rotunda* ammonite zones).

ZONE 7: *Galliaecytheridea* sp.2 Interval Zone.

The top of this zone is defined by the base of the overlying *Paranotacythere pustulata* zone. The base of this zone is undefined, but extends down into Ramalho's (1971) bed 6 at Cabo Espichel, and into the Porto da Calada formation (Rey, 1972) in Ericeira. Characteristic species include *Galliaecytheridea* sp.2 Kilenyi, *Schuleridea* sp.1, *Cytherella fullonica*, *Cytheropteron aquitanum* and *Cytherelloidea weberi* var. *recticostata*. A subzone is recognised in the lower part of this zone at Cabo Espichel, based on the

occurrence of *Cytheropteron* sp.1.

Age: This zone is assigned an Early Tithonian age, based on *Cytherella fullonica* and *Cytheropteron aquitanum*. The species *Galliaecytheridea* sp.2 compares with the form *Galliaecytheridea* sp.2 Kilenyi (1969), described from the Kimmeridge Clay (*baylei*-*cymodoce* zones), supporting this age assignment.

Occurrence: Cabo Espichel, 0-189m, Ramalho's (1971) beds 6 - 22 (lower 2m); Ericeira, 15 -16m, Porto da Calada formation.

7A: *Cytheropteron* sp. 1 Partial Range Subzone.

This subzone represents the lower portion of the *Galliaecytheridea* sp.2 zone seen at Cabo Espichel, and is based on the upper range of *Cytheropteron* sp.1. The base is undefined, but extends down into Unit 5 of Ramalho (1971). This subzone is only recognised in the Cabo Espichel section.

Age: Early Kimmeridgian, based on co-occurrence of the foraminifer *Kurnubia palastiniensis*.

Occurrence: Cabo Espichel, 0-10m.

Discussion.

The present-day spatial distribution of Ostracoda is strongly influenced by environmental factors including substrate, availability of nutrients, temperature and salinity (Pokorny, 1971). Translated into a stratigraphic column, the vertical distribution of ostracods in a sequence of varied marginal marine sediments, such as the Portuguese strata, should show considerable variation depending on the sedimentary facies present. This may

account for the overlap seen in several of the species ranges between the sections.

The ostracodal zones described above should be considered ecozones. However, where the relationships between the Ostracoda species and facies are known, changes in the former independent of the latter can be considered stratigraphically significant.

5.4: Lithostratigraphic and palynological correlation.

Lithostratigraphic correlations between the lower (Upper Jurassic) parts of the Cabo Espichel and Ericeira sections, and the Praia Azul section have not been considered in earlier studies. The major problem in this area has been the widely differing sedimentary facies combined with an absence of ammonite fossil data. The Lower Cretaceous sequences in the Cabo Espichel and Ericeira sections, on the other hand, have been correlated and related to a chronostratigraphic framework by Rey (1972) on the basis of studies of the sedimentary sequences and their invertebrate (echinoderm) content (Figure 5.3). Recently, Leereveld *et al.* (1989) were able to date and correlate the Cabo Espichel and Ericeira sections using dinocyst associations (Figure 5.4). Comparing the schemes of Leereveld *et al.* (1989) and Rey (1972), two main differences stand out: 1) the unit described as the "marno-calcaires sans Anchispirocyclines", originally regarded as Portlandian by Rey (1972), is dated as Early to ?Mid Berriasian by Leereveld *et al.* (1989); 2) the "argiles versicolores, gres et calcaires gréseux de Praia de Lagosteiros" previously regarded by Rey (1972) as Early Berriasian to Berriasian "pro parte" are now regarded by Leereveld *et al.* (1989) as Late Berriasian. The chronostratigraphic assignments and correlations for all other lithologic units are the same.

Foraminiferal and ostracodal biozonations, (Figure 5.5) differ from the above systems for the Kimmeridgian to Barremian as discussed below.

The Cabo Espichel Unit 3 together with the lowest limestone bed of the Ericeira Unit 1 and the Praia Azul unit correlate within the upper part of the *Mesoendothyra* sp.A

AGE	CABO ESPICHEL	ERICEIRA
Early Barremian	Calcaires á rudistes de Boca do Chapim	Calcaires et marnes á Choffatelles
	Grés á Dinosauriens	
	Calcaires et marnes á choffatelles	Grés á Trigonies
	Grés do Rochadouro	
Hauterivian	Calcaires et silts de Ladeiras	Calcaires á rudistes de Praia do Coxo
	Calcaires á polypiers	
	Marnes á Toxaster	Marnes et grés de Santa Susana
Late Valanginian	Calcaires roux	Dolomies, argiles et grés á foraminifères
Early Valanginian to Berriasian	Grés blancs á galets de Praia de Lagosteiros	Gres blancs de Sao Lourenco
Early Berriasian	Argiles versicolores, grés et calcaires gresseux de Praia de Lagosteiros	Dolomies, argiles et grés á cailloux noirs de Porto da Calada

Figure 5.3: Correlation of units in the Cabo Espichel and Ericeira sections according to Rey (1972).

AGE	CABO ESPICHEL	ERICEIRA
Early Barremian	Calcaires á rudistes de Boca do Chapim	Calcaires et marnes á Choffatelles
	Grés á Dinosauriens	
Early Barremian to Latest Hauterivian	Calcaires et marnes á choffatelles	Grés á Trigonies
	Grés do Rochadouro	
Late Hauterivian	Calcaires et silts de Ladeiras	Calcaires á rudistes de Praia do Coxo
	Calcaires á polypiers	
Hauterivian	Marnes á Toxaster	Marnes et grés de Santa Susana
Late Valanginian	Calcaires roux	Dolomies, argiles et grés á foraminifères
Early Valanginian to Late Berriasian	Grés blancs á galets de Praia de Lagosteiros	Grés blancs de Sao Lourenco
	Argiles versicolores, grés et calcaires greseux de Praia de Lagosteiros	Dolomies, argiles et grés á cailloux noirs de Porto da Calada
Early Berriasian	Marno-calcaires sans Anchispirocyclines	

Figure 5.4: Correlation of units in the Cabo Espichel and Ericeira sections according to Leereveld (1989).

AGE	CABO ESPICHEL	ERICEIRA
Barremian	Calcaires á rudistes de Boca do Chapim	Calcaires á rudistes de Praia do Coxo
Hauterivian	Grés á Dinosauriens	?Hiatus
	Calcaires et marnes á choffatelles	
	?Hiatus	Marnes et grés de Santa Susana
	Calcaires et marnes á choffatelles	
	Grés do Rochadouro	
Valanginian	Calcaires et silts de Ladeiras	?Hiatus
	Calcaires á polypiers	
	Marnes á Toxaster	Dolomies, argiles et grés á foraminifères
	Calcaires roux	
	?Hiatus	?Hiatus
	Gres blancs á galets de Praia de Lagosteiros	Grés blancs de Sao Lourenço
Berriasian	Argiles versicolores, grés et calcaires greseux de Praia de Lagosteiros	Dolomies, argiles et grés á cailloux noirs de Porto da Calada
	?Hiatus	upper nodular bed
Tithonian	unit 5	UNIT 1
	unit 4	
	unit 3	
	unit 2	
Kimmeridgian	unit 1	lower nodular bed

Figure 5.5: Correlation of units in the Cabo Espichel and Ericeira sections, this study.

Foraminiferal zone and the *Paranotacythere pustulata* ostracodal zone dated as Late Kimmeridgian to Early Portlandian. Previously, this interval at Cabo Espichel was assigned to the Late Portlandian (Ramalho, 1971). Lithologically, the beds in this interval in Ericeira are similar to the nodular limestone beds in Unit 3 at Cabo Espichel, and paleontologically, these beds yielded comparable microfossil assemblages. The Praia Azul Unit, in contrast, is mainly siliciclastic and although it has many species in common with the other sections, it differs by virtue of the abundant *Choffatella tingitana* and *Paranotacythere pustulata*.

The upper part of Cabo Espichel Unit 5 (Ramalho bed 43 and top of bed 42) correlates with the upper nodular limestone bed of Unit 1 in the Ericeira section within the *Cytheropteria triebeli* ostracodal zone, dated as Early Berriasian. The age for this interval at Cabo Espichel section was previously determined as latest Jurassic by Ramalho (1971) and Rey (1972). The upper beds in Unit 1 of the Ericeira section were also previously assigned to the latest Jurassic (Rey, 1972). The Early Berriasian age determined from Ostracoda in this interval at Cabo Espichel agrees with the age determined by Leereveld *et al.* (1989), Figure 5.4, from the dinoflagellates *Dicladogonyaulax culmula* and *Systematophora palmula*. The equivalent level in the Ericeira section was not examined for palynomorphs by Leereveld *et al.* (1989).

The interval from the lower part of Unit 5 at Cabo Espichel (Ramalho bed 41) down to, and including part of Unit 3 (Ramalho bed 26) was examined for palynomorphs (P. Jankhe, pers. comm. 1987), and is dated as earliest Portlandian on the basis of the species *Senoniaspheara jurassica*, *Ctenidodinium culmulum*, *C. panneum* and *Muderongia* sp. (Figure 5.6) that also occur in the *albani* ammonite zone of the Portlandian of southern England. Although palynomorphs may also be strongly facies controlled, the approximate age of this interval agrees with that based on the Ostracoda.

The upper beds of the "dolomies, argiles et grès à cailloux noirs de Porto da Calada", Unit 2 in the Ericeira section, is assigned a latest Berriasian to earliest Valanginian

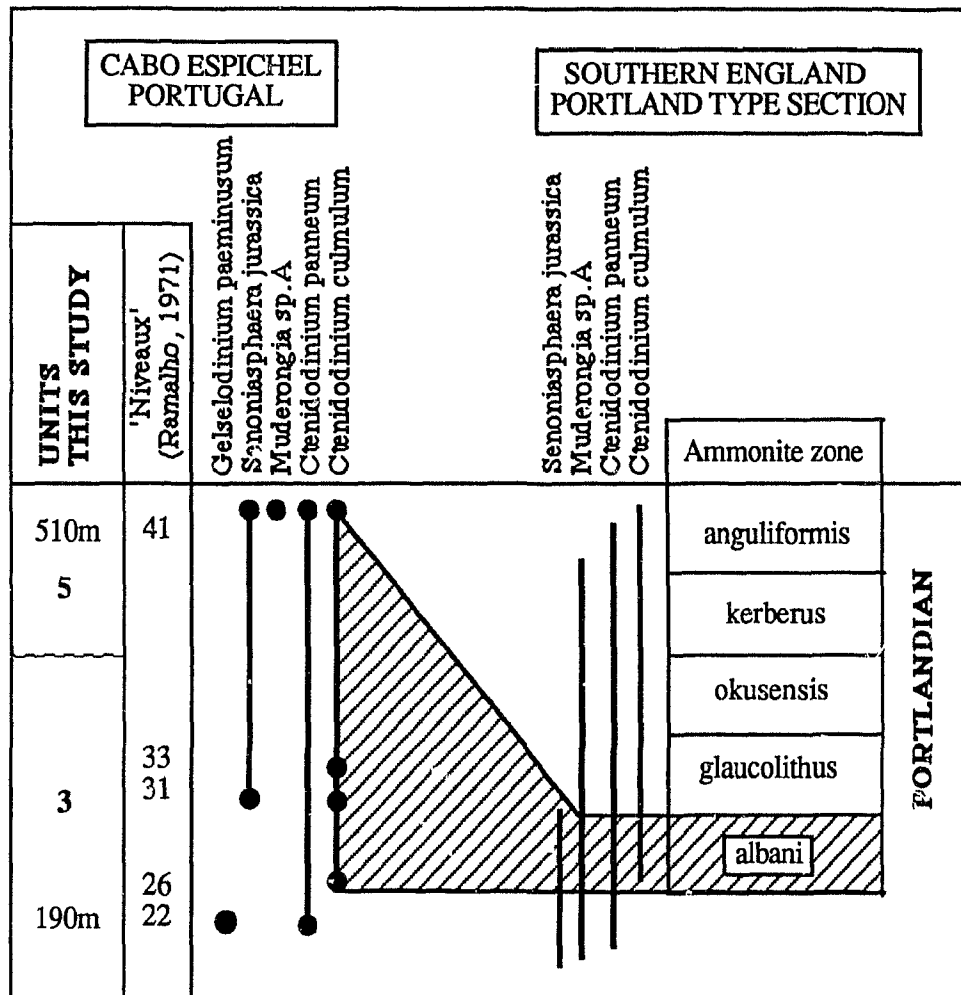


Figure 5.6: Palynologic evidence for the age of Units 3-5 at Cabo Espichel, showing the occurrence of palynomorphs in the section, and their ages in the Portlandian Type Section in southern England. Data from P. Jankhe (pers. comm. 1987).

age (*Anchispirocyclus lusitanica* zone, *Ammobaculites subcretaceous* subzone). This age assignment does not agree with Leereveld *et al.* (1989) who determined this unit to be top Early to middle Berriasian in age on the basis of the dinoflagellates *Avellodinium falsificum*, *Dichadogonyaulax culmula*, *Occisucysta tentoria* and *Systematophora palmula*. The evidence given by Leereveld *et al.* (1989), however, does not strongly support their age assignment, since the first stratigraphic appearance of the species *Occisucysta tentoria* defines the base of their Late Valanginian *Tanyosphaeridium magneticum* dinoflagellate zone. The species *Avellodinium falsificum* and *Systematophora palmula*, according to Leereveld *et al.*, are also found in younger intervals (Valanginian - Barremian). In addition, Leereveld *et al.* (1989) recognised the uppermost Jurassic species *Gochteodinia mutabilis* in Unit 2, and consider this species reworked; the same may be true for *Dichadogonyaulax culmula*.

The Cabo Espichel Unit 6 ('argiles versicolores, grés et calcaires gréseux de Praia de Lagosteiros'), is assigned by Leereveld *et al.* (1979) to the Upper Berriasian and correlated with the upper half of Unit 2 (Dolomies, argiles et grés á cailloux noirs de Porto da Calada) in the Ericeira section. No palynologic data is offered by Leereveld *et al.* to support this assignment. Rey (1972) also correlated Cabo Espichel Unit 6 with Ericeira Unit 2 and assigned these units to the Berriasian, although did not provide evidence for this. The stratigraphic position of Cabo Espichel Unit 6 and correlation with Ericeira Unit 2 is a problem that cannot be resolved due to lack of data. The Early Berriasian and Early Valanginian ages assigned to the units immediately below and above Cabo Espichel Unit 6 indicate the approximate stratigraphic position of Unit 6, however the position of this unit within the schemes presented by Rey (1972) and Leereveld *et al.* (1989) implies continuous sedimentation through the Berriasian to Valanginian, which may not be so. Field evidence (refer back to part 2.5.2) of 'paleokarst' at the top of Cabo Espichel Unit 5, suggests a hiatus at the base of Unit 6. The time represented by this hiatus cannot be determined due to lack of biostratigraphic control, but may be less than, equal to, or greater than the time

represented by Unit 6 sediments. The full sequence in Unit 6 was not examined because of poor exposure, although Rey (1972) indicates an erosive contact between this unit and that above, which may be an indication of a later hiatus. The stratigraphic position of Unit 6 (Figure 5.5) is tentatively placed at the Berriasian-Valanginian boundary.

Ericeira Unit 4 ('Dolomies, argilles et grés a foraminifères') is assigned to the Valanginian on the basis of the Foraminifera *Haplophragmium inconstans*, *Ammobaculites subcretaceous* and *Haplophragmoides concavus*. Leereveld *et al.* (1989) place this unit in the Late Valanginian on the basis of the palynomorphs *Batioladinium varigranosum*, *Exiguiphaera phragma*, *Kleithrasphaeridium fasciatum*, *Muderongia mcwhaei*, *M. simplex*, *Occisucysta tentoria*, *Oligosphaeridium complex* and *Systematophora palmula*. The Late Valanginian age indicated by Leereveld *et al.* (1989) in their lithostratigraphic correlation, Figure 5.4, however, does not correspond accurately with the discussion of the stratigraphy in the text, which states that the unit (Leereveld *et al.*, 1989, p.133), "...corresponds to the Tethyan upper lower Valanginian - lower Upper Valanginian". From the text, one would presume that Leereveld *et al.* assign the unit to the Middle Valanginian, which seemingly allows correlation of the underlying Ericeira Unit 3, (Grés blancs de São Lourenço), with the Cabo Espichel Unit 7 (Grés blancs á galets de Praia do Lagosteiros).

The Cabo Espichel Units 8 ('Calcaire roux'), 9 ('Marnes á Toxaster') and 10 ('Calcaires á polypiers de Lagosteiros') are tentatively assigned to the Valanginian. This does not agree with the chronostratigraphic assignment of Leereveld *et al.* (1989), who place the 'Marnes á Toxaster' in the middle Hauterivian on the basis of the dinoflagellate *Subtilisphaera terrula*, the 'Calcaires á polypiers de Praia do Lagosteiros' in the late Hauterivian on the evidence of representatives of the *Subtilisphaera perlucida* group of dinoflagellates, and correlate Units 9 and 10 with the Ericeira Unit 8 ('Calcaires et rudistes de Praia dos Coxos'). The 'Calcaires Roux' (Unit 8) is assigned to the late Valanginian by Leereveld *et al.*, although they did not sample this unit.

The Ericeira Unit 5 ('Marnes et grés de Santa Susana'), according to the correlation table in Leereveld *et al.* (1989), Figure 5.4, is assigned to the Hauterivian. In the discussion of the unit, however, Leereveld *et al.* (1989) state (p.133) that the dinocyst association of *Coronifera oceanica*, *Exiguisphaera phragma*, *Kleithriasphaeridium fasciatum*, *Muderongia tetracantha* and representatives of the *Subtilisphaera perlucida* group "...is characteristic for the Hauterivian-Barremian boundary interval without further subdivision". The only samples from this unit examined by Leereveld *et al.* (1989) were from the cliff section south of the Rio Safarujó, whereas those analysed in this study included a number from the siltstone in the lower part of the unit, located north of the Rio Safarujó mouth (refer back to part 2.4.2). The lower (siltstone) part of the unit is tentatively assigned to the latest Valanginian-earliest Hauterivian (*Ammobaculites* sp.A and *Marsonella kummi* zones), whereas the basal claystone of the upper part of the unit are assigned to the Middle Hauterivian (*Ammobaculites obliquus* subzone). The overlying clastic interval of the 'Marnes et grés du Santa Susana', not sampled in this study, could by virtue of the underlying Middle Hauterivian strata, correspond to the latest Hauterivian as suggested by Leereveld *et al.* (1989).

Assuming the upper part of Ericeira Unit 5 is latest Hauterivian in age as discussed above, this unit would correlate with Cabo Espichel Unit 11 ('Calcaires et silts de ladeiras') rather than with Unit 9 ('Marnes á Toxaster') as proposed in the correlation table (Figure 5.4) in Leereveld *et al.* (1989). In this study, however, Ericeira Unit 5 is correlated with Cabo Espichel Units 11 ('Calcaires et silts de Ladeiras'), 12 ('Gres do Rochadouro') and 13 ('Calcaires et marnes á Choffatelles'), Figure 5.5.

The ages of Cabo Espichel Units 11, 12 and 13, according to Leereveld *et al.* (1989), are Late Hauterivian to Early Barremian, almost a stage younger than the chronostratigraphic assignment in this study. This discrepancy may partly reflect sampling differences between the two studies, resulting from poor location details of the sections described in Rey (1972). As Leereveld *et al.* (1989) did not examine samples from Cabo

Espichel Units 11, 12 or 13, their chronostratigraphic assignments for these units are based on the stratigraphic position of these units above the 'Calcaires á Polypiers de Lagosteiros' (Unit 10), dated by Leereveld as Late Hauterivian, and below the 'Calcaires et marnes du Bellasian', dated by Leereveld *et al.* as Late Albian - Cenomanian.

The Cabo Espichel units 'Grés de Rochadouro' (Unit 14) and 'Calcaires á rudistes de Boca do Chapim' (Unit 15) and the Ericeira Unit 8 ('Calcaires á rudistes de Praia dos Coxos') were not sampled by Leereveld *et al.* (1989), although they assign these units to the Late Hauterivian to Early Barremian on the basis of their relative stratigraphic position. The Late Hauterivian age assigned to Ericeira Unit 8 by Leereveld *et al.* is in apparent conflict with the age of the underlying 'Marnes et grés de Santa Susana', assigned to the "Hauterivian-Barremian boundary interval" (Leereveld *et al.* 1989, p. 133). Assigning the latter unit to the Hauterivian-Barremian boundary would effectively date the 'Calcaires á rudistes de Praia dos Coxos' as Early Barremian. The chronostratigraphic assignment for the 'Calcaires á rudistes de Praia dos Coxos' in this study is uppermost Hauterivian to Lower Barremian, based on the Ostracoda *Protocythere triplicata*., and the unit is correlated with Cabo Espichel Unit 15 ('Calcaires á rudistes de Boca do Chapim') within the *Marsonella kummi* and *Choffatella decipiens* Foraminifera zone and the *Platycythereis crisminaensis* ostracodal zone.

Discussion.

Integration of the Foraminiferal and Ostracoda biozonations for the Kimmeridgian - Barremian of the Lusitanian Basin with the palynologic data of P. Jankhe (personal communication 1987) and Leereveld *et al.* (1989), (Figure 5.7) has improved and substantiated the chronostratigraphy of the units examined, but has also revealed discrepancies.

The palynologic data of P. Jankhe for Cabo Espichel Units 3 to 5 provided evidence of an Early Portlandian age for the *Choffatella tingitana* and lower part of the

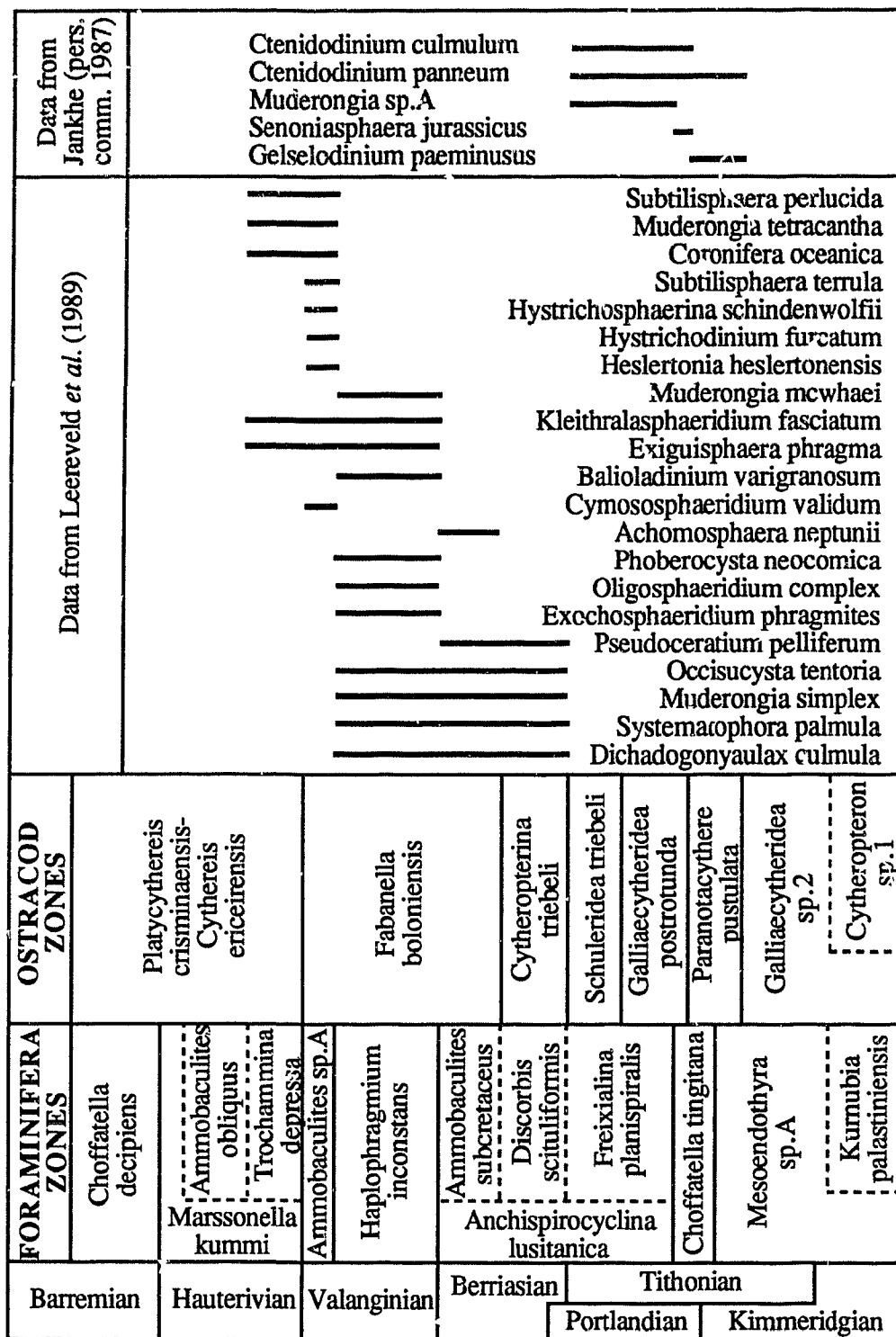


Figure 5.7: Integration of palynomorph ranges with Foraminifera and Ostracod zones in the Lusitanian Basin.

Anchispirocyclus lusitanica Foraminifera zones, and supported the Late Kimmeridgian age for the *Paranotacythere pustulata* ostracodal zone, allowing correlation of this zone with the Kimmeridge Clay type section.

The assignment of Cabo Espichel Unit 3, 4 and most of Unit 5 to the Early Portlandian (*albani* ammonite zone) implies a relatively high rate of subsidence and sediment accumulation (about 250 m / m.y.). The Berriasian age determined for the upper part of Cabo Espichel Unit 5, on the other hand, implies far lower rates of sediment accumulation (30m) for the remainder of the Portlandian and the Early Berriasian. The change in sediment accumulation rates through the Late Jurassic in the Cabo Espichel section is probably related to the "R2" (second phase) rifting pulse widely recognised in the circum north Atlantic basins (Hiscott *et al.*, 1990a).

The chronostratigraphic assignments and correlations that Leereveld *et al.* propose for the Lower Cretaceous units of the Lusitanian Basin do not accord with all the findings of this study. Because of discrepancies between the chronostratigraphic assignments of the lithologic units discussed in the text and those shown in the lithostratigraphic correlation table in Leereveld *et al.* (1989), it was decided not to emend our interpretations. An example of such a discrepancy is seen in treatment of Ericeira Unit 6 ('Marnes et grés de Santa Susana'). In their table (Figure 5.4), Leereveld *et al.* correlate Ericeira Unit 6 with Cabo Espichel Unit 9 ('Marnes á Toxaster') and assign these units to the Hauterivian, yet in the text the former unit is assigned to the Hauterivian-Barremian boundary interval. On the other hand, dinoflagellate data of Leereveld *et al.*, based on samples from the top beds of Cabo Espichel Unit 5 substantiates the Berriasian age proposed for the Ostracoda and Foraminiferal zones at that level.

It is tempting to make correlations between units on lithologic criteria alone, as Leereveld *et al.* (1989) appear to have done with the "Grés blancs de Sao Lourenço" and the "Grés blancs á galets de Lagosteiros", but there is no paleontologic evidence for this.

5.5: Extension of the biozonations outside the Lusitanian Basin.

The Lusitanian Basin outcrop sections examined contain microfossil species that are reported from other areas of northwest Europe as discussed in the biozonation schemes. The Ostracoda in particular are valuable in correlating the Portuguese sections with well-dated classic type localities in the U.K. (Figure 5.9).

The *Paranotacythere pustulata* zone recognised in all three sections in Portugal contains diagnostic species found in the *Galliaecytheridea spinosa* and *Mandelstamia maculata* ostracodal zones of Christensen and Kilenyi (1970), found in the Kimmeridge Clay type section in the Wessex Basin of the southern U.K. The two Kimmeridge Clay ostracodal zones are also widely recognised in boreholes across the U.K. (Wilkinson 1983), and are found within the *wheatleyensis* to *pallasiodes* ammonite zones in the Kimmeridge Clay type section. The Late Kimmeridgian age of the *Paranotacythere pustulata* zone in Portugal is supported by the presence of the dinoflagellate *Ctenidodinium panneum* within the zone, and the occurrence of *Ctenidodinium culmulum* and *Senoniasphaera jurassica* in the overlying beds dated as Early Portlandian (*albani* zone).

The *Cytheropteron triebeli* ostracodal zone, defined by the nominate species in the Portuguese section, equates with the *Galliaecytheridea terres* ostracodal zone of the Speeton Clay type section recognised by Neale (1978) and dated as Berriasian (*albidum* ammonite zone). The dinoflagellates *Dichadogonyaulax culmula* and *Systematophora palmula*, found within the same interval in the Cabo Espichel section (Leereveld *et al.* 1989) support the Berriasian age assignment for the ostracodal zone.

The *Platycythereis crisminaensis* ostracodal zone correlates with the *Protocythere triplicata* and *Mandocythere frankei* ostracodal zones recognised by Neale (1978) in the Speeton Clay type section, on the basis of the species *Protocythere triplicata*. The Speeton Clay ostracodal zones are dated as Hauterivian to Early Barremian (*amblygonium* through to *rarocinctum* ammonite zones).

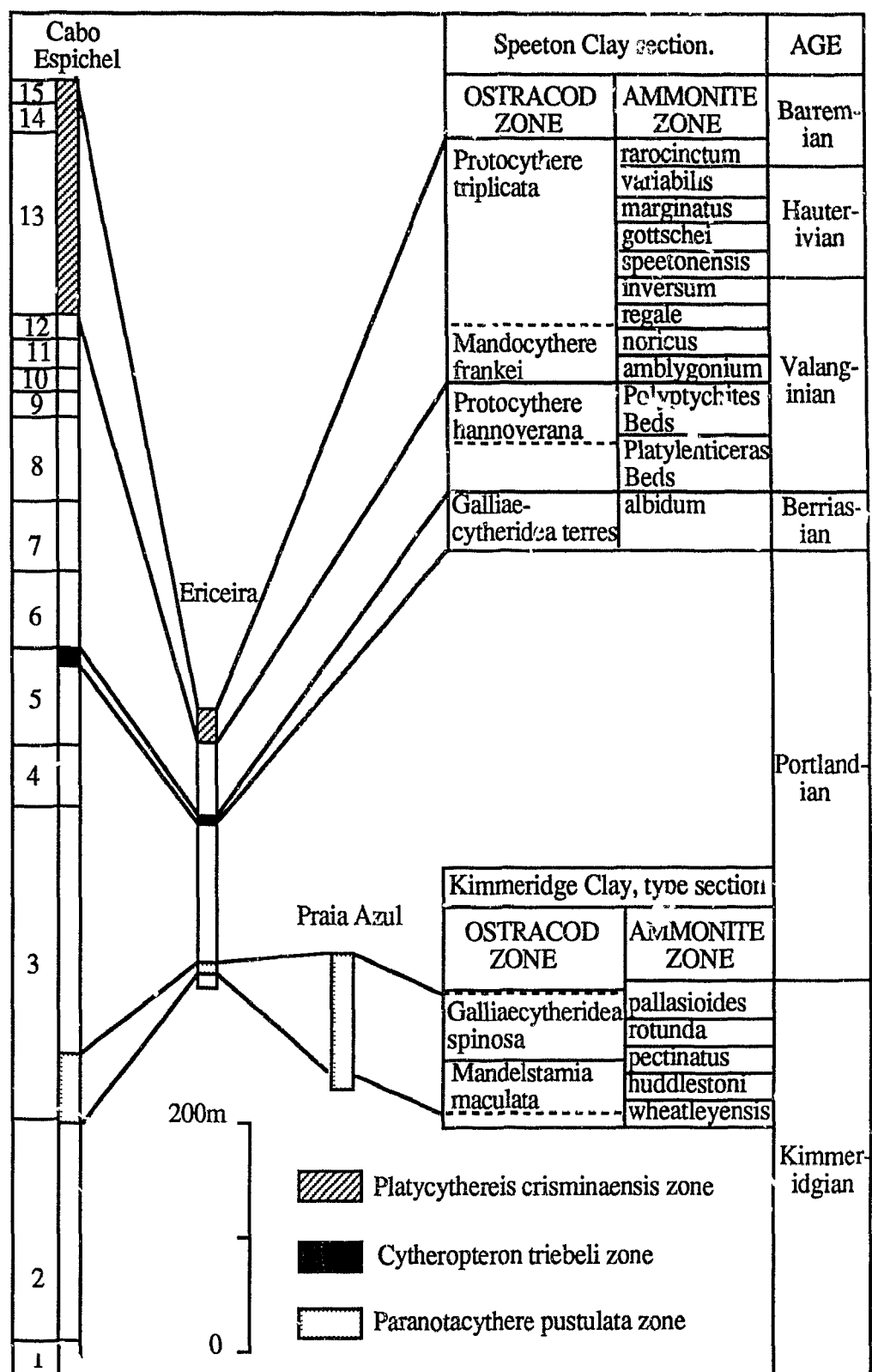


Figure 5.8. Correlation of the Portuguese sections with ostracod zones in the Kimmeridge (Christensen and Kilenyi 1970) and Speeton Clay (Neale 1978) sections

CHAPTER 6

THE GRAND BANKS OF NEWFOUNDLAND.

6.1: Introduction.

The Grand Banks, located east of Newfoundland, are underlain by a series of interconnected Mesozoic graben and half-graben, separated by basement highs, which are the locale for more than 6 km of Jurassic and Lower Cretaceous syn-rift sediments. Important sub-basins within the Grand Banks graben and half graben are, from west to east, the South Whale, Whale, Horseshoe, Jeanne d'Arc and Carson (Figure 6.1). A number of papers have dealt with the geologic development of the Grand Banks, its sub-basins, lithostratigraphic and tectonic framework, including Amoco *et al.*, (1973), Jansa and Wade (1975), Wade (1980), and Benteau and Sheppard (1982). The biostratigraphy of the Upper Jurassic and Lower Cretaceous sequences offshore eastern Canada, is dealt with in Ascoli (1976, 1981, 1984), Gradstein (1976, 1978), Barss *et al.* (1979), Jansa *et al* (1980), Stam (1986) and Williamson (1987).

Earlier (see introduction to Chapter 1), it was mentioned that recent studies had demonstrated a comparable stratigraphic and tectonic (subsidence) history for the Mesozoic syn-rift basins of the North Atlantic. Hiscott *et al.* (1990a) recognised a number of lithostratigraphic similarities between the North Atlantic syn-rift basins, attributed to a common origin during lithospheric extensional phases. Three main stratigraphic elements are cited as being present in the Tithonian to Hauterivian strata in the Grand Banks and the Lusitanian Basin: 1) Tithonian transgressive-regressive cycles; 2) Berriasian regression; 3) Valanginian to Hauterivian fining upward sequences. Also, these authors showed that broad similarities exist between many of the North Atlantic syn-rift basins, including the Grand Banks and Lusitanian Basin, in terms of apparent basement subsidence rate

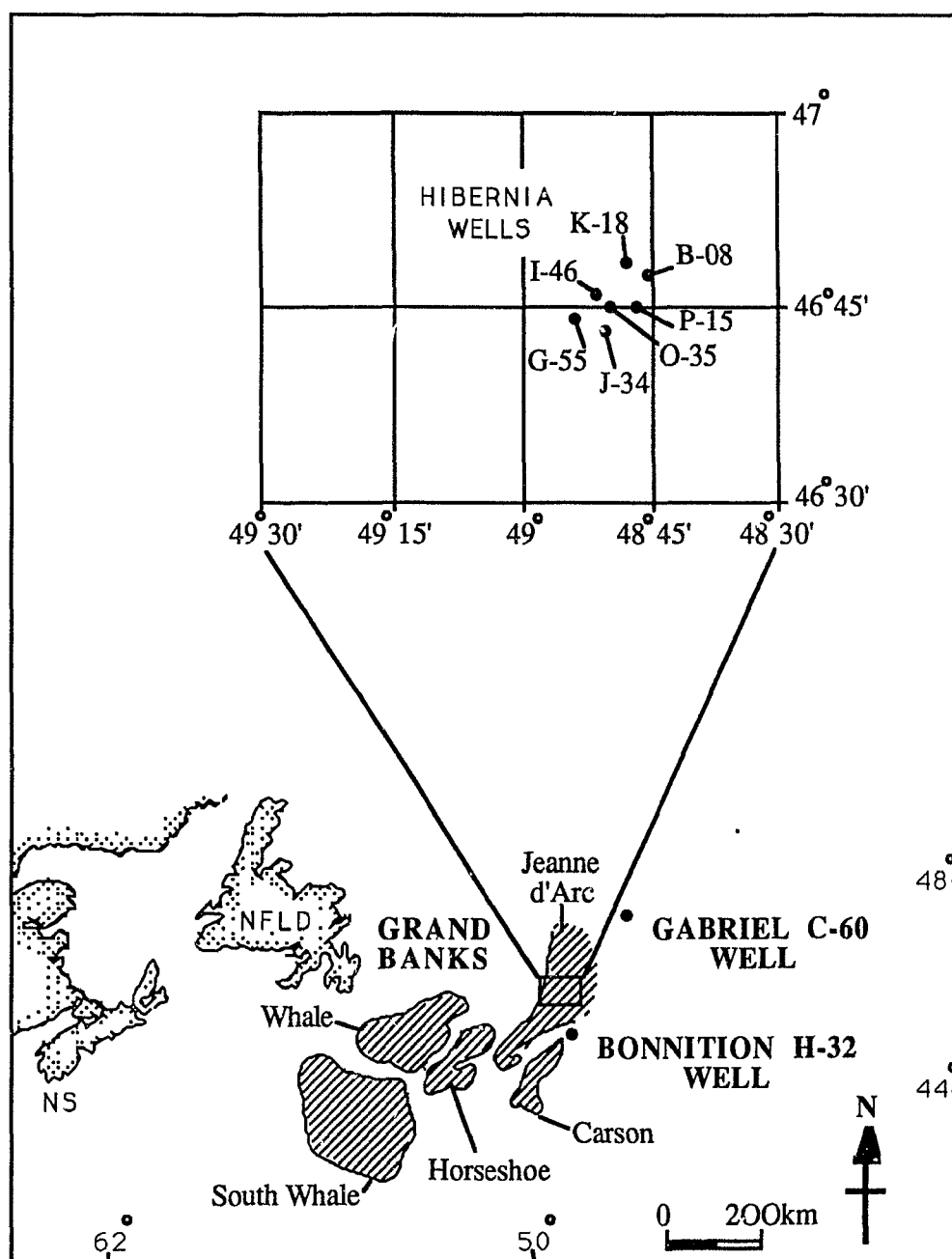


Figure 6.1: Location map of the Grand Banks area, showing subbasins and studied wells.

(ABSR), calculated through decompaction and backstripping of sediments using the recently developed DEPOR and BURSUB programs of Stam *et al.* (1987). Relatively high values of ABSR characterise the onset of rifting in the Triassic and Kimmeridgian, and the Aptian-Albian interval following continental breakup around Iberia.

Exton and Gradstein (1984) showed that the Grand Banks and Portugal have comparable Foraminiferal and Ostracodal assemblages for the Early Jurassic and recognised three zones in both areas. Stam (1986) demonstrated that coeval Foraminiferal assemblages for the Middle to Late Jurassic were closely similar. The foregoing studies have allowed a degree of indirect integration with the standard European ammonite zones.

In this part of the thesis, results of paleoecological and biostratigraphic studies of Portuguese Foraminiferal and Ostracodal assemblages will be applied to the Upper Jurassic and Lower Cretaceous intervals in a number of Grand Banks wells. The bulk of data used in this part of the study comes from oil company well reports, now public information, filed with the Canada Oil and Gas Lands Administration (COGLA) at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. Selection of wells was made, where possible, on the basis of the presence of cored intervals. A number of washed residues from conventional core intervals in selected wells were also studied, providing a further, valuable, source of data on which paleoenvironmental interpretations could be made.

6.2: Wells studied.

Seven of the eight wells examined are located in the Jeanne d'Arc sub-basin, these are the Hibernia G-55, I-46, B-08, K-18, O-35, P-15 and J-34 wells. The eighth well, Gabriel C-60, is located in the Flemish Pass sub-basin (Figure 6.1)

The depth distribution of Upper Jurassic and Lower Cretaceous intervals, based on information in the well history reports of the operating companies and Williamson (1987), and the distribution of conventional core samples studied for paleoecology in individual

wells, is shown in Figure 6.2. Two of the wells, Hibernia G-55 and J-34, contain Lower Cretaceous intervals only. Down-hole depths are measured from the rotary table.

6.3: Late Jurassic and Early Cretaceous Foraminifera and Ostracoda from the Grand Banks: comparison with the Portuguese assemblages.

The Late Jurassic and Early Cretaceous Foraminiferal and Ostracodal species recognised in the Grand Banks wells are listed in four tables: Tables 6.1 and 6.2 list all Foraminiferal and Ostracodal species groups that also occur in the sections examined in Portugal; Tables 6.3 and 6.4 list all Foraminiferal and Ostracodal species groups seen in the Grand Banks wells, but not recognised in the sections examined in Portugal.

Table 6.1 shows that 15 Late Jurassic and Early Cretaceous Foraminiferal species from Portugal are also present in strata of this age in the Grand Banks. Species of *Ammobaculites* are well represented in several wells. *Choffatella decipiens*, *Haplophragmoides concavus* and *Everticyclammina virguliana* are also represented in more than half the wells, whereas the remaining species are seen in less than half the wells. The Ostracoda (Table 6.2) have only six species in common with Portugal, and four of these are exclusive to one well, Hibernia I-46. Given the number of species recognised in the Portuguese sections (50 Foraminiferal and 32 Ostracodal species in total), the similarity between the coeval microfossil assemblages for the two study areas is surprisingly low for the Late Jurassic and Early Cretaceous; in the Middle to Late Jurassic, 25 out of the 30 Foraminiferal species seen in Portugal are also seen in the Grand Banks (Stam 1986).

Table 6.3 shows that 39 Foraminiferal species seen in the Upper Jurassic and Lower Cretaceous strata of the Grand Banks are not recognised in the coeval Portuguese sections. In the Middle to Late Jurassic, however, differences between the faunas were not so pronounced: Stam (1986) reported only fifteen Foraminiferal species in the Grand Banks that were not seen in Portugal. Differences between Late Jurassic and Early

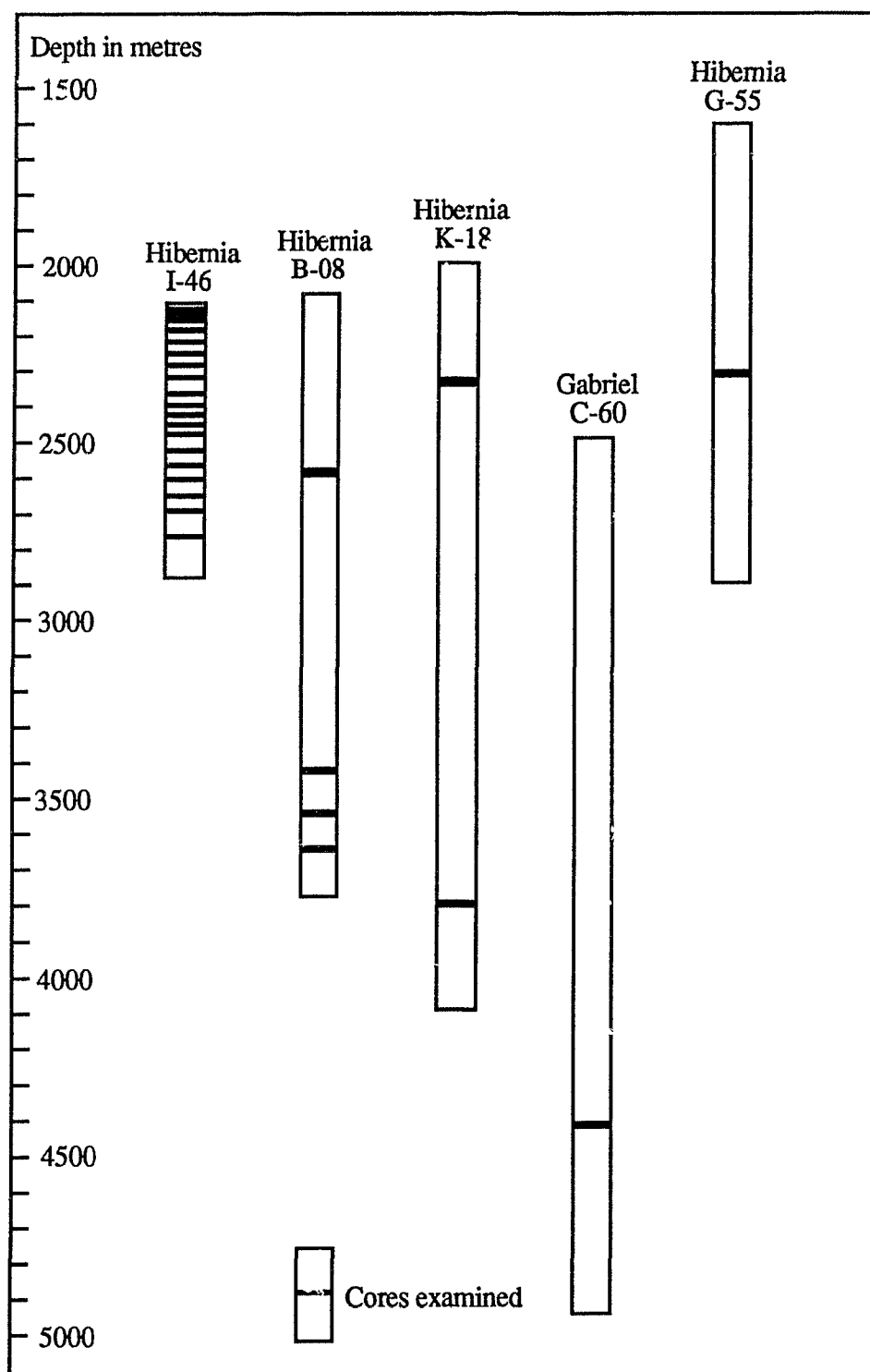


Figure 6.2: Depth of Upper Jurassic-Lower Cretaceous intervals in wells of the Grand Banks, showing approximate position of conventional cores.

SPECIES \ WELL								
	Hibernia I-46	Hibernia B-08	Hibernia K-18	Hibernia O-35	Hibernia P-15	Hibernia C-55	Hibernia J-34	Gabriel C-60
<i>Ammobaculites agglutinans</i>	X	X	X				X	X
<i>Ammobaculites coprilithiformis</i>	X	X	X	X	X		X	
<i>Ammobaculites obliquus</i>		X	X					
<i>Ammobaculites subcretaceus</i>	X	X	X	X	X	X		
<i>Ammobaculites reophacoides</i>	X	X	X				X	X
<i>Anchispirocyclus lusitanica</i>	X			X				
<i>Choffatella decipiens</i>		X	X	X	X	X		X
<i>Discorbis scituliformis</i>				X				
<i>Eoguttulina lassica</i>			X	X				
<i>Everticyclammina virguliana</i>		X	X	X	X	X		
<i>Haplophragmoides concavus</i>	X	X	X	X		X	X	
<i>Haplophragmoides nonionoides</i>		X				X		
<i>Lenticulina muensteri</i>	X	X	X				X	
<i>Pseudocyclammina lituus</i>		X			X			X
<i>Trochammina depressa</i>	X	X				X		X

Table 6.1: Distribution of typical Portuguese foraminifera in Grand Banks wells.

SPECIES \ WELLS								
	Hibernia I-46	Hibernia B-08	Hibernia K-18	Hibernia O-35	Hibernia P-15	Hibernia C-55	Hibernia J-34	Gabriel C-60
<i>Darwinula leguminella</i>		X	X					
<i>Cytherella pyriformis</i>	X							
<i>Protocythere triplicata</i>	X							
<i>Protocythere hechti</i>			X					
<i>Schuleridea thoerenensis</i>	X							
<i>Schuleridea triebeli</i>	X							

Table 6.2: Distribution of typical Portuguese ostracoda in Grand Banks wells.

SPECIES	WELLS							
	Hibernia I-46	Hibernia B-08	Hibernia K-18	Hibernia O-35	Hibernia P-15	Hibernia G-55	Hibernia J-34	Gabriel C-60
<i>Epistomina hechti</i>		X	X	X	X			
<i>Epistomina ornata</i>	X	X	X	X	X			X
<i>Epistomina stelicostata</i>		X	X	X	X			
<i>Epistomina tenuicostata</i>		X	X	X	X			X
<i>Epistomina caracolla</i>	X	X	X		X			X
<i>Epistomina omnireticulata</i>			X		X			
<i>Epistomina mosquensis</i>		X	X	X				
<i>Conorboides valendis</i>		X			X			
<i>Saracenaria frankei</i>		X						
<i>Conorboides hofkeri</i>	X	X	X		X			
<i>Lenticulina busnardoii</i>		X						X
<i>Lenticulina ouachensis</i>		X		X				
<i>Lenticulina nodosa</i>		X	X	X				X
<i>Lenticulina guttata</i>		X	X		X	X		
<i>Lenticulina gaultina</i>		X		X				X
<i>Lenticulina tricarina</i>		X						
<i>Lenticulina eichenbergi</i>		X						X
<i>Lenticulina crepidularis</i>		X	X	X				
<i>Conorboides lamplughii</i>				X		X		X
<i>Lenticulina quenstedtii</i>					X			
<i>Lenticulina saxonica</i>			X		X			X
<i>Gaveinella sigmoicostata</i>	X		X	X				X
<i>Trocholina infragranulata</i>	X		X	X	X	X		
<i>Trocholina valendisensis</i>	X							
<i>Marssonella oxycona</i>	X							
<i>Gyroidinoides ammonoides</i>	X							
<i>Reophax pilulifer</i>	X						X	
<i>Marssonella trochus</i>	X							
<i>Marssonella sigali</i>								
<i>Marssonella valendisensis</i>								
<i>Textularia chapmani</i>								
<i>Textularia bettenstaedti</i>				X				
<i>Neobulimina varsovensis</i>			X					
<i>Paalzowella feifeli</i>					X			
<i>Ophthalmidium carinatum</i>								
<i>Fronicularia franconica</i>			X					
<i>Fronicularia nikitina</i>				X				
<i>Conorboides basilensis</i>				X				
<i>Textularia transversarii</i>				X				

Table 6.3: Foraminifera found in the Grand Banks wells, but absent from the Portuguese sections examined in this study.

SPECIES	WELLS							
	Hibernia I-46	Hibernia B-08	Hibernia K-18	Hibernia O-35	Hibernia P-15	Hibernia G-55	Hibernia J-34	Gabriel C-60
Neocythere sp.	X			X				
Quasihermanites implicatus	X							
Schuleridea lamplugh	X							
Schuleridea bilobata	X							
Cythereis senckenbergi	X							
Asciocythere circumdata	X							

Table 6.4: Ostracoda found in the Grand Banks wells, but absent from the Portuguese sections examined in this study.

Cretaceous Ostracodal faunas of the two areas are not so striking: only six species recognised in the Grand Banks wells are not seen in Portugal (Table 6.4).

Discussion:

Differences in the coeval microfossil assemblages of the Grand Banks and Portugal are surprising in view of the close proximity of the two areas at the time. Continental breakup north of the Newfoundland-Gibraltar Fracture Zone associated with the third phase of rifting (R3, Hiscott *et al.*, 1990), did not take place until just prior to the Early Aptian (magnetic anomaly MO, Mauffret and Montadert, 1987). It should be noted that the species dealt with by Stam (1986) are limited to those regarded as important from the point of view a quantitative paleoecological analysis of Portuguese sections, and many species were placed in generic groupings only. Stam (1986) did not provide a full inventory of all species recognised in Portugal or the Grand Banks. Consequently, it is difficult to draw conclusions from a comparison of Stam's (1986) study with the present study. I conclude that coeval microfossils of Portugal and the Grand Banks differ more in the Late Jurassic and Early Cretaceous than for the Middle to Late Jurassic. Exton and Gradstein's (1984) work on the Early Jurassic microfossil assemblages, in which three main assemblages are recognised in both Portugal and the Grand Banks, supports the idea of increasing dissimilarity between the coeval microfossil assemblages of Portugal and the Grand Banks through time.

One further consideration is that a number of species common to both study areas are observed only in samples from cored intervals in the Grand Banks. Unlike the somewhat random process through which sample cuttings are recovered, the sampled intervals from within the cores represent specific rock types, such as thin clay layers, which may not have yielded cuttings. Clearly, examination of cored intervals eliminates some of the sampling bias associated with rock types preferentially preserved as cutting samples; many of the species recognised in the cores may not have been apparent in cutting

samples.

Considering the differences in Foraminiferal content of the Late Jurassic to Early Cretaceous interval of the Grand Banks and Portugal in terms of species present only in the Grand Banks (Table 6.3), the Hibernia wells B-08, K-18, P-15 and O-35, and the Gabriel C-60 well stand out as having the greater differences. The species by which these wells differ are predominantly those of *Epistomina* and *Lenticulina* and to a lesser extent, *Conorboides* and *Trocholina*. The Hibernia G-55 and J-34 wells stand out through the complete lack of *Epistomina*, whereas Hibernia I-46 is marked by the presence of only one species of *Lenticulina* (*L.muensteri*), and only two species of *Epistomina*. The absence of *Epistomina* and *Lenticulina* from the Hibernia G-55 and J-34 wells may be stratigraphically controlled, since these wells bottom in the Aptian. Virtual absence of epistominids and lenticulinids from the Hibernia I-46 well may be due to paleoecological factors rather than sampling bias since all data are from analyses of conventional cores. The restriction of many Ostracodal species to the Hibernia I-46 well is not easily accounted for, but may be a preservational bias relate to the better sample preparation of the cored material as well as facies differences between the wells.

The differences in the microfossil content between the Grand Banks wells discussed in overview above, may be partly due to local differences in depositional environments, and partly due to different sampling procedures. Differences between the Grand Banks and Portuguese microfossil assemblages may be due partly to local paleoenvironment differences, although a wider biogeographic controls may have been in effect. Ellis (1984) demonstrated biogeographic 'provincialism' amongst the calcareous algae during the Late Jurassic and Early Cretaceous, and reported a paucity of species in the Canadian offshore compared to coeval algal faunas in Portugal. The effects of biogeographic provincialism amongst the calcareous algae might have affected the distribution of the 'larger' Foraminifera, based on the close association of the latter with algae in the Portuguese sections.

6.4: Grand Banks paleoenvironments and paleoecology.

The paleoecological, paleoenvironmental and biostratigraphic study of the microfossil assemblages in Portugal have important implications for the interpretation of depositional environments in the the Grand Banks. A disadvantage in working with well material is that the lateral extent of the facies cannot be seen. However, the use of cores precludes problems with caved material and allows sedimentologic information to be included, which, combined with our knowledge of the paleoecologic distribution of the microfossils in Portugal, enables far more accurate interpretations to be made than those based on cuttings alone. The cored wells that yielded rich microfossil assemblages are discussed below.

6.4.1: Hibernia I-46 well.

Upper Jurassic to Lower Cretaceous strata are present in the Hibernia I-46 well from approximately 1960 to 3132 m. The biostratigraphy and depositional environments determined for this well by the operating company (Mobil) are unavailable from the well history report housed with COGLA. A total of twenty-nine conventional cores were cut into the Hibernia I-46 well between 2198 and 2836 meters, and recovery was good at 70-100 % of the total cored thicknesses. No wellsite core analysis was undertaken. Samples taken from suitable lithologies within the cores (fine sandstones, siltstones and shales) were analysed for Foraminifera and Ostracoda , and the results are shown in Table 6.5.

Interpretation of some of the core samples based on data in Table 6.5 is difficult when samples contain few specimens, however, some intervals are rich in specimens. The assemblage in the lower part of the well, represented by core 29, contains rich *Trochammina depressa*, abundant *Ammobaculites subcretaceous* along with fairly common *Anchispirocyclina lusitanica*. A few specimens of *Lenticulina muensteri*, *Marssonella*

Oxycona and *Reophax* sp. are also seen, along with the Ostracoda *Cytherella pyriformis*. The sample is from a dark grey, slightly silty and locally micaceous 1.2m thick shale bed, underlain by a very fine-grained carbonaceous (plant debris) sandstone, and overlain by a dark grey carbonaceous siltstone. The *Trochammina* and *Ammobaculites* associations in this assemblage are similar to the lower marsh to estuarine agglutinated assemblages found in the Ericeira section of Portugal, with the exception that *Anchispirocyclus lusitanica* is present. The lithology and microfossils seen in this part of core 29 suggest this interval was deposited in a near-shore, lagoonal to estuarine environment.

Slightly higher in the well, core 22 (2587m) contains an assemblage dominated by *Epistomina ornata*. *Marssonella oxycona* is also common along with a few *Anchispirocyclus lusitanica*, rare *Lenticulina muensteri* and *Planularia* sp. The Ostracoda are diverse, and dominated by *Cytherella pyriformis*, abundant *Asciocythere* sp., a few specimens of *Schuleridea* sp., *Cytheropteron* sp. and rare *Paracypris*. The sample lithology is shale, slightly calcareous with carbonaceous and micaceous grains, from a 2m thick sequence of shale interbedded with thin (5cm) very fine sandstones. Immediately below this sequence is a 2m bed of carbonaceous siltstone, whereas above it is a very fine-grained carbonaceous sandstone. Although the Ostracoda assemblage contains species seen in many intervals interpreted as slightly brackish (polyhaline) to marine in the Portuguese sections, the Foraminiferal assemblage is different to any so far seen. The sedimentologic evidence is not particularly conclusive as to the depositional environment; the sandstones do not contain glauconite, seen in other intervals, nor do they have any woody fragments although they are carbonaceous. Stam (1986) determined that *Epistomina* had preference for water depths of 200-250 m, possibly deeper, which is within the general outer neritic range proposed for *Epistomina* by Ascoli (1976). Hart (1984) noted a preservational bias in favor of *Epistomina* in clay grade sediments. The genus *Marssonella* is reported to be common in inner to outer neritic (Ascoli, 1976). An outer neritic environment is plausible from the Foraminiferal evidence, although it implies that the

slightly brackish to marine Ostracoda assemblage characterized by *Cytherella*, *Cytheropteron*, *Paracypris* and *Schuleridea* inhabited outer neritic environments as well as the nearshore environments interpreted from the Portuguese sections.

Core 11 contains an interesting Foraminiferal assemblage in the 2410m interval. The simple calcareous Foraminifera *Spirillina* sp. dominates the assemblage along with *Reophax* spp. Specimens of *Ammobaculites*, including *A. reophacoides* and *A. agglutinans* make up the remainder of the assemblage, but no Ostracoda are seen. The sample, taken from the top of the core, is from a 4m bed of soft grey carbonaceous shale, which is immediately underlain by a very fine-grained sandstone. The genus *Spirillina* was not recognised in the Upper Jurassic - Lower Cretaceous sections examined in Portugal. In the mid to Late Jurassic sections studied by Stam (1986), however, *Spirillina* is well represented. Stam (1986) reported a negative correlation between *Spirillina* and agglutinated species, but they show strong association in the Hibernia I-46 well. Stam (1986) regarded the negative correlation between the spirillinids and the agglutinates to be depth related, and considered the agglutinates characteristic of deeper (outer neritic) environments, and the spirillinids to have preferred shallower (inner neritic, probably less than 50m) depths. The agglutinated species in this interval of the I-46 well differ from those examined by Stam (1986) which may explain the discrepancy. The depositional environment represented by this interval was probably inner neritic.

The samples taken from core 1 (2207, 2211 and 2213.7m intervals) are all characterized by the predominance of *Lenticulina muensteri*. *Lenticulina* is the only Foraminifera present at 2211m, whereas the higher and lower samples also contain *Ammobaculites* and rare *Planularia* and *Nodosaria* respectively. The Ostracoda *Cythereis senckenbergi* is also present (a few specimens) in these intervals. The highest sample also has rare *Schuleridea*, *Quasihermanites ?implicata* and *Asciocythere circumdata*. All sampled intervals in core 1 were taken from fine- to very fine-grained carbonaceous sandstone. Middle neritic (50 to 150m) water depth is inferred from the dominance of

Lenticulina plus the presence of other nodosariids, based on the results of Stam (1986). The sparse Ostracodal assemblages contain genera considered typical Early Cretaceous shelf indicators.

6.4.2: Hibernia B-08 well.

Upper Jurassic-Lower Cretaceous strata are located in the Hibernia B-08 well from approximately 2219 to 3404 m depth. Apart from the well history report Mobil filed with COGLA, only Williamson (1987) has dealt with the micropaleontology and general depositional environments of this well. Six conventional cores between 2658 and 3628 m showed good recovery. Biostratigraphy of the well, based on drill cutting samples, is shown in Table 6.6.

Samples taken from suitable lithologies within the conventional cores were analysed for Foraminifera and Ostracoda (Table 6.7). Several microfossil species are abundant at certain intervals. The sample recovered from core 4, at 3564 m depth, has a virtually monospecific assemblage of *Darwinula leguminella*. A few Foraminifera are present, belonging to *Trochammina* sp., and a simple tubular form, *?Dendrophrya* sp. The lithology of the sample is grey-brown silty carbonaceous shale, taken from a 2m thick bed that is overlain by 1.5 metre interval of grey carbonaceous siltstone with thin coal stringers and interbedded fine sandstones. The depositional environment for this interval appears to have been lacustrine, on the basis of the Ostracoda *Darwinula leguminella* and the association with coal stringers.

The assemblage seen at 3448m, within core 2, contains abundant *Ammobaculites subcretaceus*, *A. reophacoides* and *Trochammina* sp. *Ammobaculites obliquus* is also present along with traces of *Lenticulina* sp. The low diversity *Ammobaculites-Trochammina* assemblage and virtual absence of calcareous species indicates that this interval was deposited in a lower marsh to transitional estuarine environment, closely similar to those determined in the Ericeira sections of Portugal. The grey carbonaceous

HIGHEST OCCURRENCE (metres)	AGE
2165	Barremian
2225	
2285	
2345	
2375	
2435	Hauterivian
2465	
2525	Valanginian
2680	
2740	
2770	
3200	
3215	Berriasian
3230	
3570	
3660	
3760	Tithonian

Choffatella decipiens
Trocholina infragranulata
Caucasella hoterivica
Lenticulina heirmanni
Lenticulina crepidularis
Epistomina caracolla
Epistomina tenuicostata
Lenticulina nodosa
Epistomina hechti
Epistomina ornata
Conorboides hofkari
Lenticulina ouachensis
Everticyclammina virguliana
Marginulina sigali
Lenticulina guttata
Pseudocyclammina lituus
Paazowella tiefelli
Lenticulina tricarinella
Epistomina stelicostata
Ophthalmidium carinatum
Epistomina uhligi

Table 6.6: Biostratigraphy of cuttings from the Hibernia B-08 well.

Table 6.7: Analysis of cored intervals in the Hibernia B-08 well.

				DEPTH (M)
2662				Ammobaculites agglutinana
2669				Ammobaculites coprilithiformis
2675				Ammobaculites obliquus
3482				Ammobaculites reophacoides
3488				Ammobaculites subcretaceus
3564				Conorboides valendisensis
				Dentalina sp.
				Dendrophrya sp.
				Epistomina ornata
				Epistomina praeornata
				Glomospirella gaultina
				Haplophragmoides concavus
				Haplophragmium inconstans
				Lenticulina busnardoii
				Lenticulina muensteri
				Marssonella trochus
				Marssonella valendis
				Planularia crepidularis
				Reophax pilulifer
				Reophax sp.
				Saracenaria frankei
				Textularia chapmani
				Trochammina depressa
				Trochammina sp
				Vermeuilinoides subiliformis
				Darwinula leguminella

shale lithology of this interval supports this interpretation.

Slightly higher in core 2, the sample at 3482 m contains an assemblage similar to that seen four metres below. However, two additional species of *Ammobaculites* are seen, *A. agglutinans* and *A. coprolithiformis*, along with abundant *Reophax pilulifer*. The depositional environment of this interval of interbedded fine sandstone with silt laminae is interpreted to have been lower marsh to estuarine.

The 2675 m interval sampled in core 1 contains a relatively rich and diversified microfauna. *Epistomina praeornata* and *Marssonella trochus* dominate the assemblage, and many smaller and agglutinated calcareous benthic Foraminifera are also common, including *Planularia crepidularis*, *Conorboides valendisensis*, *Glomospirella gaultina*, *Haplophragmoides nonionoides* and *Ammobaculites subcretaceous*. Low numbers of other calcareous and agglutinated species are also seen, including *Sarencenaria*, *Lenticulina*, *Dentalina*, and *Reophax*. The lithology of this interval is grey shale. The depositional environment is interpreted as being probably outer neritic, based on the mixed *Epistomina* dominated fauna. A degree of similarity is seen between this interval and the 2587 m interval in the Hibernia I-46 well, however, Ostracoda are not seen in this part of the B-08 well.

The interval sampled at 2669m in core 1 is dominated by simple agglutinated species; *Ammobaculites* is represented by 5 species, of which *A. reophacoides* is most abundant. *Trochammina depressa* is also abundant along with *Reophax* sp and other less common agglutinated species. Calcareous species are represented by *Epistomina* ?*praeornata*, and rare *Lenticulina* and *Conorboides*. A shallow near-shore, estuarine to lagoonal environment is inferred from the general dominance of *Ammobaculites* and *Trochammina* along with common *Haplophragmoides concavus*. Although the *Epistomina* was associated with outer neritic water depths in Stam's (1985) work, epistominids are also common in shallower, even lagoonal, paleoenvironments (P. Sikkora, pers. comm., 1989).

The top sample in core 1, at 2662m, contains a sparse Foraminiferal assemblage of *Ammobaculites*, *Trochammina* and *Reophax*. The depositional environment of this fine-grained sandstone is difficult to determine from the sparse Foraminiferal assemblage. Absence of calcareous species may indicate restricted nearshore conditions, although the general rarity of the species present may simply reflect higher sedimentation rates.

In his quantitative Ranking and Scaling (RASC) biozonation of the late Jurassic and early Cretaceous intervals of the East Newfoundland Basin, Williamson (1987) determined the water depth characteristics of his Tithonian RASC biozone (3330 to 3700 m interval in well B-08) to be middle neritic (50-100 m). Detailed study of cores 2 and 4 in this interval indicates water depth was much shallower, and in fact there may have been emergence during this interval based on the assemblage of marsh Foraminifera in core 2. Review of the data in Table 6.6 (Mobil's ditch cutting biostratigraphy of B-08) shows the presence of only two species of *Epistomina* and one species of *Fronicularia* for the interval in question, and it is on the basis of these calcareous species that Williamson (1987) determined water depth to be middle neritic.

Williamson (1987) determined the depth characteristic of his Berriasian-Valanginian biozone (2650-3330m interval in Hibernia B-08) to be inner neritic (0-50m). The Foraminiferal assemblages observed in core 1 within this interval indicate water depths may have been far greater, possibly up to 250 m (outer neritic). Again, study of Mobil's data in Table 6.6 shows the presence of only a few species that Williamson (1987) determined as characteristic of inner neritic water depths.

Analysis of the cores in this well suggest abrupt changes in paleobathymetry, particularly for core 1, where a change from outer neritic to estuarine paleo-water depth is inferred over a 6 m interval.

6.4.3: Hibernia K-18 well.

Upper Jurassic and lower Cretaceous strata are located in the Hibernia K-18 well

between 2274 - 5039 m. The biostratigraphy and general depositional environment for this well are considered in regional context in Williamson (1987). Ten conventional cores were cut from this well, and recovery was good. Drill-cutting biostratigraphy is shown in Table 6.8.

Suitable rock types within the core intervals were analysed for microfossils, and the results are shown in Table 6.9. The interbedded shales and siltstones in core 8 yielded moderate numbers of *Trochammina* and frequent specimens of *Ammobaculites reophacoides*, *A. agglutinans*, *A. obliquus* and rare epistominids. The depositional environment is interpreted to be inner-neritic, probably lower marsh to estuarine.

Species of *Ammobaculites* are abundant in core 7 (shale to very fine sandstone) along with *Reophax* sp. *Ammobaculites reophacoides* and *A. agglutinans* are the dominant species of *Ammobaculites*, although *A. obliquus* is also common. *Trochammina* is represented by a few specimens only. The depositional environment is interpreted as estuarine, based on the dominance of *Ammobaculites*.

The sample at 3800m in core 3 (grey brown silty shale) is made up of low numbers of *Ammobaculites*, *Trochammina* and *Haplophragmoides concavus*. *Lenticulina* is also present, but is poorly preserved. The Ostracoda *Darwinula leguminella* is also present.

Although the microfossil assemblage is sparse, a nearshore environment, perhaps lagoonal, marsh or estuarine is tentatively suggested by the simple agglutinated Foraminifera and the freshwater Ostracoda *Darwinula*.

The assemblage seen in core 1 (interbedded siltstone and very fine sandstone) contains the calcareous forms *Lenticulina* (frequent), *Epistomina ornata* and *Planularia crepidularis* (rare), in addition to a few specimens of *Ammobaculites agglutinans* and *Reophax* sp. The Ostracoda *Schuleridea rhomboidalis* and *Protocythere hechti* are also present in the assemblage, interpreted to indicate more mid to outer neritic paleoenvironment.

Williamson's (1988) study suggests a middle neritic paleoenvironment for the

HIGHEST OCCURRENCE (metres)	AGE
2233 *	Barremian -----?
2360 *	
2450 *	
2510 *	
2540 *	
2570 *	
2600 *	
2690 *	
2905 *	
3090 *	
3630 *	Valanginian
3660 *	
3720 *	Berriasian
3880 *	
3910 *	Tithonian
4060 *	
	Kimmeridgian

Table 6.8: Biostratigraphy of cuttings from the Hibernia K-18 well.

3330-3700 m interval. Study of cores 3, 7 and 8 indicates that paleobathymetry may have been much less, possibly lagoonal, marsh or estuarine. The mid to inner neritic paleobathymetry suggested by Williamson's (1988) study for the 2265-2360 m interval supported by the evidence provided by core 1.

6.4.4: Hibernia G-55 well.

Lower Cretaceous strata are located in the Hibernia G-55 well between 2420 and 3422 m depth. The well was examined in a regional biostratigraphic context by Williamson (1987). Biostratigraphy of ditch cuttings is shown in Table 6.10a.

Three conventional cores were drilled from the 2443 to 3460 m interval with moderate recovery. Analysis of the assemblage in core 1 between 2455-7m depth (Table 6.10b), showed the presence of common *Trochammina depressa* plus a few specimens of *Haplophragmoides concavus* and *Reophax* sp. The sample from core 2 (3369-8m) contained a single specimen of *Haplophragmoides* only.

Interpretation based on core evidence for this well is tentative; the assemblage in core 1 is likely to be indicative of a nearshore (marsh) environment of deposition. This interpretation is in general agreement with Williamson (1987) who proposed an inner neritic depositional environment.

6.4.5: Gabriel C-60, Hibernia O-35 and Hibernia P-15 wells.

The biostratigraphy of these 3 wells, based on ditch cuttings is summarized in Tables 6.11, 6.12 and 6.13. The conventional cores recovered from those wells were either of unsuitable lithology for sampling (Hibernia O-35) or, when sampled, were barren (Hibernia P-15). The Gabriel C-60 core sample at 4440 m yielded sparse agglutinated Foraminifera including *Trochammina depressa*, *Ammobaculites reophacoides* and *A. agglutinans*. A shallow to marginal marine depositional environment is suggested, which is in accord with Ascoli's (1984) paleoenvironmental interpretation.

DEPTH (M)		AGE
1860	★ ★	Aptian
1980	★ ★	
2385	★	
2416	★ ★	
2420	★	Barremian
2870		

DEPTH (M)		PALEOENVIRONMENT
Core 1		
2445.7	■ ■ ■	?Estuarine/Marsh

(a)

(b)

Table 6.10: (a) Biostratigraphy of cuttings from the Hibernia G-55 well. (b) Analysis and interpretation of cored interval in the Hibernia G-55 well.

DEPTH (M)		AGE
3020		Aptian
3170	★ ★	
3710	★	
4580	★	Barremian
4670	★ ★ ★	
5000	★ ★	Hauterivian
		Valanginian

DEPTH (M)		PALEOENVIRONMENT
Core 8		
4440	■ ■ ■	Shallow-marginal marine
4447	■ ■ ■	

(a)

(b)

Table 6.11: (a) Biostratigraphy of cuttings from the Gabriel C-60 well. (b) Analysis and interpretation of cored interval in the Gabriel C-60 well.

DEPTH (M)	AGE
2320 *	Aptian
2500 *	
2620 *	
2680 *	
2750 *	
3107 *	
3170 *	
3730 *	
3800 *	
3910 *	
4245 *	
4275 *	
	Barrenian ?----- Hauterivian ?----- Valanginian Berriasian Tithonian Kimmeridgian

Table 6.12: Biostratigraphy of cuttings from the Hibernia O-35 well.

DEPTH (M)			
2460	★	Choffatella decipiens	Aptian
2570	★	Epistomina caracolla	
2610	★	Trocholina infragranulata	
2670	★	Epistomina tenuicostata	
2910	★	Conorboides hofkeri	
3000	★	Epistomina hechti	
3080	★	Pseudocyclammina lituus	
3090	★	Epistomina ornata	
3120	★	Everticyclammina virguliana	
3540	★	Marginulina sigali	
3600	★	Lenticulina saxonica saxonica	
3720	★	Conorboides valendisensis	
3805	★	Ammobaculites coprilitiformis	
		Lenticulina guttata	
		Epistomina omnireticulata	
		Epistomina stelligostata	
		Epistomina uhligi	
		Trocholina alpina	
		Lenticulina quenstedti	
		Paazowella fiefelli	
		Alveosepta jaccardi	
			Valanginian
			Berriasian
			Tithonian
			Kimmeridgian

Table 6.13: Biostratigraphy of cuttings from the Hibernia P-15 well.

6.4.6: Discussion.

The Grand Banks wells appear to have experienced broader fluctuations in water depth than the Portuguese sections. In general, the Portuguese strata were deposited in nearshore, inner neritic environments including bays, lagoons, estuaries and marshes. The fine-grained siliciclastic facies contain 'smaller' agglutinated Foraminiferal faunas and freshwater and lagoonal Ostracoda, whereas the carbonate facies contained 'larger' agglutinated Foraminifera and slightly brackish to normal marine Ostracoda. The strata in the Grand Banks were deposited in nearshore lagoonal, estuarine and marsh environments, as well as in middle to outer neritic environments. Inner neritic facies of the Grand Banks contain Foraminiferal and Ostracodal assemblages almost identical to those seen in the siliciclastic Portuguese strata, whereas the middle to outer neritic environments are characterized by abundant calcareous Foraminiferal species, typically the epistominids, nodosariids and lenticulinids.

As noted earlier, these apparent differences may reflect in part sampling procedures and biogeographic factors. Interpretations from core samples differed widely from those based on cuttings alone; in a number of wells, intervals formerly regarded as middle to outer neritic were shown to contain microfossil assemblages that are characteristic of nearshore, including estuarine and possibly marsh, paleoenvironments in Portugal.

Assemblages of *Epistomina* and *Lenticulina* in the Grand Banks wells are considered characteristic of outer neritic paleoenvironments with water depths in the region of 150-250m (Stam 1986). This being the case, it may be argued that the difference between the Grand Banks and Portuguese coeval Foraminiferal assemblages is due to bathymetric differences.

If so, it is surprising that the 'larger' Foraminifera (of presumed mid to inner neritic paleodepth) are scarce in the Grand Banks wells in view of the paleobathymetric fluctuations between nearshore and mid to outer neritic water depths inferred from the calcareous and 'smaller' agglutinated assemblages; one would expect to encounter 'larger'

Foraminifera in facies transitional to the inner neritic facies. The larger lituolid Foraminifera are more diverse, in terms of genera and species, in North Africa than in Portugal (Hottinger 1967), and more diverse in Portugal than in offshore Eastern Canada, possibly reflecting in part the biogeographic distribution of the calcareous algae, which favour a low latitude "Tethyan" paleoenvironments.

Changes from nearshore estuarine or marsh to outer neritic paleoenvironments appear to have been abrupt locally. It is difficult to determine how the Foraminiferal assemblages might have responded to such changes, although it was suggested in the discussion of the Cabo Espichel paleoecology and paleoenvironments that the larger Foraminifera may have flourished when nearshore sedimentation patterns were undisturbed.

6.5: Grand Banks microfossils: biostratigraphic implications.

6.5.1: Introduction and previous work.

The biostratigraphy of the Kimmeridgian - Tithonian interval of the Grand Banks is dealt with in Gradstein (1976), who recognised two larger Foraminiferal zones (*Alveosepta jaccardi* and *Anchispirocyclina lusitanica* zones) in 'very shallow water' facies, and a calcareous benthic Foraminiferal zone (*Epistomina mosquensis* zone) developed in 'shallow-deep' neritic facies (Figure 6.3). The Upper Jurassic and Lower Cretaceous zonal schemes of Ascoli (1981, 1989) were based partly on Gradstein's (1977) Upper Jurassic Foraminiferal zones, but were modified using additional species common to the Scotian Shelf wells. In addition to the agglutinated benthic Foraminiferal scheme covering the Kimmeridgian to Barremian, Ascoli (1981, 1989) used the Ostracoda and abundant calcareous (*Lenticulina* and *Epistomina*) Foraminiferal assemblages in an 'integrated' zonation (Figure 6.4), applicable from the Baltimore Canyon Trough, through the Scotian Shelf, and into the Grand Banks. Stam (1986) also utilized Gradstein's (1977)

AGE		GRAND BANKS FORAMINIFERAL BIOZONATION	
		NERITIC	
		SHALLOW-DEEP	VERY SHALLOW
LATE JURASSIC	TITHONIAN		<i>Anchispirocyclina lusitanica</i>
	KIMMERIDGIAN	<i>Epistomina mosquensis</i>	
	OXFORDIAN		<i>Alvosepta jaccardi</i>

Figure 6.3: Foraminiferal biozonation of the Grand Banks after Gradstein (1977).

AGE	CALCAREOUS BENTHIC FORAMINIFERA ZONES
VALANGINIAN-BERRIASIAN	<i>Lenticulina saxonica</i> - <i>L. busnardoii</i>
TITHONIAN	<i>Epistomina uhligi</i> - <i>E. stelicostata</i>
KIMMERIDGIAN	<i>Epistomina mosquensis</i> - <i>Planularia tricarlinella</i>

AGE	ARENACEOUS BENTHIC FORAMINIFERA ZONES
VALANGINIAN-BERRIASIAN	<i>Everticyclammina virguliana</i>
TITHONIAN	<i>Anchispirocyclina lusitanica</i> - <i>Ammobaculites coprilithiformis</i>
KIMMERIDGIAN	
OXFORDIAN	<i>Alveosepta jaccardi</i>

AGE	OSTRACOD ZONES
VALANGINIAN-BERRIASIAN	<i>Schuleridea</i> aff. <i>praethoerenensis</i> - <i>Asciocythere</i> sp.1
TITHONIAN	<i>Schuleridea</i> sp.1 - <i>Galliaecytheridea postrotunda</i> - <i>Hutsonia</i> gr. <i>collinsensis</i>
KIMMERIDGIAN	<i>Schuleridea triebeli</i> - <i>Cytherelloidea weberi</i> - <i>Eocytheropteron decoratum</i>

Figure 6.4 Ostracod, calcareous and arenaceous benthic foraminiferal biozonation of the Grand Banks, after Ascoli (1981, 1984).

Upper Jurassic Foraminiferal zonation, although he modified it slightly by using Ascoli's (1981) scheme for the Tithonian in the absence of larger arenaceous Foraminifera in the deeper water epistominid - dominated facies. More recently, Williamson (1987) published a quantitative Foraminiferal zonation for the Late Jurassic - Early Cretaceous of 13 Grand Banks (Jeanne d'Arc Basin) wells utilizing the Ranking and Scaling technique (Gradstein and Agterberg, 1986) and recognised eleven Kimmeridgian to Cenomanian zones.

The difficulty in assigning detailed chronostratigraphic ages to the Foraminiferal assemblages lies not only in the general absence of planktonic fossils from these horizons, but also in that there exist no Foraminiferal species of "worldwide" distribution that have their highest stratigraphic occurrence at or near the top of the Berriasian (Bartenstein 1979). Consequently, the oldest Foraminiferal zone for the Early Cretaceous of the Grand Banks is dated as "Berriasian to Valanginian" (Ascoli, 1976, 1981). Another problem lies in the recognition of the Jurassic-Cretaceous boundary. In the zonation schemes outlined earlier, the top of the Tithonian, and hence the Jurassic-Cretaceous boundary, has been extrapolated from the ranges of Foraminiferal (and Ostracodal) species reported from Europe. Although this seems a reasonable approach, the results achieved do not always agree with those obtained using palynological data (eg. Barss *et al.*, 1976). Chronostratigraphic re-evaluations discussed for a number of wells below, are based on Portuguese biostratigraphy, and sometimes agree more closely with palynological interpretations.

6.5.2: Bonniton H-32 well: calpionellid evidence for the age of *Anchispirocyclus lusitanica*:

The top of the Tithonian in the Grand Banks has been recognised in inner neritic facies by the occurrence of the larger Foraminifera *Anchispirocyclus lusitanica*, first observed by Gradstein (1976) at 7590' depth in the Egret K-36 well. The Tithonian age assigned to the *Anchispirocyclus lusitanica* zone by Gradstein (1976) was based on a

Jurassic-Cretaceous boundary Ostracoda marker, *Dictyocythere*, at 7200', and a lower, typically "Portlandian-Purbeckian" Ostracoda assemblage at 9000-9500'. The range of *Anchispirocyclus lusitanica* in Europe has been a matter of some debate (see discussion in Rey 1979). According to Maync (1959b) and Van Hinte (1976) *Anchispirocyclus lusitanica* ranged into the Early Valanginian, whereas Rey (1979) reported the species from the Berriasian. Hottinger (1967), however, did not find *Anchispirocyclus lusitanica* in strata younger than Tithonian in the Jura and North Africa. In Grand Banks outer neritic facies, the top of the Tithonian is based (Ascoli, 1984) on the top of the European range of the Foraminifera *Epistomina stelicostata*.

Both *Anchispirocyclus lusitanica* and *Epistomina stelicostata* were subsequently recognised in the Bonniton H-32 well in the Grand Banks, where they were observed in calpionellid bearing limestones dated by as Tithonian (Jansa *et al.* 1980). The Late Tithonian age of *Anchispirocyclus lusitanica* (Jansa *et al.* 1980; subsequently in Ascoli *et al.* 1984), was based co-occurrence of the latter species with the calpionellid *Crassicollaria parvula* at 2314m depth in the Bonniton H-32 well. *Crassicollaria parvula* is characteristic of Calpionellid Zone B, dated as Latest Tithonian to Berriasian in the Mediterranean realm. Also occurring within calpionellid zone B in Europe are the species *Tintinnopsella carpathica* and *Calpionella alpina*. The latter is reported to be larger and of spherical morphology at the top of the Tithonian (Remane 1971), and on that basis, the calpionellid B zone is divided. Jansa *et al.* (1980) reported that the species *Calpionella alpina* occurring between 2326 and 2329 m (7630-7640') in Bonniton H-32 was represented by a large spherical form characteristic of the lower part of Calpionellid Zone B, and on that basis they dated *Anchispirocyclus lusitanica*, found a few metres higher at 2314 m, as latest Tithonian.

In the discussion of the calpionellid faunas, however, Jansa *et al.* (1980) commented that the calpionellid limestones at 2314 m were rare, may not have been in-situ, and could not be precisely dated. On evidence presented in Jansa *et al.* (1980) it is difficult

to see how *Anchispirocyclus lusitanica* could be dated as latest Tithonian, since the calpionellid with which it was found, *Crassicollaria parvula*, occurs throughout calpionellid Zone B. Examination and comparison of plate 5 figs. 1-3 in Jansa *et al.* (1980) shows that specimens of *Calpionella alpina* between 2326 and 2329 m depth are identical in size and form to those seen at higher levels, implying that this interval lies within the upper (Berriasian) part of Calpionellid Zone B. On these grounds the calpionellid limestone of the 2314 to 2332 m interval should be regarded as Berriasian in age, and the Tithonian-Berriasian boundary should lie below this, between 2332 and 2418 m (7650-7930'). The occurrence of *Anchispirocyclus lusitanica* at 2314 m indicates a Berriasian age for the species.

The position of the Jurassic-Cretaceous boundary in Bonniton H-32, and the age of *Anchispirocyclus lusitanica* in this well according to Jansa *et al.* (1989) are by no means supported by later work, as Figure 6.5 demonstrates. Ascoli *et al.* (1984) placed the base of their Berriasian-Valanginian *Lenticulina busnardoii-L. saxonica bifurcilla* assemblage at 7580' in Bonniton H-32, eighty feet below the postulated Tithonian-Berriasian boundary in Jansa *et al.* (1980). Ascoli *et al.* (1984) also stated (p.43) that: "...the Late Jurassic Foraminiferal and Ostracodal species whose highest stratigraphic appearances are most useful for correlation, consistently disappear 100 to 150 feet below the Tithonian stage as defined by Calpionellids", yet placed the top of their *Epistomina stelicostata-E. uhligi* zone only 90' below the postulated Tithonian-Berriasian boundary. Ascoli *et al.* (1984) did not consider *Anchispirocyclus lusitanica* in their arguments, as it would have meant that the species occurred at the base of their Berriasian-Valanginian Foraminiferal zone. Ascoli (1989) placed the base of the Berriasian, according to Foraminifera, at 7399' and placed the upper boundary of his Tithonian Foraminiferal zones at 7500', although he offered no explanation for the change. The palynologic zonation in this well, dealt with in Barss *et al.* (1979), indicates that the Tithonian-Berriasian boundary is significantly lower (7850') than that determined by calpionellids or

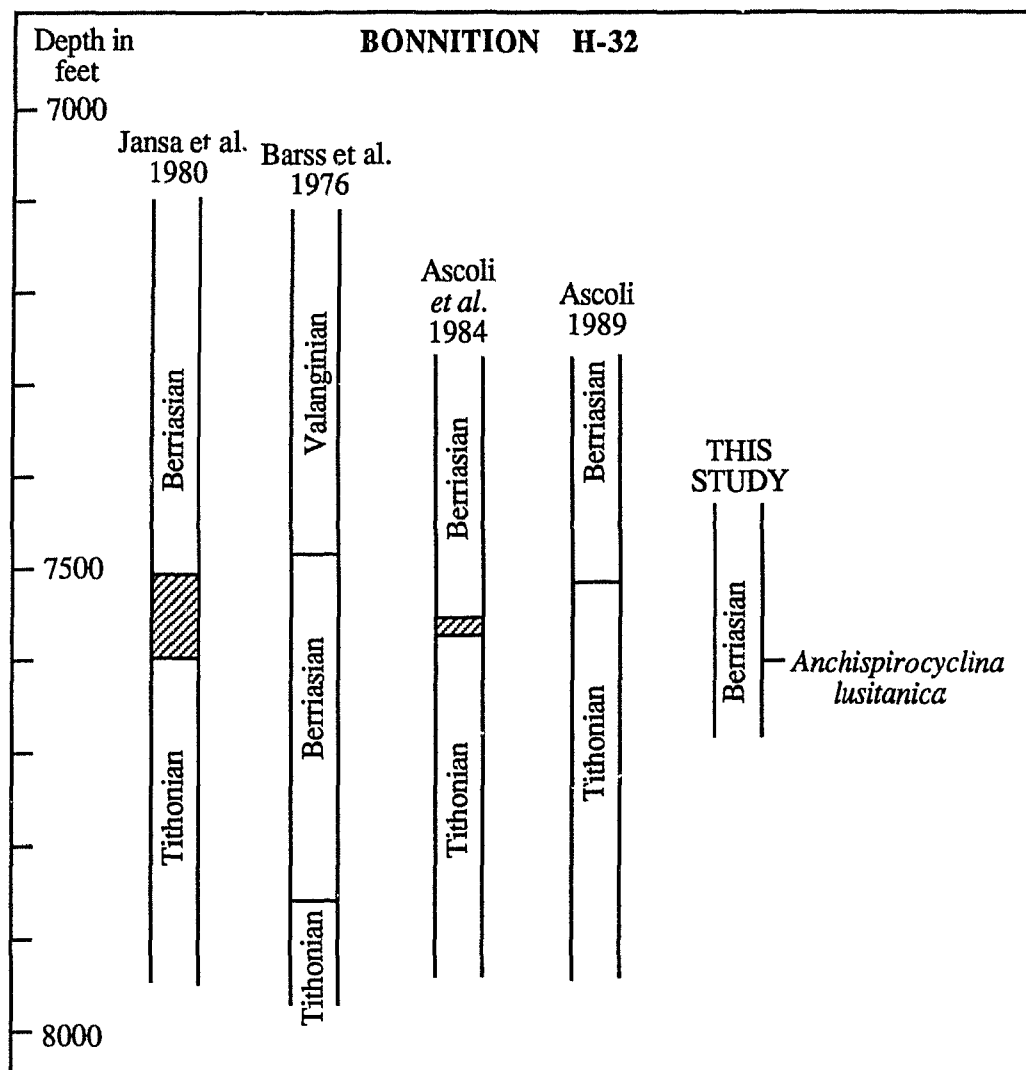


Figure 6.5: Stratigraphic interpretations of the Bonnition H-32 well.

existing Foraminiferal zonations, which accords with the 7650-7930' interval proposed in this study. A Berriasian age for *Anchispirocyclus lusitanica* in the Grand Banks, as determined by the youngest occurrence of this species in the Cabo Espichel and Ericeira sections, accords with the age-depth intervals determined by Barss *et al.* 1976.

6.5.3: Hibernia I-46 well and the co-occurrence of *Anchispirocyclus lusitanica* and *Ammobaculites subcretaceus*:

Evidence of a Berriasian age for the top of *Anchispirocyclus lusitanica* in Portugal was presented in chapter 2. It does not necessarily follow that the species should have the same range in offshore eastern Canada, although re-evaluation of the Bonniton H-32 well above suggests it may have. This possibility is examined further in the Hibernia I-46 core samples.

Study of the Hibernia I-46 core (Table 6.5), revealed the presence of a number of specimens of larger Foraminifera at depths of 2552 m and 2587 m and co-occurrence of these specimens with rich *Ammobaculites* at 2830 m. Thin-sectioning of the larger Foraminiferal tests showed them to be of *Anchispirocyclus lusitanica* (see Plate 19, Figures 2-3), and *Pseudocyclamina muluchensis*, whereas glycerine immersion of the *Ammobaculites* tests (Plate 19, Figures 6-8) showed they closely resembled, even in the 'inverted' mode of coiling, those described from the Ericeira section of Portugal as *A. subcretaceus*. On the basis of *Anchispirocyclus lusitanica* and *Ammobaculites subcretaceus*, the 2552 - 2830 m interval in Hibernia I-46 may be dated as Late Berriasian. No industrial age determinations for this well were available, however Ascoli (1989) dated the same interval as Berriasian to Early Valanginian (Figure 6.6). It is interesting that Ascoli (1989) did not consider the agglutinated Foraminifera in the dating of this well, but used Ostracoda and calcareous Foraminifera instead.

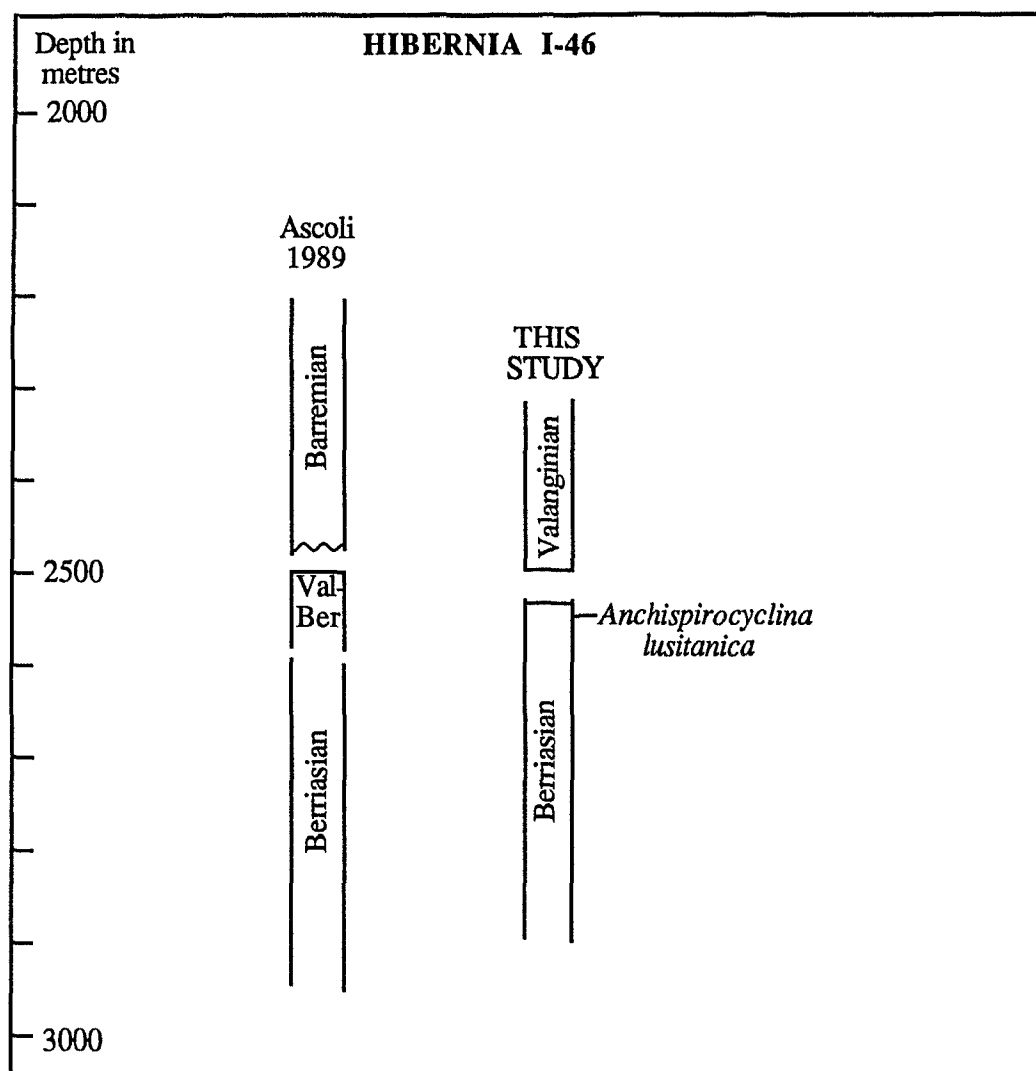


Figure 6.6: Stratigraphic interpretations of the Hibernia I-46 well.

6.5.4: Stratigraphic re-evaluation of Hibernia B-08 well.

The late Berriasian age proposed for *Anchispirocyclus lusitanica* and *Ammobaculites subcretaceus* has important stratigraphic implications for other Grand Banks wells, as illustrated in the stratigraphic re-evaluation of the Hibernia B-08 well. Biostratigraphic data based on cuttings for the Hibernia B-08 well are shown in Table 6.6. Stratigraphic interpretations according to Ascoli (1989), Williamson (1987) and this study are summarised in Figure 6.7.

In the Hibernia B-08 well, Ascoli (1989) assigned the 2165-2355 m interval to the Hauterivian, the 2375-2555 m interval to the Valanginian, and the 2740-3185 m interval to the Berriasian (Figure 6.7). It is unclear, however, what Ascoli (1989) based these assignments on since all Foraminifera seen above 2740 m are dated as Hauterivian or younger in Ascoli's (1989) zonation scheme. Details of any core analysis are not given in Ascoli (1989). The 3215- 3360 m interval is dated as Tithonian by Ascoli (1989) which accords with ranges of all but one Foraminiferal species in Ascoli's (1989) Tithonian zonation. The latter species is *Paazowella fiefelli*, which Ascoli (1989) considered to be Valanginian in age. Possibly Ascoli (1989) regarded *P. fiefelli* at 3215 m as caved, otherwise his Berriasian and Valanginian depth assignments do not agree with his zonation scheme.

Williamson (1987) recognised the difficulty of "pre-conceived" stratigraphy in many of the wells, and used the quantitative Ranking and Scaling method of Gradstein and Agterberg (1982) in an attempt to resolve it. Williamson's (1987) stratigraphic interpretation for Hibernia B-08 (Figure 6.7) placed the Hauterivian-Valanginian boundary at 2650 m depth, 295 m below Ascoli (1989), and the Berriasian-Tithonian boundary at 3330 m, 145 m below Ascoli (1989). Williamson's (1987) scheme did not distinguish between the Valanginian and the Berriasian, due to the apparent lack of faunal extinctions at the top of the Berriasian.

Examination of core samples in this study (Table 6.7) gave interesting results. Core

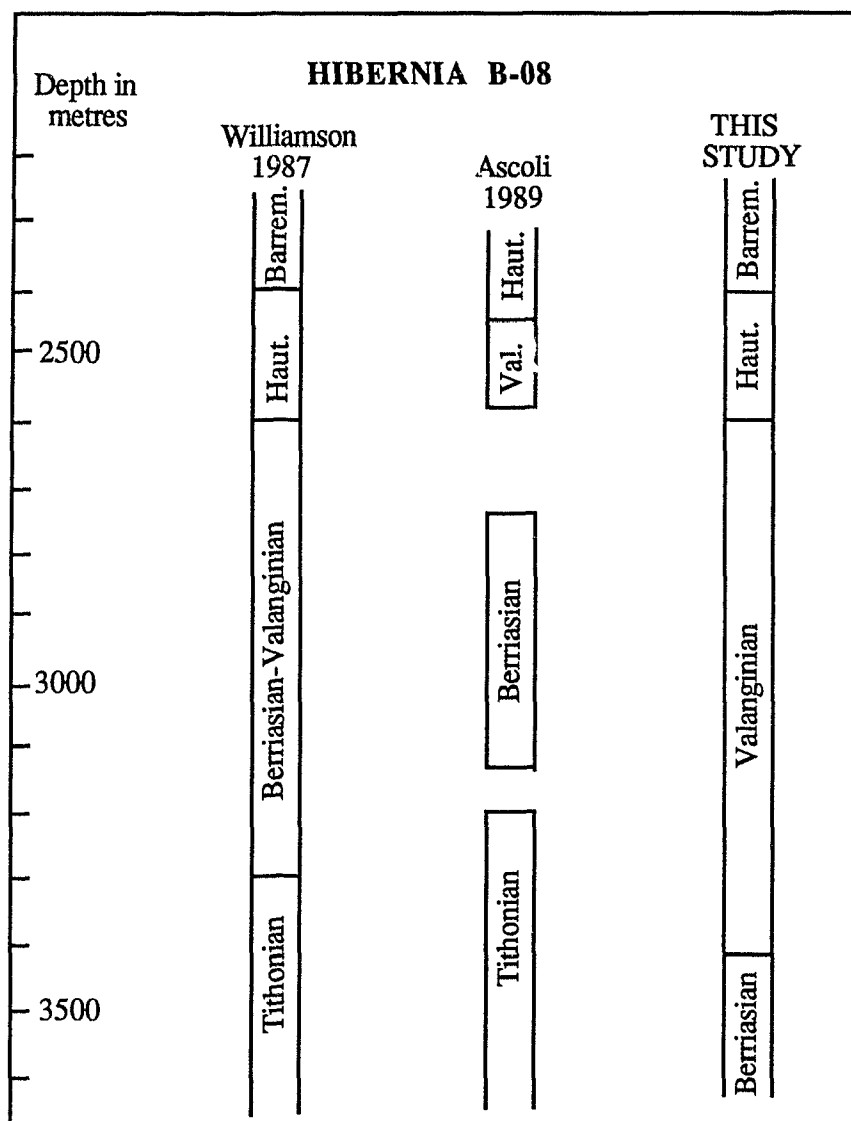


Figure 6.7: Stratigraphic interpretations of the Hibernia B-08 well.

1 samples (2662-2675 m) contain *Ammobaculites subcretaceus*, *A. obliquus* and *Trochammina depressa*, assigned to the Early Hauterivian in Portugal. Other species in Core 1 are *Planularia crepidularis*, *Conorboides hofkeri* and *Epistomina ornata*, typical of the Valanginian-Hauterivian in the northern hemisphere (Bartenstein 1977). The latter supports the Early Hauterivian age suggested by the agglutinated species in the core. Species from core 2 (3482-3488 m) include *A. subcretaceus*, *A. obliquus* and *Trochammina* sp. Examination of *A. subcretaceus* under glycerine immersion (plate 19, figures 5-6) reveals that they are very similar to those from the Hibernia I-46 well and the Ericeira section of Portugal in that they possess an 'inverted' coil. It is not known if the 'inverted' coil in these specimens of *A. subcretaceus* is stratigraphically significant, however assuming it is, a late Berriasian age is suggested, based on the occurrence of this form in Portugal. Occurrence of *Paalzowella feifeli* (Valanginian, according to Ascoli 1989) above core 2 in cuttings at 3215 m supports a late Berriasian age for core 2, and lowers the depth of Berriasian strata considerably with respect to Ascoli's (1989) interpretation.

6.5.5: Stratigraphic re-evaluation of the Hibernia K-18 well.

An alternative stratigraphic interpretation of Hibernia K-18 is proposed on the basis of cored intervals (Figure 6.8), and compared to Ascoli (1989) and Williamson (1987). Core 1 (2286-2300 m) contains the Foraminifera *Epistomina ornata*, *E. caracolla*, *Planularia crepidularis*, and the Ostracoda *Protocythere hechti*, which indicate a Hauterivian to Early Barremian age. *Choffatella decipiens* in cuttings at 2300 m and *Epistomina hechti* in cuttings at 2360 m may be caved, but otherwise indicate an Late Hauterivian to Early Barremian age. This age agrees with Ascoli's (1989) interpretation.

Core 3 (3798-3806 m) contains only *Ammobaculites subcretaceus*, suggesting a Berriasian to Valanginian age. Cores 7 and 8 (3857-3867 m) are also assigned to the Berriasian - Valanginian, based on *Ammobaculites obliquus*. Valanginian is also indicated

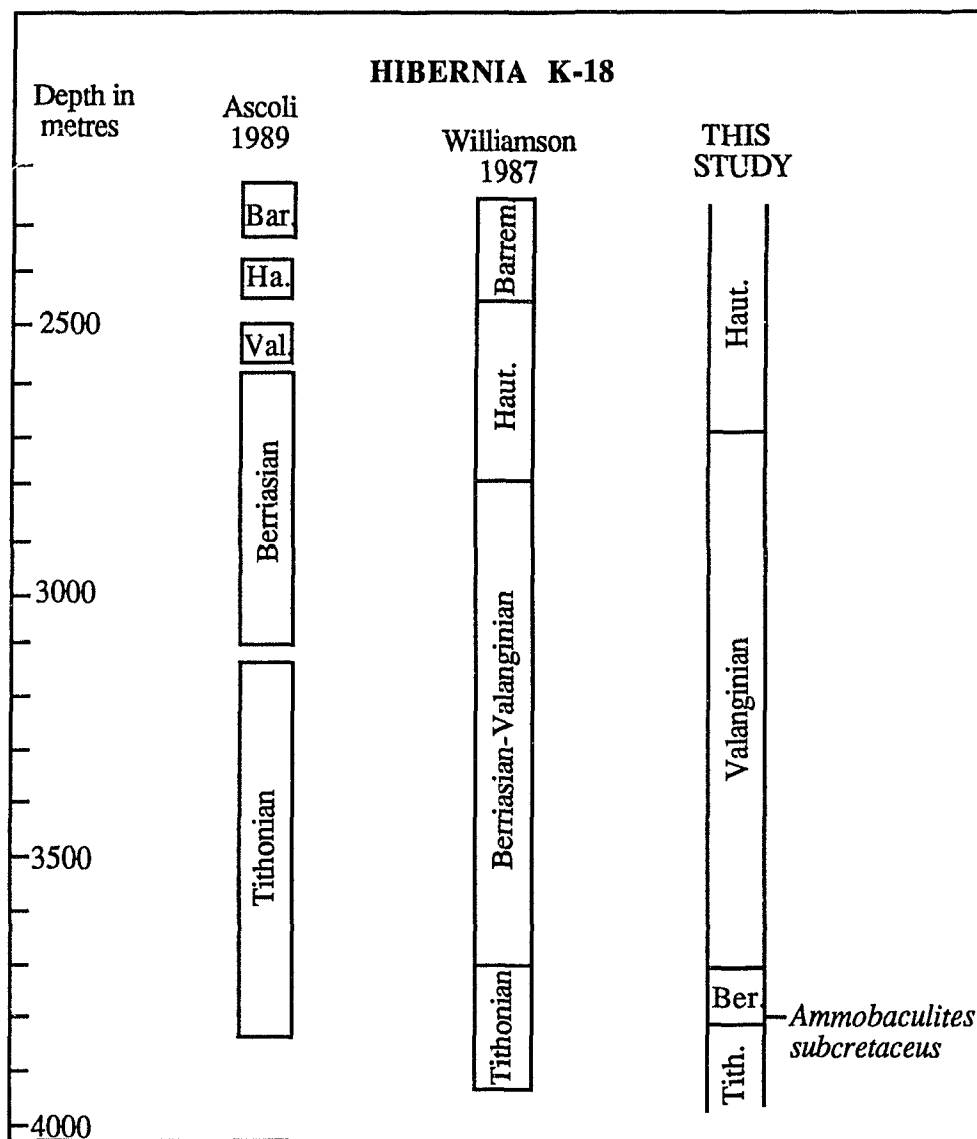


Figure 6.8: Stratigraphic interpretations of the Hibernia K-18 well.

in cuttings from a higher level (2690 m) by *Conorboides hofkeri*. Occurrence of *Epistomina stellicostata* in cuttings at 3660 m, above *Ammobaculites subcretaceus*, suggests this species range may extend to the Berriasian, perhaps even the Valanginian, in Grand Banks wells. *Epistomina uhligi*, in cuttings at 3880 m, is regarded as a Tithonian marker (Ascoli 1984; Stam 1986), whereas *Epistomina mosquensis* at 3910 m is evidence for a Kimmeridgian age (Stam 1986).

Stratigraphic interpretations of the Hibernia K-18 well in this study well differ markedly from Ascoli (1989) with respect to the distribution of Tithonian, Berriasian and Valanginian strata, but are fairly similar to those of Williamson (1987).

6.5.6: Stratigraphic re-evaluation of Hibernia O-35 well.

Stratigraphic interpretation of Hibernia O-35 is difficult since core samples were barren. In cuttings, caving is a likely problem, however an alternative interpretation (Figure 6.9) is made on the basis of the revised ranges of species discussed so far, and compared with interpretations of Ascoli (1989) and Williamson (1987). *Choffatella decipiens* at 2320 m indicates an Late Hauterivian- Early Barremian age which is in accord with Ascoli (1989), although Williamson (1987) extended the Barremian down to below 2420 m. The 2320-3170 m interval is hard to assign to stages. Ascoli (1989) did not recognise Hauterivian strata in this interval, and placed an unconformity at the base of the Barremian. Williamson (1987), in contrast, recognised Hauterivian strata down to 3000 m depth. Ascoli (1989) dated the 2750 - 3730 m interval as Berriasian, whereas Williamson (1987) recognised Berriasian strata in the 3000-3790 m interval. *Anchispirocyclina lusitanica* at 3730 m and *Epistomina stellicostata* at 3800 m indicates these depths may be assigned to the Tithonian to Berriasian. *Discorbis scituliformis* at 3910 m, however, suggests Berriasian strata at this depth, based on the Berriasian age of this species in Portugal. *Epistomina uhligi* at 4245 m may be an indication of Tithonian strata whereas *Epistomina mosquensis* at 4275 m, suggests a Kimmeridgian age. Ascoli (1989) recognised Tithonian

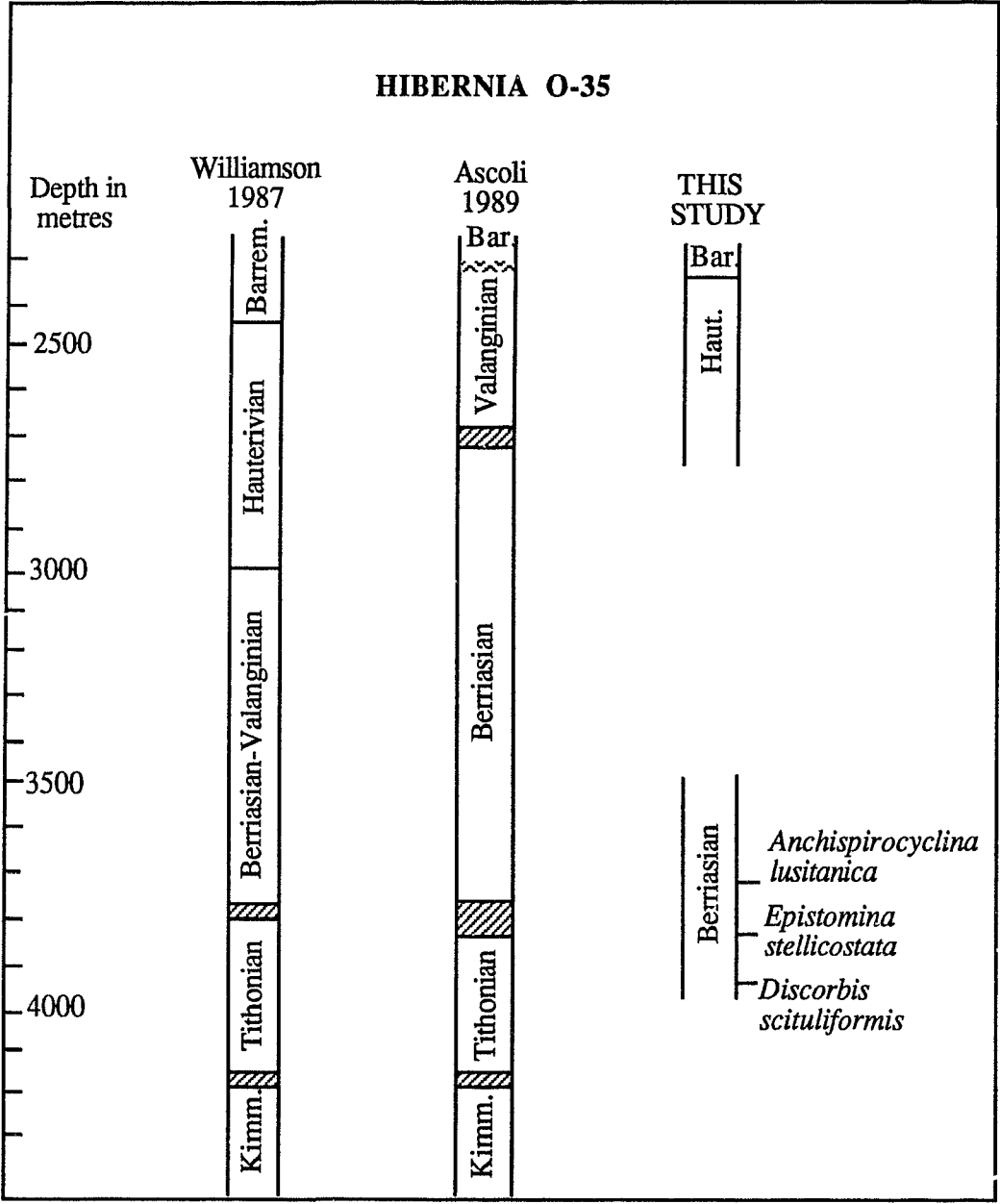


Figure 6.9: Stratigraphic interpretations of the Hibernia O-35 well.

strata between 3880-4225 m, whereas Williamson (1987) assigned the 3790-4250 m interval to the Tithonian.

6.5.7: Proposed new Foraminiferal biozonation for the Grand Banks.

On the basis of the new stratigraphic interpretations made for selected Grand Banks wells, a new biozonation is proposed (Figure 6.10). Ascoli's (1989) multiple biozonation for the North American Atlantic margin appears applicable to the George's Bank and Scotian Shelf basins. Application of Ascoli's (1989) scheme to the Grand Banks basins, however, is not so successful because many of the Foraminifera and Ostracoda used in the scheme are not found in the Grand Banks wells and because the age interpretations of some zones do not agree with evidence provided in this study, or with Williamson (1987). Several of Ascoli's (1989) zones are based on species recognized only in the Scotian Shelf, for example the Berriasian calcareous benthic zones and the Valanginian Ostracoda zone, and the age of such zones have not been established outside of eastern Canada.

The new zonation proposed here (Figure 6.10) utilizes several species that were used in Ascoli (1989), however, the ages in many cases differ. The *Alveosepta jaccardi* and *Epistomina mosquensis* zones are unaltered from the definitions given in Gradstein (1976). The definitions for the other zones are given below.

Epistomina uhligi Interval Zone

Definition: The top is based on the highest stratigraphic occurrence of *Epistomina uhligi* Mjatliuk. *Epistomina stellicostata* Bielecka and Pozaryski has its range through this zone. The lower limit of this zone coincides with the top of the underlying *Epistomina mosquensis* zone.

This zone corresponds in part to Ascoli's (1984) *Epistomina stellicostata* - *E. uhligi* zone, although in the wells examined in this study, *E. stellicostata* is found higher than *E. uhligi*. The Tithonian age of this zone is based on the highest stratigraphic range of the

nominate species in Europe (Espitalie and Sigal, 1963; Bielecka, 1975). The top of this zone is found in the Bonniton H-32 well at 2515m, Hibernia N-08 at 3660m, Hibernia K-18 at 3880m, Hibernia O-35 at 4245m and Hibernia P-15 at 3600m.

Anchispirocyclus lusitanica Interval Zone

This top of this zone is based on the highest stratigraphic occurrence of *Anchispirocyclus lusitanica* (Egger). The base is defined by the top of the underlying *Epistomina uhligi* zone. *Epistomina stelicostata* Bielecka and Pozaryski and *Discorbis scituliformis* (Seibold and Seibold) also have their highest occurrences within this zone. The top of the zone contains large coiled (microspheric) morphotypes of *Ammobaculites subcretaceus* that are seen in littoral facies.

This zone is dated as Berriasian, based on the age determined for *Anchispirocyclus lusitanica* and *Ammobaculites subcretaceus* in the Portuguese sections. Calpionellid and palynologic evidence indicate a similar age for species found in this zone in the Grand Banks. This zone correlates with the *Anchispirocyclus lusitanica* zone in Portugal and is found in Hibernia wells B-08 (3660-3880m), O-35 (3730-4245m), P-15 (3540-3600m), I-46 (2552-2830m) and Bonniton H-32 (2314-2347m).

Ammobaculites subcretaceus B-form Range Subzone

This subzone is defined by the range of the large coiled microspheric (B-form) specimens of *Ammobaculites subcretaceus* at the top of the *Anchispirocyclus lusitanica* zone.

The age of this subzone has been determined to be latest Barriasian based on the occurrence of specimens of *Ammobaculites subcretaceus* that display 'inverted' coiling in Portugal. Large coiled specimens of *Ammobaculites subcretaceus* have been reported from higher levels in Europe (eg Magniez-Jannin 1975), although the inverted mode of coiling seen in specimens from the Grand Banks and Portugal appears to be unique to

specimens from this stratigraphic level, found in Hibernia B-08 Core 2 (3482-3488m) and Hibernia I-46 Core 29 (2830m).

Conorboides hofkeri Interval Zone

The top of this zone is based on the highest stratigraphic occurrence of *Conorboides hofkeri* (Bartenstein and Brand 1951). The base is defined by the top of the underlying zone. *Conorboides valendisensis* (Bartenstein and Brand 1951) also has its highest occurrence at the top of this zone. Other species occurring in this zone include *Lenticulina busnardoii*, *L. eichenbergi*, *L. guttata*, *Planularia crepidularis*, *Trocholina infragranulata* and *Epistomina ornata*.

This zone is assigned to the Valanginian, based on the highest stratigraphic occurrence of the nominate species in Europe (Bartenstein and Brand 1951; Bartenstein 1977). This zone correlates with the *Ammobaculites* sp.A and *Haplophragmium inconstans* zones in Portugal, and is found at the following well depths: Bonniton H-32, 2118-2314m; Hibernia B-08, 2680-3460m; Hibernia K-18, 2690-3660m; Hibernia P-15, 2610-3540m.

Lenticulina saxonica Interval Zone

The top of this zone is defined by the highest stratigraphic occurrence of *Lenticulina saxonica* Bartenstein and Brand. *Epistomina ornata* (Roemer) also has its highest occurrence at the top of this zone. The base of the zone coincides with the top of the underlying *Conorboides hofkeri* zone.

This zone is tentatively assigned to the Hauterivian, although this is difficult to determine from the ranges of the nominate species in Europe. Bartenstein (1977) gives the upper range of *Epistomina ornata* as Early Barremian in Europe, although in the Grand Banks, this species is consistently found below *Epistomina hechti* (considered by Bartenstein (1977) to range through the Barremian). *Epistomina ornata* is also consistently

found below *Planularia crepidularis* in the wells examined. The latter has its upper range in the Early Barremian of Europe (Bartenstein, 1977).

The zone is found at the following well depths: Bonniton H-32, 1874-2118m; Hibernia B-08, 2435-2680m; Hibernia K018, 2600-2690m; Hibernia P-15, 2670-3000m; Hibernia I-46, 2200m-2257m.

Choffatella decipiens Interval Zone

The top is defined by the highest stratigraphic occurrence of *Choffatella decipiens*. The base is defined by the top of the underlying *Lenticulina saxonica* zone. *Epistomina hechti* also has its highest stratigraphic occurrence near the top of this zone.

The age of this zone, based on the highest stratigraphic occurrence of *Choffatella decipiens* Schlumberger in Europe according to van Hinte (1976) is Barremian to Early Aptian. *Epistomina hechti* is considered restricted to the Barremian (Bartenstein 1977). This zone correlates with the *Choffatella decipiens* zone in Portugal.

This zone is found in the Hibernia B-08 well at 2225-2435m, Hibernia K-18 well between 2330-2600m, Hibernia O-35 well between 2320-2750m and the Hibernia P-15 well between 2460-2670m.

6.5.8: Stratigraphic correlation.

The biostratigraphic zonation developed for the Grand Banks (Figure 6.10) permits stratigraphic correlation between the Grand Banks wells and outcrop sections in Portugal. Correlation of Grand Banks and Lusitanian Basin Foraminiferal zones, well to well correlation, and correlation with Lusitanian Basin sections is shown in Figure 6.11.

Stratigraphic boundaries in wells are based on highest occurrences because of the problem of caving. Fortunately, zonal species used in this study displayed little 'cross-over' of their highest occurrences between adjacent wells, although as Williamson (1987) pointed out, this may be a problem when the ranges of all species are considered.

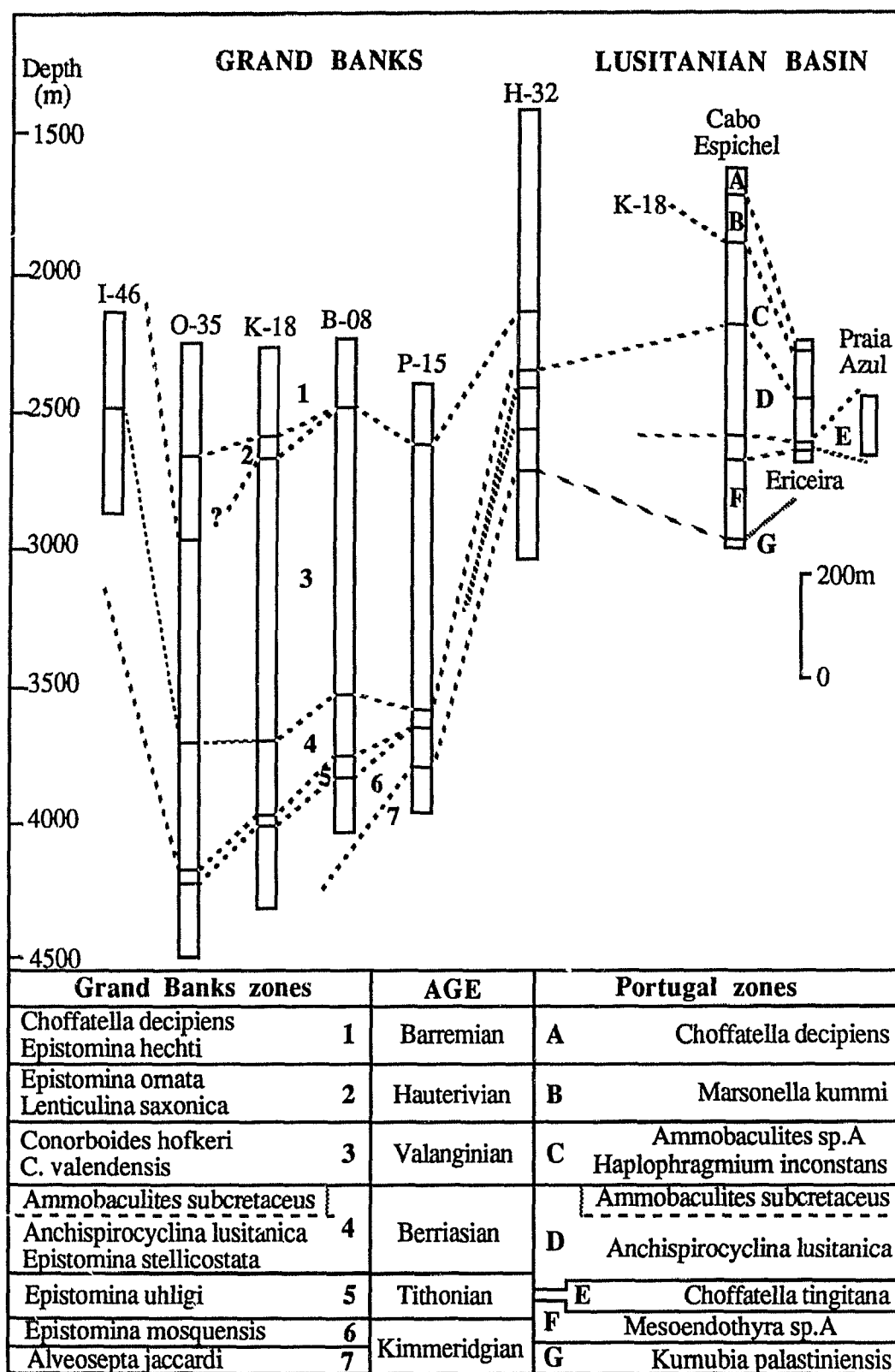


Figure 6.11: Correlation between Grand Banks wells and outcrop sections in the Lusitanian Basin.

CHAPTER 7

REGIONAL SYNTHESIS AND CONCLUSIONS

7.1: Introduction:

The research goals of this study have been to understand the paleoecology of the Ostracoda and Foraminifera, and the use of these microfossils in paleoenvironmental interpretations. In view of the geological setting of the study areas as conjugate North Atlantic basins, it is important to consider the development and distribution of the Late Jurassic-Early Cretaceous biofacies in a regional context.

Of interest in this respect is the notion of coeval trends of transgression and regression on independent plate margins, and the relationships, if any, of these trends to the eustatic sea level changes predicted by the so-called "Exxon curve" of Vail *et al.* (1977, 1984) and Haq *et al.* (1987). The principal difficulty for geologists dealing with sequence stratigraphy and the "Exxon curve" is the absence of detailed and accurate biostratigraphic data, necessary to establish synchronicity between apparent cycles of sea-level change in different regions. If coeval changes in sea-level can be established on independent plate margins, then it is likely that these can be related to global eustatic events (Hallam, 1984). Obscuring the sea-level 'signal' are the effects of local or regional tectonics. Clearly, some distinction has to be made between eustatic and tectonic events. Geohistory analysis offers a method of determining the tectonic component in basin evolution, through comparing trends in apparent basement subsidence rates (Hiscott *et al.* 1990a). It is appropriate at this point to briefly review the work of Hiscott *et al.* (1990a) as a starting point for further discussion.

7.2: Comparative stratigraphic and subsidence histories of the Mesozoic syn-rift basins of the North Atlantic: a review.

7.2.1: Background.

Hiscott *et al.* (1990a) compared Upper Jurassic to Lower Cretaceous stratigraphic sequences in the main Mesozoic rift basins of the North Atlantic, in an attempt to demonstrate the links between the tectonic events which caused the rifting, and the stratigraphic successions seen in the basins. Table 7.1 summarizes the main stratigraphic elements Hiscott *et al.* (1990a) recognised in the Mesozoic rift basins of the North Atlantic. The location map in the introduction of the thesis (Figure 1.1) shows the position of the basins.

Using outcrop, seismic and well data for the Mesozoic rift basins, Hiscott *et al.* (1990a) determined rates of apparent basement subsidence (RABS) for each of the basins, through decompaction and backstripping techniques. The latter methods are used in the computer programs DEPOR and BURSUB developed by Stam *et al.* (1987). The DEPOR and BURSUB programs calculate RABS for selected time intervals using depth and porosity curves for major rock types, with estimates of water depth changes from litho- and bio-facies and long-term eustatic sea level changes. The RABS calculated for the Lusitanian and Jeanne d'Arc basins are shown in Figure 7.1.

Hiscott *et al.* (1990a) reviewed current ideas on continental breakup and formation of new oceans through lithospheric stretching over a period of 20-50 m.y., and, based on published tectonic subsidence curves for several of the North Atlantic basins, illustrated that the extensional stresses that formed the North Atlantic rift basins were episodic in nature and occurred in three phases. Phase 1 occurred in the Late Triassic and resulted in thick deposition of continental siliciclastics and marine evaporites. This extensional phase was followed by thermal subsidence in the Early-Mid Jurassic as the crust cooled in the North Atlantic, whereas continued extension in the Central Atlantic during the Late

Description	Age	Basins							
		Jeanne d'Arc	Lusitanian	Cantabrian	Soria/Cameros	Asturias	Aquitaine	Celtic Sea	Fastnet
Condensed markers	Barremian	×	×				×		
Fining upward, transgression	Valanginian-Hauterivian	×	×	×			×	×	×
Unconformity beneath sandstone	latest Berriasian-Valanginian		×	×	×		×	×	×
Regressive sandstones, delta	early Berriasian	×	×	×	×		×	×	
Transgressive-regressive cycles	Tithonian	×	×	×		×			
Backfills of paleovalleys	Kimmeridgian	×	?	×	×	×			
Deep basins with siliciclastic influx	early Kimmeridgian		×						
Hiatus and restricted brackish or hypersaline basins	early Oxfordian	?	×	×	×	×	×	×	×

Table 7.1: Summary of main stratigraphic elements in the North Atlantic rift basins (after Hiscott *et al.* 1990a).

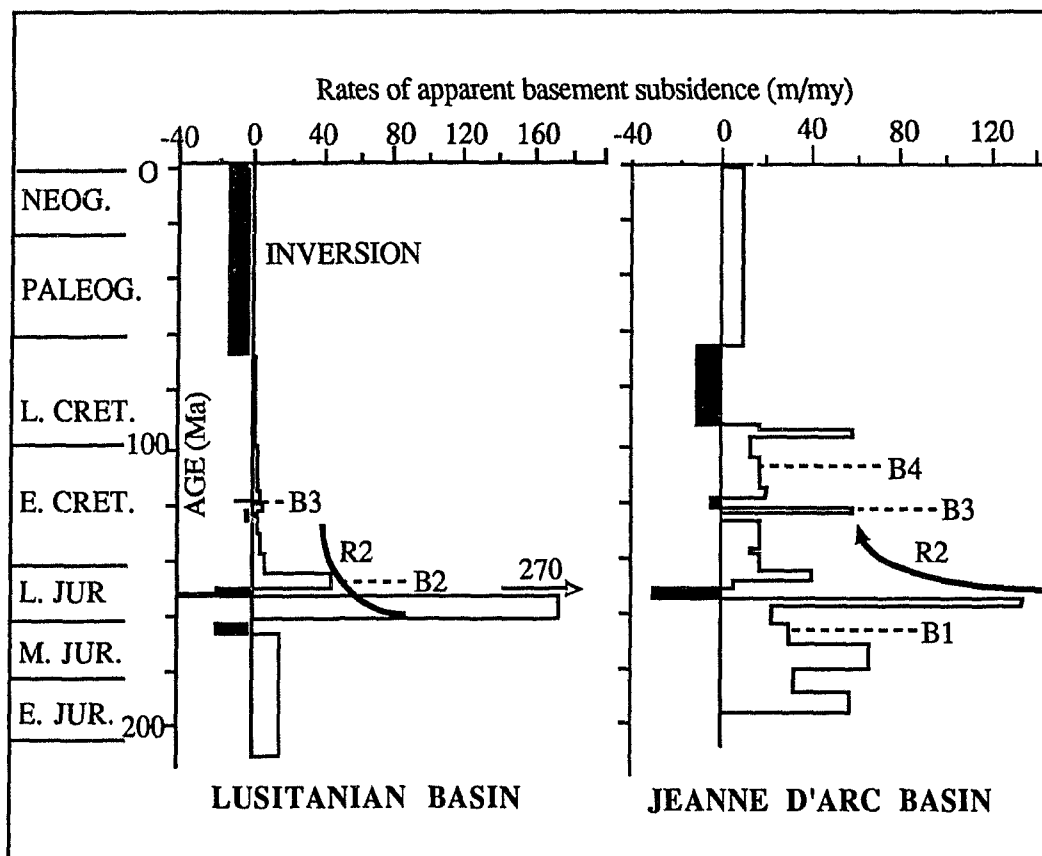


Figure 7.1: Rates of apparent basement subsidence (RABS) for the Lusitanian and Jeanne d'Arc basins (after Hiscott *et al.* 1990a).

Bathonian-Callovian resulted in continental breakup in that area. Extensional phase 2 occurred in the Kimmeridgian, and possibly caused limited breakup between southern Iberia and the southern Grand Banks. This was followed by sedimentation in 'structurally uncomplicated' basins until the Aptian, with the exception of an unconformity at the Jurassic-Cretaceous boundary in the U.K and Irish basins, and an unconformity at the base of the Valanginian in Iberia. Phase 3 extension caused continental breakup between Flemish Cap and the Galicia Bank at, or just prior to, the early Aptian, and was contemporaneous with widespread Aptian deformation on North Atlantic continental margins.

In their discussion, Hiscott *et al.* (1990a) referred to the three extensional phases of rifting as R1, R2 and R3, the episodes of continental breakup as B1, B2 and B3. The timing of these events is shown on the RABS curves (Figure 7.1). The relationships between the stratigraphic elements seen in the rift basins (Table 7.1) to the tectonic episodes outlined above and depicted in the RABS plots are discussed below.

7.2.2: Relationships between stratigraphic elements of the Mesozoic rift basins and the tectonic evolution of the North Atlantic.

Hiscott *et al.* (1990a) discuss this topic in considerable detail. Their interpretations are dealt with here, and, where appropriate, are related to the Portuguese sections treated in this study. It is not within the scope of this study to enter into debate on the ramifications of the tectonic models used in explanations offered by Hiscott *et al.* (1990a); detailed references to these are provided in their paper.

The early Oxfordian hiatus and restricted basins recognized in all the rift basins (Table 7.1) is suggested to be the result of broad thermal updoming around the North Atlantic margins just before R2 extension (Hiscott *et al.* 1990a). The Kimmeridgian deepening in the Lusitanian Basin is attributed to transtensional strike-slip movements and uplift of eastern fault blocks that acted as source areas for clastic basin infill, while the

apparent basement uplift of 40m/my following the Kimmeridgian R2 stretching phase is possibly related to Brown and Beaumont's (1988) prediction that rapid extension will cause adiabatic elevation of hot lower lithosphere into zones of lower pressure, causing lithospheric melting and resulting in volume increase and uplift (Hiscott *et al.* 1990a). The paleovalley topography of the Jeanne d'Arc and Spanish basins has attributes of a Vail *et al.* (1984) type 1 unconformity, although such is not indicated by Exxon data at that time (Hiscott *et al.* 1990a). Rapid and severe eustatic sea level falls result in Type 1 unconformities according to Vail *et al.* (1984), and although evidence of shelf edge exposure is seen in many basins, this may be related to compressional intraplate stresses in the Iberia-Grand Banks region, but not in other parts of N.W. Europe, rather than eustatic sea level changes (Hiscott *et al.* 1990a).

The transgressive-regressive cycles of the Tithonian seen in all Iberian and Grand Banks basins are related to short term fluctuations in sea level akin to those predicted by Haq *et al.* (1987) for the latest Jurassic, but are interpreted to be responses to regional fluctuations in intraplate stress during R2 extension, rather than a eustatic model (Hiscott *et al.* 1990a). With reference to the findings in the present study, transgressive-regressive cycles are also suggested through the correlation of the nodular limestone beds in Unit 1 at Ericeira with parts of Units 3 and 4 in the Cabo Espichel section and the Praia Azul Unit. The difficulty in the interpretation of these beds as transgressive-regressive cycles, however, lies in the fact that it is hard to determine the absolute changes in paleobathymetry in that part of the Cabo Espichel section, since all units were probably deposited in shallow water depths; lateral migration of facies may have produced the alternations of facies in the same result. The presence of marine nodular limestones within the fluvatile sequence of Unit 1 at Ericeira, however, indicates a rise in relative sea level of at least several metres. The high RABS following the Kimmeridgian R2 episode in the Lusitanian Basin indicates high sedimentation rates that kept pace with subsidence, since no appreciable deepening is seen with respect to the microfossils or facies in any of the sections.

The early Berriasian regressive sandstones and deltas reported from many of the basins are thought to be related to a first-order slow drop in sea level from the Tithonian into the Berriasian, and the effects of this in Iberia were probably accentuated by tectonic uplift since the regression was followed by an unconformity and influx of coarse pebbly Valanginian facies of the Calada member in the Ericeira section (Hiscott *et al.* 1990a). In the Cabo Espichel section it was suggested, following van Harten (1988), that the turnover of ostracod species seen at the top of Unit 5 may be related to marine regression. This is plausible from the RABS for the Lusitanian Basin, which shows minimal basement subsidence during the latest Jurassic, and inversion in the early Cretaceous. Hiscott *et al.* (1990a) relate the two sharp Valanginian sea level minima recognised by Haq *et al.* (1987) to structural disturbance of segments of the North Atlantic margins rather than eustatic sea level falls.

The low positive values in the RABS for the Lusitanian Basin during the Late Berriasian to Valanginian are in contrast to the those for the Jeanne d'Arc Basin, which remain relatively high. Hiscott *et al.* (1990a) suggest that an asymmetric extensional regime between the Grand Banks and Iberia may account for this difference, but admit that controversy surrounds current asymmetric rift theory. Widespread fining-upward and generally transgressive trends seen in the North Atlantic basins in the Valanginian-Hauterivian are attributed by Hiscott *et al.* (1990a) to steady rise in global sea level. The Barremian condensed sequences may have either resulted from rapid sea level rises that trapped siliciclastic sediments close to source (no progradation), allowing increased carbonate production, or a Barremian high sea level stand combined with continued subsidence resulting in a reduction in terrigenous input (Hiscott *et al.* 1990a).

7.3: Transgressions and regressions on independant plate margins: implications from this study.

Following the review of Hiscott *et al.*'s (1990a) work on the comparative stratigraphic and subsidence history of the Mesozoic rift basins, it is of interest to present some of the findings from the study of two basins, the Grand Banks and west Portugal.

The changes in the depositional environments of sections and wells considered in this study are summarized in Figure 7.2. Duration of units and intervals is based on the biostratigraphic interpretation of this study. There are, however, uncertainties regarding the positioning of the stage boundaries especially in marginal and non-marine strata. On the biostratigraphic evidence of cuttings (highest occurrences) alone, it is not possible to determine if sedimentation was continuous across stage boundaries, and hiatuses may usually only be recognized by the absence of microfossil zones. In the Lower Cretaceous well sequences this is a particular problem because of the absence of many extinction events prior to the Barremian. Absence of a zonal species may simply indicate ecological (facies) exclusion rather than non-deposition and, in the absence of core material, this is difficult to evaluate. Hiatuses in the Grand Banks wells may be of shorter duration than indicated. The position of hiatuses in the Lusitanian Basin sections is based partly on missing zones but also on field evidence. Duration of hiatuses is difficult to determine and, in the absence of biostratigraphic data from the coarser clastic intervals, is tentative.

From Figure 7.2, there appears to be little or no evidence that transgressive and regressive events can be correlated between the Grand Banks and Lusitanian Basins, or even within either basin. There is, however, evidence of shallowing in the Upper Jurassic in both basins, and Lower Cretaceous regressive facies are present in all wells and sections, which may be loosely related to a first order eustatic sea level signal.

Hiatuses identified in the Grand Banks occur at different times in different wells. Todd (1988) suggested that thermal doming, associated with the Central Atlantic mid-ocean

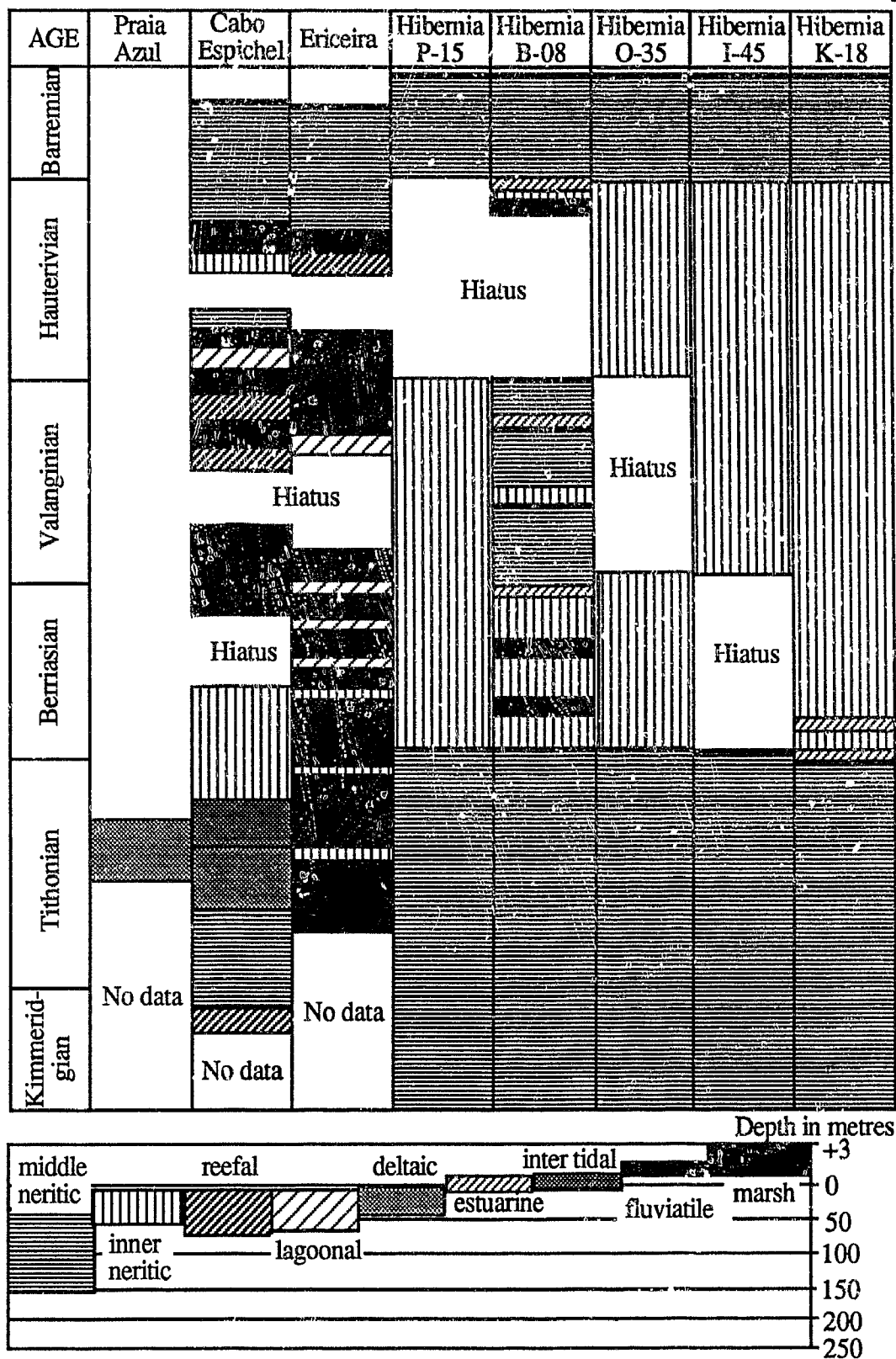


Figure 7.2: Summary of paleoenvironments in Portugal and the Grand Banks.

ridge, migrated in a south-easterly direction on the Central Atlantic side of the Southwest Newfoundland Transform Margin, resulting in continental lithospheric uplift of the transform margin. This uplift supplied sediments for the Jeanne d'Arc basin, and resulted in the development of progressively younger unconformities as the thermal dome migrated. The timing of the hiatuses in the Hibernia B-08 and P-15 appears to support Todd's (1988) model. Continued migration of the Central Atlantic thermal dome between the Oxfordian and Aptian (Todd, 1988) is a possible cause for clastic sedimentation through most of the interval in the wells examined in this study.

7.4: Ostracodal 'chronoecology'

Earlier (Chapter 4), it was suggested that the rapid turnover of ostracod species seen in the upper beds of Cabo Espichel Unit 5 may be related to paleoenvironmental change associated with a Berriasian marine regression. It is appropriate at this point to consider this idea further. Using the methodology outlined in van Harten (1988), the stratigraphic ranges for the ostracod species in each basin have been re-arranged according to the time of first entry and duration of each species, and plotted in a chart (Figure 7.3). As van Harten's (1988) method claims to be non-taxonomic, it is not necessary to consider the names of the species. Data used in this exercise are from the Cabo Espichel and Ericeira sections of Portugal, from the Grand Banks and Scotian Shelf in Ascoli (1976). Interpretation of the "chronoecologic signal" is based on van Harten's (1988) assumption that a species will survive as long as the environment provides the original niche to which the species was adapted. Environmental changes will be greatest immediately before, and immediately after, the passing of a shoreline during transgressions and regressions. During initial and final marine phases, the turn over of species will be high, and many new species will be short lived (van Harten, 1988). The "ideal" chronoecologic signal associated with a transgressive-regressive cycle, according to Lethiers (1983), has a sigmoidal shape. Van

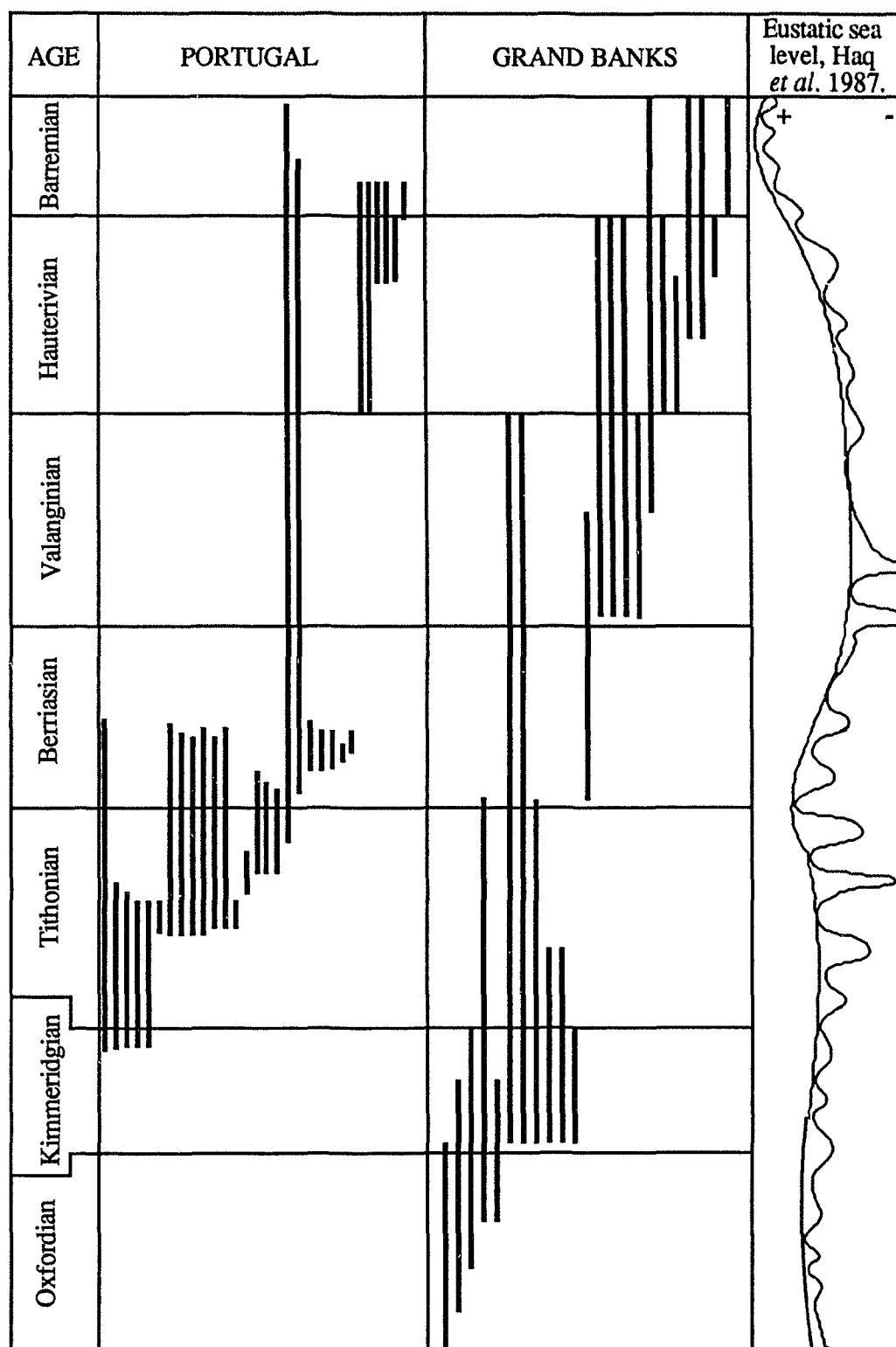


Figure 7.3: Chronoecologic chart of ostracod species from sections in Portugal and wells offshore eastern Canada. Eastern Canada data from Ascoli (1976) and Ascoli *et al.* (1984).

Harten (1988) analysed the Jurassic and Cretaceous ostracod assemblages of the southern U.K. and northern France using the 'chronoecologic' method, and compared the resulting signal to a eustatic chart with seemingly good results.

Examination of the 'chronoecologic' groupings for Portugal and offshore eastern Canada (Figure 7.3) shows similarity between the curves in that both show clusters of species during the Late Jurassic and Early Cretaceous. Several differences stand out between the curves for the two regions. The mid-Tithonian of Portugal displays a turnover of species corresponding to the clastic-dominated part of Cabo Espichel Unit 3. Additional Ostracodal species also appear in the Late Tithonian, although there is little decline in existing species. The mid-Tithonian Ostracodal turnover does not correspond to any first-order eustatic sea level change in the eustatic curve of Haq *et al.* (1987). The 'chronoecologic' signal is quite different for offshore Eastern Canada, being characterized by several new species appearing at the base of the Kimmeridgian, and a gradual turnover of species through the Kimmeridgian. This pattern is equally hard to relate to Haq *et al.*'s (1987) eustatic cycle chart, although the appearance of new species at the base of the Kimmeridgian may correlate with the suggested third-order sea level fall at the Oxfordian-Kimmeridgian boundary.

A turnover of Ostracodal species occurs in the Berriasian of Portugal, with several species disappearing and a number of short-ranging species being restricted to this interval. The 'chronoecologic' cycle corresponds loosely to the first-order Berriasian sea level drop in the Haq *et al.* (1987) curve. In offshore Eastern Canada, such a turnover of species is not apparent in the Berriasian. The chronoecologic chart for Portugal shows that a number of new Ostracodal species appear in the Hauterivian to Barremian, and examining Haq *et al.*'s (1987) curve, this may loosely relate to the Hauterivian-Barremian first-order rise in sea level. The Valanginian-Hauterivian interval of the Ostracodal 'chronoecologic' curve for offshore Eastern Canada, in contrast, shows a small 'pulse' of new species at the base of the Valanginian, and a number of smaller 'pulses' through to the Hauterivian-Barremian

boundary. The latter is marked by the disappearance of several Ostracodal species and the appearance of one new one. Interpreting the chart for offshore eastern Canada according to van Harten (1988), we would relate the appearance of new species at the base of the Valanginian to Haq *et al.*'s (1987) predicted third-order sea-level fall at the Berriasian-Valanginian boundary. The turnover of species at the Hauterivian-Barremian boundary, however, corresponds to a third-order eustatic cycle of only small magnitude.

Summarizing the 'chronoecologic' signals for Portugal and offshore Eastern Canada, both charts show clusters of species in the Late Jurassic and Early Cretaceous which do not coincide in time and only relate to Haq *et al.*'s (1987) eustatic chart in a very general way. A number of 'peaks' of species turnover are seen within the charts, notably in the mid-Tithonian, Berriasian and at the Hauterivian-Barremian boundary in Portugal, and at the base of the Kimmeridgian, the base of the Valanginian and the top of the Hauterivian in the Grand Banks wells. These 'peaks' appear to correlate with third-order eustatic cycles, but do not relate to the same cycles in both regions.

Discussion

From the comparison of the 'chronoecologic' charts of Portugal and the Grand Banks with the eustatic cycle of Haq *et al.* (1987), it appears that van Harten's (1988) notion that the method may be used to 'fine tune' global sea-level charts is rather simplistic. While the method was used with success with data from the U.K. and France in van Harten (1988), the technique does not appear successful for Portugal and the Grand Banks of Newfoundland. The reason may be because there is a general paucity of Ostracoda in many of the eastern Canadian wells, which may be an artefact of preservation or simply the lack of data.

The age ranges of Ostracodal species in Scotian Shelf and Grand Banks wells given by Ascoli (1976, 1984), are difficult to establish in the absence of reliable planktonic microfossils, and those based on well cuttings are not reliable because of caving. The first

occurrence of species may be an artifact of a biostratigrapher's desire to define stage boundaries. The turnover of species at stage boundaries in the 'chronoecologic' curve for the Grand Banks may be artifacts of extended species ranges, rather than rapid species turnover; human error in extending the ranges of species in the wells in an attempt to accentuate stratigraphic boundaries would result in an impression of high rates of speciation at stage boundaries.

There is little evidence to support van Harten's (1988) arguments that new species seen during episodes of species turnover can be used to correlate transgressive and regressive peaks, despite the possibility that such species may have evolved as a result of the sea level change. In the Cabo Espichel section, most 'newly evolved' species characterizing faunal turnovers are unrelated to existing species (*Cytherella*, *Schuleridea* and *Cytherelloidea* excepted), suggesting they simply migrated in when the ecological conditions permitted. A species may have inhabited a particular facies in an area adjacent to a studied section, yet its range may never be known if that particular facies occurs in the section only once. The low rate of species turnover in the Grand Banks wells during the Tithonian-Berriasian seems to be due to the absence of carbonate facies.

A final point of interest concerning the 'chronoecologic' charts involves the new stratigraphic interpretations made for the Grand Banks wells examined in this study, and the implications for the main episode of Late Jurassic Ostracodal evolution offshore eastern Canada. Based on data published in Ascoli (1976, 1981), mainly from Scotian Shelf wells, the bulk of the turnover of Ostracodal species in the Late Jurassic took place during the Kimmeridgian and early Tithonian. The biostratigraphic results of this study, however, indicate that intervals previously regarded as Tithonian in the Grand Banks may in fact be Berriasian. Extrapolation of the ages of the Grand Banks biozones back to the Scotian Shelf wells, in the same way Ascoli (1989) assigned ages to Grand Banks biozones based on evidence from the Scotian Shelf, suggests that depth intervals assigned to the Tithonian by Ascoli (1989) may be Berriasian. The implication of this to the 'chronoecologic' chart of

the Grand Banks (Figure 7.3) is that a large turnover of Ostracodal species took place during the Mid-Tithonian, at approximately the same time as in the Lusitanian Basin. Assuming this to be the case, the chronoecologic charts for each region would match each other more closely, but neither would tie in any better with Haq *et al.*'s (1987) sea level curve.

7.5: Overview of the Upper Jurassic-Lower Cretaceous biofacies in Portugal and the Grand Banks of Newfoundland.

As discussed previously (Chapter 6), the microfossil assemblages seen in the Grand Banks differ significantly from those seen in the Lusitanian Basin during the Kimmeridgian-Barremian, in comparison with those seen in Middle to Late Jurassic strata examined by Stam (1986). The main difference between the Portuguese and Grand Banks assemblages is the large number of calcareous Foraminiferal species (predominantly lenticulinids and epistominids) found in the Grand Banks. These differences may have been due to differences in the depositional environments and biogeographic distribution, the latter possibly related to other factors such as the distribution of calcareous algae. It was also suggested that morphological groupings of Foraminifera may reflect environmental stability, with the epifaunal groups developing in response to the stabilization of substrates by phytal communities. Of particular interest to this study has been the distribution of the larger Foraminifera, locally so abundant in the Portuguese sections, but generally rare in the Grand Banks during this interval. *Choffatella tingitana* is locally very abundant in the Praia Azul section, common in the Cabo Espichel section, but uncommon in Ericeira. *Choffatella tingitana* is prevalent in the fine siliciclastic facies, and is associated with high sedimentation rates as indicated by the high RABS in the Lusitanian Basin during the early part of the Late Jurassic. Sedimentation rate in itself is not generally considered to be a physical ecological parameter controlling the distribution of Foraminifera

(apart from the diluting effects it may have on assemblages), but it surely is a factor which affects the ecology of other (larger) marine invertebrates and may have an as yet undiscovered influence on Foraminiferal assemblages. Substrate may have been an important factor in the distribution of this species, combined with brackish salinity. The absence of this species from the Grand Banks is hard to explain; possibly this is related to the lower incidence of calcareous algae in offshore eastern Canada compared to the Lusitanian Basin (Ellis, 1984).

The occurrence and stratigraphic distribution of *Anchispirocyclus lusitanica* has been a source of debate among stratigraphers working in Portugal and the Grand Banks (eg. Rey 1979; Gradstein 1978; Leinfelder 1987). *A. lusitanica* is abundant in marine to slightly hyperhaline carbonates in the Cabo Espichel section, but rare in the slightly brackish nodular limestones of the Ericeira section, and absent from the siliciclastic strata at Praia Azul. The range of this species is thought to be incomplete in the Cabo Espichel section, compared with its range in the Sintra and Monsanto sections of Portugal (Leinfelder 1987). This may be related to ecological exclusion from the siliciclastic sequences in the lower part of Unit 3, perhaps because of the substrate (siliciclastic rich facies), but since other 'larger' Foraminifera are present in those facies, possibly due to lowered salinity. In the Grand Banks, *Anchispirocyclus* is rare, but is associated with carbonate facies in the Bonniton H-32 well. Absence of significant carbonate in the other Grand Banks wells probably accounts for the rarity of the species. Moullade *et al.* (1988) reported rich associations of *A. lusitanica* in carbonate facies from the Ocean Drilling Program (ODP) Leg 103 Site 639 drilled in the Galicia margin. The carbonate environment was interpreted as a shallow marine carbonate ramp of open marine salinity. A paleo-oceanographic implication of the ODP Leg 103 site is that it represents an important bridge between Portugal and the Grand Banks during the Late Jurassic.

Everticyclammina virguliana is locally abundant in the Portuguese sections where it is associated with nodular limestones and fine siliciclastic sediments. From the distribution

of this species in the Praia Azul section, it seems that it could tolerate only slight brackishness, which may explain the rarity of the species in the Berriasian, and its absence from younger units. In the Grand Banks this species is reported from the Hauterivian and Barremian, which may reflect normal marine salinity.

The 'smaller' agglutinated Foraminifera play an important role in both paleoenvironmental reconstruction and biostratigraphy of Portugal and the Grand Banks from the Berriasian through to the Hauterivian. Most important in the latter application is *Ammobaculites subcretaceus*. Although this is essentially a long ranging species and has been regarded as a Barremian-Aptian marker (Williamson 1987), the form that displays an 'inverted' mode of coiling may be stratigraphically restricted to the Berriasian, where it is abundant in estuarine facies. This form occurs in Portugal and the Grand Banks, and future work may prove it to be an important stratigraphic marker. The co-occurrence of *Ammobaculites subcretaceus* with *Anchispirocyclina lusitanica* in Grand Banks cores is considered evidence for a Late Berriasian age, based on the overlapping ranges of these species in Portugal, and redefines the depth of the Jurassic-Cretaceous boundary in the Grand Banks.

Abundance of *Ammobaculites* occurring on its own is taken to indicate estuarine paleoenvironments, and its association with abundant *Trochammina* may indicate lower marsh paleoenvironments in both Portugal and the Grand Banks during the Berriasian to Hauterivian. Monotypic assemblages of trochamminids are thought to indicate upper marsh paleoenvironments in Portugal, but these paleoenvironments have not been observed in the Grand Banks wells. The biostratigraphic utility of such agglutinated assemblages is questionable since they are obviously strongly facies controlled, and have evolved little if at all since the Mesozoic (D.B Scott, pers. comm. 1990). *Trochammina depressa* appears to be an important local marker in the Hauterivian.

The larger Foraminifera *Choffatella decipiens* appears brackish-tolerant in Portugal, and is abundant in fine siliciclastic and carbonate facies of Late Hauterivian to

Early Barremian age. In the Grand Banks, although reported from the Hauterivian, this species does not become abundant until the Late Barremian or slightly younger (Williamson 1987). It is interesting that Colin *et al.* (1981) reported this species from Aptian sediments in the North Celtic Sea Basin. The latter locality represents the most northern reported occurrence of the species, traditionally regarded as a typical 'Tethyan' species. The implications of the apparent diachronous first appearance of *Choffatella decipiens* are hard to assess. Proponents of global temperature gradient as a control on the distribution of 'Boreal' versus 'Tethyan' faunas during the Early Cretaceous would argue that warmer global temperatures in the late Early Cretaceous would account for the northerly migration of *C. decipiens*. The view adopted by Hallam (1969) that salinity and facies were probably more important controls to the distribution of 'Boreal' and 'Tethyan' faunas is shared here.

As noted earlier, few Ostracodal species are common to Grand Banks and Portugal. Ascoli (1978) reported the Ostracodal assemblages of offshore eastern Canada to be fairly similar to those reported from Europe, although the majority of the species he considered were from wells located on the Scotian Shelf. The Ostracodal assemblages from the Upper Jurassic strata of Portugal are characterized by euryhaline genera such as *Schuleridea*, *Galliaecytheridea* and *Asciocythere*. Forms regarded as more stenohaline are also present, including *Cytherella*, *Cytheropteron* and *Cytherelloidea*. With the exception of *Schuleridea*, the other genera are rare or absent from the Grand Banks.

The Berriasian and Valanginian are poorly defined in terms of Ostracoda in both study areas, although *Darwinula leguminella* is present in marginal marine to fresh water paleoenvironments. The Hauterivian-Barremian interval in both areas is characterized by few species of Ostracoda, although representatives of *Protocythere* and *Schuleridea* are present and enable correlation to be made between Portugal and the Grand Banks.

7.6: Conclusions, shortcomings and recommendations.

Paleoecological, biostratigraphic and regional conclusions, perceived shortcomings with the study and recommendations for future research are dealt with below.

7.6.1: Paleoecological conclusions.

1). The distribution of the Ostracoda is controlled primarily by salinity. This permits shallow marine environments to be differentiated into salinity realms. The Ostracoda were probably more sensitive to changes in salinity than the invertebrate macrofossils of the Late Jurassic. Population studies of the Ostracoda enable autochthonous assemblages to be distinguished from allochthonous ones and assists in paleoenvironmental interpretation.

The shortcoming of attempting this type of work with Mesozoic Ostracoda is that with few exceptions (*Darwinula* for example), most are pre-actualistic, and salinity estimates are frequently based on lithofacies criteria in previous studies. Isotope studies of Mesozoic Ostracoda (eg. Allen and Keith, 1965) have largely been inconclusive.

2). Classification of Foraminifera into morphogroups enables subenvironments to be recognised within ostracod-defined salinity realms. Morphogroups based on gross chamber morphology cannot be used to determine primary environments such as estuaries, marshes or lagoons since test morphology and inferred habitats are not species specific, but, with the possible exception of certain 'larger' Foraminifera that are restricted to shallow photic-zone water depths, occur within most marine environments. In sediments that have undergone little or no reworking, successive hierarchies of morphogroups from infaunal to epifaunal ones may be linked with the establishment of phytal communities and the evolution of the environment from unstable to stable. In sediments that have been heavily bioturbated, the use of morphogroups is not recommended since downward transportation

of the Foraminifera will have blurred the boundaries between subenvironments that may have existed.

Clearly this field of research requires further work, particularly in the relationship between living Foraminifera and microhabitats as well as the paleoecological application of such methods. It would be an interesting field of research to undertake a study of relationships between the larger Foraminifera and the distribution of fossil algae, much in the same way Brazier (1975b) has done with sea-grass communities. Sea grasses, as angiosperm plants, did not appear in the fossil record until the mid Cretaceous at the earliest, yet larger Foraminiferal communities are documented as far back as the Paleozoic. Sea grasses today represent only about 2% of marine phyta, the remainder of sea vegetation being composed dominantly of red and green algae, commonly known as seaweeds. The marginal marine facies of the late Jurassic and early Cretaceous represent an important area for this type of study, since it is from the broad coastal plains that the marine and terrestrial angiosperms are thought to have evolved. Interestingly, this period also saw important changes in Foraminiferal 'stocks', in which the calcareous agglutinated 'larger' Foraminifera declined in importance, and the 'larger' calcareous milioline and rotaliine started to become important.

3). Agglutinated Foraminifera within estuarine environments appear to have been grain selective, which is in contrast to what is observed for many Recent agglutinated species in fully marine environments. Possibly this is related to the restricted and potentially short-lived nature of estuarine environments in which rapid, yet efficient test construction was achieved through the use of an optimum grain size for a given test architecture.

The drawback in these types of studies stems from a lack of reliable data from the Recent, combined with taxonomic difficulties. There is vast potential for research in the field of test morphology, habitat and environment that will have important paleoecological and paleoenvironmental implications. A shortcoming of the paleoecological work on the

Grand Banks is that it was concerned only with the microfossils and limited sedimentological data. It was not the intention of the thesis, however, to undertake a full paleoenvironmental analysis of the Grand Banks; the intention was merely to demonstrate the applicability of the results of the Portuguese study to the Grand Banks, and to assess some of the paleoenvironmental implications with respect to earlier work. Future studies attempting to undertake detailed paleoenvironmental analyses in the Grand Banks should obviously use seismic and electric log data in conjunction with sedimentological and micropaleontological criteria.

4). Opportunism appears to have been an important strategy used by faunas of the past in much the same way as it is in the Recent. Species of *Ammobaculites*, *Anchispirocyclus*, *Choffatella*, *Discorbis* and *Platycythereis* appear to have used this strategy.

The difficulty in interpreting large abundances of a particular species as being opportunistic is in not knowing reproduction rates, mortality rates or life cycles of these organisms, all of which may affect the apparent abundance. *Anchispirocyclus lusitanica*, for example, reproduced asexually at times, and the asexual forms may have had a very rapid reproductive cycle to ensure continuity of the species. Preservation is also an important factor, particularly in the case of a 'monospecific' assemblages of agglutinated Foraminifera which may simply be an artefact of the dissolution of calcareous species. Little can be done to resolve this potential difficulty.

5) The larger Foraminifera appear to have been controlled in part by salinity, and in part by facies. It is hard to distinguish between these two variables, since to some extent they are closely related in nearshore environments; siliciclastic facies are frequently deposited close to river mouths and consequently are often within areas of lowered salinity. Superimposed over the constraints of salinity and facies is the likelihood that these Foraminifera were confined to the photic zone in much the same way as larger Foraminifera are today.

Distribution of larger Foraminifera within the photic zone may ultimately depend on the occurrence of algae.

In this type of work it is obviously important not to assume that the most 'obvious' ecological factor is the principal one controlling the assemblages. Most ecological factors are not quantifiable in the fossil record, and interrelated factors were probably at work.

7.6.2: Biostratigraphic conclusions.

1) Foraminifera and Ostracoda seen in the Portuguese sections may be used in biozonations for correlation between sections in Portugal. Certain Ostracodal zones may also tie in with other European Ostracodal zones to permit correlation outside of the Lusitanian Basin.

The strength of both the Ostracodal and Foraminiferal biozones in correlation within the Lusitanian Basin and potentially to all other North Atlantic rift basins is partly due to the fact that these basins share a common tectonic origin that resulted in similar stratigraphic sequences being deposited in each of the basins. On the basis of the paleoecology, it is clear that many of the ostracods and Foraminifera are strongly facies controlled, and their stratigraphic utility can only be realised in similar facies to which they are found in. The utility of the biozonations can only be determined through future work.

2). The form of *Ammobaculites* displaying 'inverted' coiling appears to be restricted to the latest Berriasian. This form is assigned to the species *A. subcretaceus*. Specimens of *A. subcretaceus* are reported from various other stratigraphic levels in Europe and offshore eastern Canada, but these forms have not been described as having the unusual coiling mode. Careful examination of specimens under glycerine immersion is necessary in order to determine the style of growth.

Further work is necessary before it can be established whether the forms with the

inverted coil are stratigraphically significant or not.

3). Stratigraphic re-evaluation of Grand Banks wells based on biostratigraphic findings from the study of Portuguese outcrops suggests that the Jurassic-Cretaceous boundary may be deeper than previously thought. A Berriasian age is proposed for the occurrence of *Anchispirocyclus lusitanica* in the Grand Banks, based on its highest occurrence in Portugal, and its co-occurrence with Berriasian, rather than Tithonian calpionellids in the Bonniton H-32 well. A new Foraminiferal biozonation is proposed for the Grand Banks wells that permits some correlation with the Lusitanian Basin.

The obvious shortcoming with this work relates to correlating the biozones back to European stratotypes. Second order correlations using rare calpionellids leave some doubts as to the ages of the biozones. This is a problem that can only be resolved through future work.

7.6.3: Regional conclusions.

1). Analysis of the stratigraphy and subsidence histories for the North Atlantic syn-rift basins suggests that synchronous tectonic events related to phases of lithospheric stretching, rather than eustatic sea level changes, resulted in the similar stratigraphic elements seen in the basins.

While the study of Hiscott *et al.* (1990a) convincingly demonstrated the relationship between the tectonic evolution of the North Atlantic rift basins and the stratigraphic sequences found within them, it did not provide any estimates of residual components in the RABS that may related to sea level rise. It would have been interesting to see their estimates of the magnitude of eustatic events. Local tectonic effects, such as the 'migrating thermal dome' of Todd (1988) appear to be lost within the RABS.

2). Comparison of the transgressive-regressive trends of the Lusitanian Basin with those seen in the Grand Banks shows little similarity between the two areas.

The difficulty with such a conclusion is that data used in this study was very localized from within the Jeanne d'Arc Basin, and it may not be valid to make such a comparison since local faulting may further alter the combined effects of subsidence and any eustatic signal. However, the goals of the thesis did not include a detailed regional stratigraphic study of the tectonic history of the North Atlantic, but rather, to relate paleoenvironmental interpretations to the tectonic framework and discuss any implications. Burial history analysis seems to be the only valid method from which to make comparisons.

3). A progressively younger unconformity seen in a number of the Grand Banks wells may be related to the migrating thermal dome model of Todd (1988), since the unconformities get progressively younger in wells to the south east, in the same direction as the migrating thermal dome.

It is probably unwise to attempt stratigraphic comparisons in wells adjacent to offset transform margins unless the effects of thermal doming are accounted for. In a burial history curve, the localised thermal doming would have a negative effect to the apparent rate of basement subsidence that may not be easily recognised.

4). The chronoecological charts for the Lusitanian Basin and the Grand Banks do not agree with each other, nor do they correspond to the sea level chart of Haq *et al.* (1990).

The implication is that the concept of Ostracodal 'chronoecology' is invalid. Wells examined, however, did not have sufficient data to examine the theory properly. First appearances of species cannot be accurately determined from cuttings, and species' ranges may be somewhat artificial, resulting from a human desire to define stage boundaries. Exploration wells may be a poor testing ground for Ostracodal chronoecology.

CHAPTER 8

TAXONOMIC NOTES.

8.1: Introduction.

The taxonomic notes on the Portuguese foraminifera and ostracoda are dealt with in three parts: (1) smaller foraminifera, those with calcareous or simple agglutinated walls normally identified by the external test morphology, (2) larger foraminifera, those with complex walls that are identified by the morphology of the test as observed in thin section and (3) ostracoda.

Classification of the foraminifera follows Loeblich and Tappan (1964). The revised foraminiferal classification of Loeblich and Tappan (1985) was considered not suitable for this study as it elevates too many species to genera and "obscures" a natural classification. The ostracod classification follows that of Benson *et al.* (1961).

Species dealt with here are stratigraphically, paleoenvironmentally or numerically important. Comments on the species abundance are based on the following specimen counts per sample: rare, 1-5; common, 6-20; frequent, 21-50; abundant, more than 50 specimens.

Seventy-five species of foraminifera and ostracoda are discussed, including 7 new or previously un-named forms which have been left in open nomenclature. In the interests of brevity, reference lists are limited to the first citation of the species in the literature, additional references where appropriate, and more recent and easily available publication(s) that figure the species. Maximum size of species are given

8.2: Taxonomic concepts.

The species concept in this study may be defined from various standpoints, depending on the type of microfossil being dealt with. The calcareous foraminifera (nodosariids) generally form a small part of the microfauna, and consist of only a few species, most of which belong to the genus *Eoguttulina*. An argument could be made for grouping these together as '*Eoguttulina* spp.', particularly since they do not appear to be of any stratigraphic significance in this study. However, as each species can be distinguished fairly easily, and shows only limited morphological variation, it was decided to treat each one separately.

The smaller agglutinated foraminifera, on the other hand, include forms that show considerable morphological range. These were grouped as single species. The species *Ammobaculites agglutinans* may be cited as an example. This species possesses a planispiral involute coil of 3-6 chambers with indistinct to slightly depressed sutures and a smooth to lobate outline. The uncoiled portion has 2-5 chambers that are generally broader than high. All specimens of *Ammobaculites* with these characters have been grouped with *A. agglutinans*.

The larger agglutinated foraminifera present another type of situation. Many of these forms display morphological gradation between 'end member' species, although this gradation is usually only recognised in detailed thin sections. Short of making thin sections of each specimen, the gradational forms were grouped with the end member species together with all specimens of similar external appearance. The best example of this is seen within the concept of the species *Pseudocyclammina muluchensis* adopted in this study. This species displays a variable external morphology, particularly with respect to the equatorial diameter-axial diameter ratio. The morphotypes with the highest ratio have an external appearance approaching that of *Choffatella tingitana*, while those with the smaller ratio approach *Pseudocyclammina sphaeroidalis*. Thin sections of these morphotypes reveal

a proloculus of about 100 μm diameter in the megalospheric generation which is outside the range of the other two species. The broader and slimmer morphotypes are all grouped with *Pseudocyclammina muluchensis*, although theoretically they may include specimens of the other two species. Fortunately, *Choffatella tingitana* may be distinguished by the single row of pores on the apertural face, although poorly preserved specimens may not be so distinctive.

The ostracoda, on the other hand, include a number of short ranging species that are of stratigraphic importance in this study. Morphological gradation is seen between a number of the species, and these are separated into 'end member' species. Typically, the gradation is seen within the 'smooth' forms such as *Cytherella*, *Schuleridea* and *Asciocythere*, and these have had to be distinguished on subtle changes in the carapace outline. The fact that these 'end member' species have been widely reported and used in European biostratigraphy justifies this approach. The short ranging species, in contrast, are markedly distinct and uniform in their morphology, and include two distinctive forms that differ enough from published descriptions of any similar species as to warrant the creation of new species.

8.3: Smaller foraminifera.

Superfamily LITUOLACEA de Blainville, 1825

Family HORMOSINIDAE Haeckel, 1894

Subfamily HORMOSININAE Haeckel, 1894

Genus REOPHAX Montfort, 1808

Reophax aff. *scorpiurus* Montfort

Plate 1, figs. 3-4

Reophax scorpiurus Montfort, 1808, p. 331, text-fig p. 330; Lloyd, 1962, p. 308, pl. 54, fig. 15; Neagu, 1965, p. 4, pl. 2, fig. 12; Maync, 1973, p. 1082, pl. 1, fig. 9;

Magniez- Jannin, 1975, p. 27-29, pl. 1, figs. 9-18; Crittenden, 1981, p. 17-18, pl. 1, figs. 11-13.

Diagnosis and remarks: Three to four chambers increasing in size as added; chambers as broad as high; sutures straight, slightly depressed; wall coarsely agglutinated; aperture simple, terminal, on a short neck.

Portuguese specimens resemble forms described in Crittenden (1981), although lack the rapid chamber growth and the constriction of the final chamber of the specimens figured in Magniez-Jannin (1975). The Portuguese specimens are constructed from coarse silica grains, and occur mainly in siliciclastic sediments.

Size: Length 0.93-1.07mm

Occurrence: Cabo Espichel, I/4, I/5, rare; Ericeira, B/3, E/5, E/6, E/8, rare. Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Lloyd 1962, Kimmeridge Clay); Barremian-Aptian (Maync 1970, DSDP site 120); Albian (Neagu 1965, Rumania). This study: Lusitanian Basin: Early Kimmeridgian - Early Hauterivian, *Mesoendothyra* sp.A to *Marsonella kummi* zones.

Reophax horridus (Schwager)

Plate 1, figs.1-2

Haplostiche horrida Schwager, 1865, p. 92, pl.2, fig. 2a-c.

Reophax horridus (Schwager); Gordon 1967, p. 448, pl. 1, figs. 6-8; Maync, 1973, p. 1082, pl. 1, fig. 9; Sliter, 1980, pl. 1, fig. 17.

Diagnosis and remarks: Uniserial, compressed, four to six chambers increasing in size gradually as added; early chambers usually broader than high, final chamber higher than broad, inflated near suture, constricted terminally; sutures straight, depressed, periphery lobate; aperture terminal, oval to round with a narrow, low lip.

This species is recognised by its tapering margins and the inflated, drawn out final chamber. Specimens from the Espichel and Ericeira sections are similar to those described in Sliter (1980). The Portuguese specimens are finely agglutinated from silt, and are associated with silt and clay facies.

Size: Length 0.5-0.63mm

Occurrence: Cabo Espichel, rare, samples I/4, I/9, I/17; Ericeira, rare, samples B/8, E/2, E/5, H/2. Widely reported from N.W. Europe and north America.

Stratigraphic age: Long ranging: Callovian (Gordon 1967); Tithonian (Sliter 1980, DSDP Sites 415 & 416); Aptian-Albian (Maync 1973, DSDP Site 120). This Study: Middle Kimmeridgian-Late Hauterivian, *Choffatella tingitana* zone to *Marsonella kummi* zones.

Family LITUOLIDAE de Blainville, 1825

Subfamily HAPLOPHRAGMOIDINAE Maync, 1952

Genus HAPLOPHRAGMOIDES Cushman, 1910

Haplophragmoides concavus (Chapman)

Plate 1, figs. 5-7

Trochammina concava Chapman 1892, p. 327, pl. 6, fig. 14.

Haplophragmoides concavus (Chapman); Bartenstein & Brand, 1951, p. 268, pl. 1, figs. 24-25; pl. 14c, figs. 1-2; Maync, 1973, p. 1082-1083, pl. 1, figs. 13-14; Magniez-Jannin, 1975, p. 38, pl. 2, figs. 5-8; Crittenden, 1981, p. 18, pl. 1, figs. 15-16;

Sliter, 1981, p. 774, pl. 2, figs. 1-3.

Diagnosis and remarks: Test compressed with five to six chambers in final whorl; chambers flat or slightly inflated, depressed towards the umbilicus and periphery, final chamber larger than previous; sutures straight, depressed; equatorial profile slightly lobate, axial profile sharp to gently rounded.

The species is easily distinguished by the 'collapsed' chambers and depressed umbilicus. Some variability is seen in the size of material used to construct the test, resulting in smooth forms such as those illustrated in Magniez-Jannin (1975), and rough forms similar to the specimens figured in Crittenden (1981). The species occurs in clay, silt and sandy facies, and may be abundant.

Size: Maximum diameter 0.33-0.47mm; Thickness 0.07-0.13mm

Occurrence: Cabo Espichel, I/2, I/4a, I/5, I/6, I/7, I/9, I/10, I/13, I/15, I/16, I/17, L/2, L/4, L/5, M/8. Rare to frequent; Ericeira, MB/4, MB/5, MB/6b, MB/7, E/1, E/2, E/3; Praia Azul, A/2, A/3, (common) A/4 (rare), A/5 (common) A/6, A/8 (rare). Reported widely from Europe.

Stratigraphic age: Berriasian-Hauterivian (Sliter 1981, DSDP site 416); Middle Valanginian (Bartenstein & Brand, N.W. Germany); Barremian-Albian (Maync 1970, DSDP site 120); Early Aptian (Crittenden 1981, Atherfield Clay, southern England). This study: Lusitanian Basin: Early Kimmeridgian - Barremian, *Mesoendothyra* sp.A to *Choffatella decipiens* zones

Haplophragmoides minor Nauss, 1947

Plate 1, figs. 8-9

Haplophragmiodes minor Nauss, 1947, p. 338-339, pl. 49, figs. 10a-b; Geroch, 1966, p. 441-2, fig. 10 (1-3); Haig, 1980, p. 102, pl. 3, figs. 8-9.

Diagnosis and remarks: Involute, 8 to 14 chambers in the final whorl with a narrow depressed umbilicus. Chambers increase in size rapidly, and are inflated and lobate around the umbilicus. Sutures are depressed and curved backwards towards the peripheral margin. The equatorial outline is lobate, and the periphery bluntly angled.

This species is distinguished from *H. concavus* (Chapman) by the curved sutures and greater number of chambers in the final whorl. Also distinctive of this species are lobate chambers around the umbilicus, and the bluntly angled periphery. Specimens are finely agglutinated with a polished appearance, and compare well to those figured by Geroch (1966). Specimens are found in silts.

Size: Maximum diameter, 0.52mm; thickness, 0.22mm.

Occurrence: Ericeira, samples D4 (rare), D10, C10 (abundant). Widely reported from Europe, North America and Australia.

Stratigraphic age: Albian-Cenomanian (Geroch 1966, Polish Carpathians); Aptian-Albian (Haig 1980, Queensland, Australia). This study: Lusitanian Basin: Berriasian, *Anchispirocyclus lusitanica* zone, *Ammobaculites subcretaceus* -subzone.

Haplophragmoides nonionoides (Reuss) 1862

Plate 1, figs. 10-13

Haplophragmium nonionoides Reuss, 1862, p. 30, tab. 1, fig. 8.

Haplophragmoides nonionoides (Reuss); Magniez-Jannin, 1975, p. 30-36, text-figs. 11-12, pl. 2, figs 9-18; Crittenden, 1981, p.18, pl. 1, figs. 17-18.

Haplophragmoides concavus (Chapman); Sliter, 1981, p. 374, pl. 2, figs. 5-6.

Diagnosis and remarks: Planispiral involute, compressed with 6 to 14 chambers in the final whorl. The umbilicus is narrow and slightly depressed, and chambers increase in size gradually. The sutures are straight to slightly curved and faintly depressed. The equatorial profile is subcircular to slightly lobate, and the periphery sharply to broadly rounded.

This species is distinguished from *Haplophragmoides concavus* by the greater chamber inflation and larger number of chambers in the last whorl. Considerable variation is seen in the Portuguese specimens. Coarsely agglutinated forms are similar to those figured by Crittenden (1981), while the finely agglutinated specimens with a sharper periphery and more open umbilicus are similar to those figured by Magniez-Jannin (1975) as *H. nonionoides* f. *angulosa*.

Specimens are found in silts, dolomitic limestones and sandstones, frequently in association with brackish water ostracod assemblages.

Size: Maximum diameter 0.4-0.53mm; thickness 0.17-0.27mm.

Occurrence: Cabo Espichel, samples I/4a, I/5, I/6, I/8, I/9; Ericeira, samples C/2, C/3, C/5, C/9, D/1, D/2, D/3, D/4, D/6, D/9, E/5, F/2, H/1, H/2, H/7. Widely occurring in Europe.

Stratigraphic age: Valanginian (Fletcher 1973, Speeton Clay type section, bed D4); Early Aptian (Crittenden 1981, Atherfield Clay, southern England); Aptian-Early Albian (Sliter, 1981, DSDP Site 416); Albian (Magniez-Jannin 1975, Aube, France). This study: Lusitanian Basin: Early Kimmeridgian - Early Barremian, *Mesoendothyra* sp.A to *Choffatella decipiens* zones.

Genus FREIXIALINA Ramalho 1969

Freixialina planispiralis Ramalho, 1969

Plate 1, fig. 14

Freixialina planispiralis Ramalho, 1969, p. 39-40, pl. 1, figs. 1-4; Ramalho, 1971, p. 144, pl. XIII, figs. 10-11.

Diagnosis and remarks: Partly evolute coil of 3-4 whorls, 14-18 chambers in final whorl, increasing in size rapidly as added. The sutures are slightly raised and gently curved backwards near the periphery. The equatorial profile is sub-circular and slightly lobate, while the axial profile is lenticular, sharply rounded at the periphery and compressed in the umbilicus.

The genus *Freixialina* is recognised by its semi-evolute planispiral coiling and its elongate triangular aperture, by which it is distinguished from *Haplophragmoides* and *Daxia*. Specimens are finely agglutinated and are identical to those illustrated by Ramalho (1969). Roughly 5% of specimens show an uncoiling of the last few chambers, also noted by Ramalho (1969). Specimens are common to abundant in shale, marl and nodular limestone.

Size: maximum diameter, 0.52mm, thickness 0.14mm.

Occurrence: Cabo Espichel, samples J/2, J/4, I/1, I/2, I/4, I/5, I/8, I/13, I/16, I/17, I/18, I/19, I/20, I/21, I/22, K/1, K/3, K/5 (common to abundant); Ericeira samples B/1, B/2, B/3 (rare to common); Praia Azul, samples A/1, A/4, A/5 (rare to common), A/7, A/8, A/9 (abundant), A/10 (rare). Previously reported from Portugal.

Stratigraphic age: Early Kimmeridgian to Early Portlandian, *Mesoendothyra* sp.A to

Choffatella tingitana zone, *Discorbis scituliformis* subzone.

Subfamily LITUOLINAE de BLAINVILLE, 1825

Genus AMMOBACULITES Cushman, 1910

Ammobaculites agglutinans (d'Orbigny) 1846

Plate 2, figs. 1-3

Spirolina agglutinans d'Orbigny, 1846, p. 137, pl. 7, figs. 10-12.

Ammobaculites agglutinans (d'Orbigny); Bartenstein & Brand, 1951, p. 269, pl. 2, figs. 29-32; Gordon, 1961, p. 521, text-fig. 1 (4); Lloyd, 1962, p. 309, pl. 54, figs. 9-11, text-figs. 4b-d; Barnard & Shipp, 1981, p. 8, pl. 1, fig. 3.

Diagnosis and remarks: Planispiral involute coil of three to six chambers followed by an uncoiled portion of two to five chambers. The umbilicus is slightly depressed with straight sutures that are indistinct to slightly depressed in the coiled portion and depressed in the uncoiled part; periphery lobate in the straight portion and smooth to lobate in the coil.

Some variation is seen in the size of the initial coil, depression of the sutures and development of the uncoiled portion. Similar variability is also noted in specimens from the Kimmeridge Clay of southern England (Lloyd 1959), to which Portuguese specimens compare closely. Specimens are finely agglutinated from silt, and occur mainly in marl and shale in association with marine ostracoda.

Size: Maximum coil diameter, 0.17mm; maximum test length, 0.45mm; maximum thickness of uniserial portion, 0.135mm.

Occurrence: Cabo Espichel, samples J/4, I/2, I/4, I/5, I/7, I/10, I/13, I/16, I/17, I/18, I/19; Ericeira, samples B/1, B/2, B/3. Widely reported from Europe.

Stratigraphic age: Callovian-Oxfordian (Barnard *et al.* 1981, Oxford Clay, England); Kimmeridgian (Lloyd 1962, Kimmeridge Clay Type Section); Bathonian-Kimmeridgian (Coleman *et al.* 1981); Middle-Late Valanginian (Bartenstein & Brand 1951, N.W. Germany). This study: Lusitanian Basin: Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Ammobaculites coprolithiformis (Schwager)

Plate 2, figs.4-5

Haplophragmium coprolithiforme, Schwager, 1867, p. 654, pl. 34, fig. 3.

Ammobaculites coprolithiformis (Schwager); Bielecka & Pozaryski, 1954, p. 160, tbl. 3, figs. 6,7; Lloyd, 1962, p. 311, pl. 54, figs. 12a,b; Barnard, Cordey & Shipp, 1981, p. 389-390, pl. 1, figs. 3-4, 9, text-fig. 4.

Ammobaculites eocretaceus Bartenstein & Brand, 1951, p. 271, pl. 2, figs. 47-48.

Diagnosis and remarks: Involute coil of three to five chambers followed by uniserial portion of one to three chambers. The chambers are inflated and partially embrace those previous, and increase gradually as added. The sutures are slightly depressed resulting in a lobate periphery. The round to ovate aperture is often surrounded by a thickened rin. The test is agglutinated from silica grains in the 150 to 200 μm size range.

This form is distinguished by its inflated chambers and large size. Two variants are apparent, a close coiled form with a well developed uncoiled portion, and a larger, loosely coiled form with an uncoiled portion of only one inflated chamber. The latter form is most common. Barnard *et al.* (1981) discussed similar variation in this species from the Oxford Clay of England, and recognised microspheric and megalospheric generations of the species. Specimens are virtually identical to those figured by Bartenstein and Brand (1951) as *Ammobaculites eocretaceus*.

Size: Maximum test length: small coiled forms, 1.7mm; large coiled forms, 1.57mm.

Occurrence: Cabo Espichel, samples I/2, I/17, K/1, L/2, M/3, M/; Ericeira, samples E/9, H/3, H/4, H/5. Widely reported from Europe and north Africa.

Stratigraphic age: Callovian-Oxfordian (Barnard *et al.* 1981, Oxford Clay, England); Kimmeridgian (Lloyd 1962, Kimmeridge Clay Type Section); Upper Valanginian (Bartenstein & Brand 1951, N.W. Germany). This study: Lusitanian Basin: Lower Kimmeridgian - Lower Barremian, *Mesoendothyra* sp.A to *Choffatella decipiens* zones.

Ammobaculites euides Loeblich & Tappan, 1949

Plate 2, figs. 6-7

Ammobaculites euides Loeblich & Tappan, 1949, p. 250, pl. 46, figs. 8a, b; Sliter, 1981, p. 368, pl. 2, figs. 10-12.

Diagnosis and remarks: Planispiral coil of 4 to 5 chambers followed by straight to curvilinear portion of 4 to 5 chambers. The coil is involute with closely appressed chambers, indistinct sutures, and a diameter slightly greater than width of the uncoiled portion. The uncoiled portion has straight sutures, often obscure in the early stage, and slightly constricted in later stages producing a lobate outline. The test is agglutinated from silt..

This form is distinguished from *Ammobaculites obliquus* by the small tight coil, straight sutures and slightly lobate curvilinear uncoiled portion. Specimens are identical to those figured in Loeblich & Tappan (1949) and Sliter (1981).

Size: Maximum test length, 0.8mm; maximum width, 0.2mm; diameter of coil, 0.22mm.

Occurrence: Ericeira samples E-5 and E-8, common. Also reported from the N.E. Atlantic (DSDP site 416, Sliter 1981) and the U.S.A. (Walnut Clay, Loeblich & Tappan 1949).

Stratigraphic age: Hauterivian (Sliter 1981); Aptian (Loeblich and Tappan 1949). This study: Late Valanginian-Early Hauterivian, *Haplophragmium inconstans* to *Marsonelia kummi* zone, *Trochammina depressa* subzone.

Ammobaculites godmani (Barnard 1953)

Plate 2, fig. 8

Ammobaculites minuta Barnard, 1953, p. 185, fig. A, 3a, b, c.

Ammobaculites godmani (Barnard); Barnard, Cordey and Shipp, 1981, p. 390, pl. 1, fig. 5,

Diagnosis and remarks: Involute close coiled portion of four to five inflated chambers followed by a single inflated chamber in the uncoiled part. The sutures are slightly depressed resulting in a lobate outline.

This species is distinguished by its inflated chambers and small size. Barnard (1953) noted development of a curvilinear uncoiled portion of two to three chambers, but this is not seen in the Portuguese examples. The Portuguese material closely resembles specimens from the Oxford Clay of England lacking the uncoiled stage, reported by Barnard *et al.* (1981).

Size: Maximum diameter, 0.3mm.

Occurrence: Cabo Espichel, samples I/16 (common) and K/3 (rare); Ericeira, samples B/2 and B/8 (common). Previously reported from England.

Stratigraphic age: Callovian-Oxfordian (Barnard *et al.* 1981). This study: Middle-Late Kimmeridgian, *Choffatella tingitana* zone.

Ammobaculites obliquus Loeblich & Tappan, 1949

Plate 2, figs. 9-10

Ammobaculites obliquus Loeblich & Tappan, 1949, p. 250, pl. 46, figs 4a-5; Skolnick, 1957, p. 281-282, pl. 36, figs. 3a-d; Crittenden, 1981, p. 20, pl. 2, figs. 4-6.

Diagnosis and remarks: Involute close coiled portion of five to seven chambers followed by uncoiled portion of one to four chambers. Chambers enlarge gradually as added, are generally higher than broad and are inflated at proximal sutures, constricted distally. Sutures are straight in the coiled portion, oblique in the uncoiled portion and highest dorsally. The terminal aperture is sometimes with a narrow lip. The test is agglutinated from silt.

This species is distinguished by the oblique sutures. It is identical to the forms from the Walnut Clay, illustrated by Loeblich and Tappan (1949). The species is common to abundant in silts and clays.

Size: maximum test length, 0.64mm; maximum test thickness (uniserial portion), 0.17mm; maximum coil diameter, 0.14mm.

Occurrence: Cabo Espichel, sample L/5 (common); Ericeira, samples E/2, E/8, F/2, H/2 (common to abundant). Widely reported from north America, and from southern England.

Stratigraphic age: Early Aptian (Crittenden 1981, Atherfield Clay, southern England); Albian (Skolnick 1958, Black Hills, Wyoming, U.S.A.). This study: Valanginian-Middle

Hauterivian, *Haplophragmoides inconstans* to *Marsonella kummi* zone, *Ammobaculites obliquus* subzone.

Ammobaculites reophacoides Bartenstein, 1952

Plate 2, figs. 11-12

1952 *Ammobaculites reophacoides* Bartenstein, 1952, p.307, fig. 1; Bartenstein & Bettenstaedt, 1962, p. 279, tab. 18, tab. 36, fig. 9; Bhalla & Abbas, 1978, p. 172, pl. 3, fig. 4.

Diagnosis and remarks: Close coiled involute planispire of two to three chambers followed by uncoiled portion of three to four chambers. The coil diameter is generally less than the width of the uncoiled part. Sutures are straight and depressed. The early chambers in the uncoiled portion are broader than high, while the final chamber is of greater height than width and is drawn out, inflated towards the suture. The test is agglutinated from fine sand and silt.

This species is distinguished by its reduced coiled portion and the drawn out nature of the final chamber. Portuguese specimens are identical to those figured by Bartenstein & Bettenstaedt (1962).

Size: Maximum test length, 1.0mm; maximum test width (final chamber), 0.33mm.

Occurrence: Ericeira, sample H/2. Also reported from southern England, N.W. Germany, and India.

Stratigraphic age: Oxfordian (Bhalla & Abbas 1978, Kutch, India); Berriasian-Barremian (Fletcher, 1973, Hart *et al.* 1981, England); Lower Aptian (Crittenden 1981, Atherfield Clay, southern England). Bartenstein (1977, 1979) suggests this species is an important

stratigraphic marker for the Barremian to Albian stages in both the northern and southern hemisphere. The Portugal finding extends the range to Middle to Upper Hauterivian. This study: Middle-Upper Hauterivian, *Marsonella kummi* zone, *Ammobaculites obliquus* subzone.

Ammobaculites subcretaceus Cushman & Alexander, 1930

Plate 2, figs. 13-16; Plate 3, figs. 1-5

Ammobaculites subcretaceus Cushman & Alexander, 1930, p. 6, pl. 2, figs. 9-10; Loeblich & Tappan, 1949, p. 251, pl. 46, figs. 9-13; Maync, 1973, p. 1004, pl. 1, fig. 19; Magniez-Jannin, 1975, p. 42-44, pl. 1, figs. 28-39; Crittenden, 1981, p. 19, pl. 2, figs. 2-3.

Diagnosis and remarks: Flattened planispire of four to nine chambers followed by uncoiled portion of one to four chambers. The coil is partially evolute, displaying chambers of previous whorl in the excavated umbilical region. The early chambers of the uncoiled portion are frequently broader than high, sometimes irregular or wedge shaped, and the final chamber may be inflated. Sutures are indistinct. The coiled portion of the test is agglutinated from fine sand to silt size grains, while the uncoiled portion is constructed from coarser sand grains up to 350 μm diameter.

Magniez-Jannin (1975) described the variability of this form in the Albian of France, and recognised a microspheric generation with a large spire of six to eight chambers, and a megalospheric form with a small spire of four to six chambers. Similar variation is shown in the examples figured in Loeblich & Tappan (1949). The Portuguese specimens include both large and small coiled variants. An interesting feature is that the coarse grained uncoiled portion does not commence as a simple uncoiling of the planispire, but it angles back on itself at 90 to 120 degree tangent to the coil, resulting in a biserial appearance in the initial stages.

The compressed nature of the test, along with the pseudo-biseriality, give specimens an appearance similar to *Ammobaculoides plummerae* Loeblich. Immersion in glycerine, however, reveals areal rather than basal apertures in the planispire, a characteristic of *Ammobaculites*.

Dimensions: Maximum test length 0.87mm; maximum test width, 0.27mm; maximum coil diameter, 0.35mm.

Occurrence: Cabo Espichel, samples L/2 (rare) and L/5 (common; Ericeira, samples MB/5, MB/6a (rare), C/10 (abundant), MB/7, E/1, E/4, E/5, E/6 (rare to common), E/8, F/1, F/2 (abundant). Widely reported from Europe and North America.

Stratigraphic age: Valanginian (Fletcher 1973, Speeton Clay, bed D4); Barremian (Maync 1970, DSDP Site 120); Early Aptian (Crittenden 1981, Atherfield Clay, England); Albian (Magniez-Jannin 1975, France). This study: Berriasian-Middle Hauterivian, *Anchispirocyclina lusitanica* zone, *Ammobaculites subcretaceus* subzone to *Marsonella kummi* zone, *Ammobaculites obliquus* subzone.

Ammobaculites sp.A

Plate 5, figs. 1-7

Diagnosis and remarks: Test small, stout, with an inflated coil of two to three closely appressed chambers followed by uncoiled portion of one or two chambers; the uncoiled portion partially overlaps the earlier coil; the sutures are depressed, straight to gently curved, and often indistinct in the coil; the peripheral margin is lobate; the aperture is surrounded by a thick rim.

Size: Maximum length, 0.32mm; diameter of coil, 0.17mm.

Remarks: *Ammobaculites* sp.A. is recognised by its small size, stout form and inflated chambers. It differs from the small Jurassic species *A. godmani* (Barnard) in having fewer chambers in the coiled portion, and in its more rapid chamber growth. The Lower Cretaceous species *Ammobaculites obliquus* Loeblich and Tappan resembles *Ammobaculites* sp.A, particularly specimens with reduced uncoiled portions, however the former possesses a larger coil typically containing 5-7 chambers and lacks the thick apertural rim seen in *Ammobaculites* sp.A. The species *Ammobaculites torosus* Loeblich and Tappan also resembles *Ammobaculites* sp.A, but is 2-3 times as large, has a relatively larger coil, and distinctive sutures. Our specimens are finely agglutinated from silt, and occur in silt facies interpreted as marsh deposits.

Occurrence: Cabo Espichel, sample L/5 (rare); Ericeira, sample E/6 (abundant).

Stratigraphic age: Late Valanginian, *Ammobaculites* sp.A zone.

Genus FLABELLAMMINA Cushman, 1928

Flabellamina vitrea Crespin, 1963

Plate 3, fig. 9

1963 *Flabellamina vitrea* Crespin, 1963, p. 47-48, pl. 12, figs. 12-16; Haig 1980, p. 109, pl. 4, figs. 16-17.

Diagnosis and remarks: Compressed, with an indistinct coil of 3-5 chambers and a later uncoiled stage with 3-4 broad, low chevron shaped chambers; aperture ovate; the test is agglutinated from sand and silt.

This species has only been described from Australia where it is dated as Aptian. Portuguese specimens represent the first documentation of this species from the northern hemisphere. Specimens are poorly preserved, but resemble those figured by Haig (1980).

Specimens are found in silt facies in low diversity agglutinated assemblages.

Size: Maximum test length, 0.8mm; maximum test width, 0.56mm.

Occurrence: Ericeira, sample E/7, rare. Also reported from Australia.

Stratigraphic age: Albian (Haig 1980), northern Carpentaria Basin, Queensland, Australia).

This study: Early Hauterivian, *Marsonella kummi* zone, *Trochammina depressa* subzone.

Genus HAPLOPHRAGMIUM Reuss, 1860

Haplophragmium inconstans erectum Bartenstein and Brand 1951.

Plate 3, figs. 6-8

1951 *Haplophragmoides inconstans erectum*, Bartenstein and Brand, 1951, p. 272-273, pl. 3, figs. 50-61; Sliter, 1980, p. 374, pl. 2, figs. 19-20.

Diagnosis and remarks: Early part of the test is streptospirally coiled, with three chambers; the later portion is uniserial, with up to 6 chambers; sutures are slightly depressed, straight; the peripheral margin is slightly lobate.

This species is distinguished by the streptospirally coiled initial part. The chambers are quite inflated, but closely appressed, and the sutures are rather indistinct in many cases. Specimens are finely agglutinated from silt.

Bartenstein and Brand (1951) divided the species into three sub-species, *Haplophragmoides inconstans erectum*, *H. inconstans gracile*, and *H. inconstans inconstans*. The Portuguese specimens compare with those figured in Bartenstein and Brand (1951) as *H. inconstans erectum*. Specimens occurs sporadically in nodular limestone and occasionally in silt.

Size: Maximum test length, 0.77mm; maximum test width, 0.4mm.

Occurrence: Cabo Espichel, samples L/4, M/2, and M/4; Ericeira, samples MB/7, and E/6.

Reported from Europe and north Africa.

Stratigraphic age: Tithonian-Berriasian (Sliter 1980, DSDP Site 416, Agadir Canyon, north Africa); Middle Valanginian (Bartenstein & Brand 1951, N.W. Germany). This study: Valanginian-Early Hauterivian, *Haplophragmium inconstans* to *Marsonella kummi* zone, *Trochammina depressa* subzone.

Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily SPIROPECTAMMININAE Cushman, 1927

Genus SPIROPECTAMMINA Cushman, 1927

Spiropectammina ammovitrea Tappan

Plate 3, figs. 10-11

1940 *Spiropectammina ammovitrea*, Tappan, 1940, p. 97, pl. 14, fig. 13 a-b; Frizzell, 1954, p.66, pl. 4, figs. 22a-b; Scheibnerova, 1976, p. 48, pl. 8, fig. 6; text-figs. 21-22; Sliter, 1981, p. 376, pl. 3, figs. 1-5.

Diagnosis and remarks: Test compressed with a planispirally coiled early portion of 5-6 chambers and a later biserial portion with 5-6 pairs of chambers. Biserial portion with almost parallel, but slightly lobate margins; sutures oblique, slightly depressed. Aperture a small arch.

This species is distinguished by its near parallel margins. The oblique sutures are rather indistinct in the specimens examined. The Portuguese material compares well with examples illustrated by Scheibnerova (1976) from the Lower to middle Albian of Australia, and those figured by Sliter (1980) from DSDP Site 416 in the eastern north Atlantic. Specimens are agglutinated from silt.

Size: Maximum test length, 0.52mm; maximum coil diameter, 0.12mm.

Occurrence: Ericeira, samples E/7 and H/2 (rare). Also reported from North Africa and Australia.

Stratigraphic age: Early Aptian-Albian, (Sliter 1981, DSDP site 416, Agadir Canyon, north Africa); Early-mid Albian (Scheibnerova 1976, Conrada Ooroonoo borehole, Queensland, Australia). This study: Hauterivian, *Marsonella kummi* zone.

Spiroplectammia dorni Michael, 1967

Plate 3, fig. 12

1967 *Spiroplectammia dorni* Michael, 1967, p. 28-29, text fig. 7a,b; Bartenstein, 1978, p. 22, text fig.2.4.

Diagnosis and remarks: Test conical, with an initial small planispiral coil of 4 to 5 chambers. The later biserial portion is of 7 to 8 pairs of chambers; sutures are feint and slightly depressed. The aperture is an elongate slit.

This species is distinguished by its tapering biserial portion. The initial planispire helps distinguish it from otherwise similar species belonging to *Dorothia*.. The species is rare in Portugal, and is found in shaley limestone.

Size: Maximum test height, 0.33mm; maximum test width, 0.165mm.

Occurrence: Cabo Espichel, sample M/7; Ericeira, samples H4 and H5. Previously reported from Germany.

Stratigraphic age: Hauterivian (Bartenstein 1978, N.W. Germany). This study: Late Hauterivian, *Marsonella kummi* zone. Bartenstein (1978) placed the species in a phylogenetic lineage that included *Marssonella kummi* and *D. subtrochus*. According to Bartenstein's (1978) phylogeny, *Spiroplectammina dorni* evolved from *D. (M). kummi* through a change in the initial spire form triserial to planispiral in the lower Hauterivian, and ranged into the upper Hauterivian

Family TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager, 1877

Genus TROCHAMMINA Parker & Jones, 1859

Trochammina depressa Lozo 1944

Plate 4, figs. 1-3

Trochammina depressa Lozo, 1944, p. 552, pl. 2, figs. 4a-5; Loeblich & Tappan, 1949, p. 256, pl. 49, figs. 1a-2; Haig, 1980, p. 117, pl. 6, figs. 5-7; Crittenden, 1981, p. 21, pl. 2, fig. 13.

Diagnosis and remarks: A strongly compressed form with a lobate periphery; dorsal side a low trochospire with 2 whorls visible, and gently curved sutures; ventral side flat with 5 to 7 chambers visible, increasing in size moderately as added, sutures straight to gently curved.

This species is distinguished by its compressed test and lobulate outline. *Trochammina depressa* Lozo is distinguished from *T. limbata* (Chapman) by the greater compression of the test, lower spire, and more rapid increase in chamber size with growth. The sutures tend to be indistinct and not as strongly curved on the ventral side, rather than limbate as in *T. limbata*.

Variability is seen in the nature of the sutures and number of chambers on the ventral side. The final chamber in many specimens is as broad as high, a feature similar to

that in *Trochammina guamata* Jones & Parker and *T. limbata*. Specimens are finely agglutinated from silt.

Size: Maximum diameter, 0.34mm; thickness, 0.13mm.

Occurrence: Ericeira, samples E/7 (frequent), E/8 and E/10 (common). Widely reported from Europe, America and Australia.

Stratigraphic age: Early Aptian (Crittenden 1981, southern England); Albian (Haig 1980, Queensland Australia). This study: Early Hauterivian, *Marsonella kummi* Zone, *Trochammina depressa* subzone.

Trochammina globigeriniformis (Parker & Jones)

Plate 3, fig. 17

Lituolia nautiloidea Lamark, var. *globigeriniformis* Parker & Jones, 1865, p. 407, pl. 15, figs. 46-47, pl. 17, figs. 96-98.

Trochammina globigeriniformis (Parker & Jones); Cushman, 1910, p. 124. text-figs. 193-195; Lloyd, 1959, p. 317, pl. 54, fig. 31; text-fig. 5c; McNeil & Caldwell, 1981, p. 168-169, pl. 13, figs. 9a-c; Maync, 1970, p. 1084, pl. 1, figs. 27-28.

Diagnosis and remarks: Planoconvex with one and a half to two and a half whorls visible on the spiral side. Chambers increasing gradually in size as added, and gently curved sutures on the dorsal side. Four inflated and moderately appressed chambers visible on umbilical side, with strongly depressed, straight sutures. The umbilicus is narrow and deep.

This species is recognised by its four globose chambers seen in the final whorl. Specimens are finely agglutinated from silt.

Size: Maximum diameter, 0.25mm; maximum height, 0.1mm.

Occurrence: Ericeira, samples E/7 and E/8 (common). Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Lloyd 1962); Barremian - Albian (Maync 1970, DSDP Site 120). This study: Early Hauterivian, *Marsonella kummi* zone, *Trochammina depressa* subzone.

Trochammina raggatti Crespín 1944

Plate 4, figs, 7-9

Trochammina raggatti Crespín, 1944, P.20, pl. 1, figs. 4a-5; Scheibnerova, 1976, p. 52-53, pl.13, fig. 7; pl. 14, figs. 1-5; pl. 15, figs. 1-3; text-figs. 33-36; Haig, 1980, p.118-119, pl. 6, figs. 11-16; pl. 11, fig. 8.

Diagnosis and remarks: A compressed, bi-convex form characterised by an extension of the final chamber over the umbilical region as a bulla. Five or 6 chambers seen on the umbilical side, with radiate depressed sutures. The bullate extension of the final chamber has 6 or more accessory marginal apertures. Two whorls are visible on the dorsal side with chambers increasing gradually as added, and depressed, slightly curved sutures. The peripheral margin is lobate, the axial profile lenticular with a rounded periphery.

The umbilical bulla with the secondary apertures characterise this species. Portuguese specimens are generally more compressed and smaller than the Australian forms figured in Scheibnerova (1976) and Haig (1980), but are otherwise the same. Tests are finely agglutinated from silt. The form has previously only been described from Australia.

Size: Maximum diameter, 0.3mm; Maximum thickness 0.15mm.

Occurrence: Ericeira, samples E/6 and E/7 (abundant). A commonly occurring species in Australia.

Stratigraphic age: Early Aptian (Scheibnerova 1976, Queensland, Australia). This study: Late Valanginian - Early Hauterivian, *Ammobaculites* sp.A to *Marsonella kummi* zone, *Trochammina depressa* subzone.

Trochammina aff. *quineloba* Geroch 1959

Plate 4, figs. 4-6

Trochammina quineloba Geroch, 1959, p. 118, tab. 12, fig. 1-3; Gradstein, 1983, pl. 1, figs. 10-11.

Diagnosis and remarks: An inflated form with a low trochoid spire. Two to 2.5 whorls visible on the dorsal side with straight, depressed sutures. The umbilical side has 5 to 5.5 chambers visible, the final chamber one and a half times larger than the penultimate. The umbilicus is open and deep, the sutures strongly depressed and straight. Chambers increase in size gradually. The peripheral margin is lobate, and the periphery broadly rounded.

This form is characterised by its low spire, inflated chambers and a deep umbilicus. The Portuguese specimens differ from *Trochammina quineloba* Geroch in having only 2 to 2.5 whorls visible on the spiral side instead of 3, a more inflated final chamber and an open umbilicus. The form is finely agglutinated from silt.

Size: Maximum diameter 0.3mm; maximum thickness, 0.22mm.

Occurrence: Ericeira, samples E/5 and E/7 (common).

Stratigraphic age: Berriasian to Cenomanian (Polish Carpathians, Geroch 1959); Tithonian to Berriasian (DSDP. Site 534, Gradstein 1983). This study: Late Valanginian- Early Hauterivian, *Haplophragmium inconstans* to *Marsonella kummi* zone, *Trochammina depressa* subzone.

Genus TIPHOTROCHA Saunders 1957

?*Tiphotrocha* sp.

Plate 4, figs. 10-12

Diagnosis and remarks: A low trochospiral compressed form that is flat to gently convex on the dorsal side and flat to excavated on the umbilical side. Two and a half to 3 whorls visible on the dorsal side with the early chambers increasing in size rapidly with growth, but later chambers increasing more slowly. Sutures are gently curved but poorly defined. The peripheral outline is lobate. The umbilical side has 5 to 6 crescentic shaped chambers visible, each with a small lobe extending into the umbilicus. Secondary apertures are in posterior re-entrants behind the umbilical lobes. The umbilicus is small and open.

The secondary apertures differentiate this form from the genus *Trochammina*. Specimens are not well preserved and the secondary apertures tend to be infilled making distinction from *Trochammina depressa* difficult. The specimens are otherwise similar to the Recent form *Tiphotrocha comprimata*. The tests are agglutinated from silt.

Size: Maximum diameter, 0.33mm; maximum thickness, 0.15mm.

Occurrence: Ericeira, samples E/5, E/7, and E/8 (abundant).

Stratigraphic age: Late Valanginian- Early Hauterivian, *Haplophragmoides inconstans* to *Marsonella kummi* zone, *Trochammina depressa* subzone.

Family ATAXOPHRAGMIIDAE Schwager, 1877

Subfamily VERNEULININAE Cushman, 1911

Genus VERNEULINOIDES Loeblich & Tappan, 1949

Verneulinoides minuta Said & Barakat 1968

Plate 3, figs 13-14

Verneulinoides minuta Said & Barakat, 1968, p. 242-243, pl. 4, figs. 25a-b; Stam, 1986, pl.4, fig.4.

Diagnosis and remarks: The test is sub-triangular in section, a high trochospire of 4 whorls. Chambers are inflated and increasing in size rapidly. The last whorl occupies roughly half of the length of the test. Sutures are distinct and depressed.

This species is distinguished by its rapid chamber growth and the inflated final chambers. Portuguese specimens are slightly larger than those figured in Said & Barakat (1968) and Stam (1986). Specimens are agglutinated from silt.

Size: Maximum length, 0.4mm; width, 0.4mm.

Occurrence: Cabo Espichel, samples I/3, I/5, I/6, I/7, I/8, I/10, I/16, I/17 (rare to common);

Ericeira, sample B/1 (rare); Praia Azul, sample A/5 (rare).

Stratigraphic age: Late Oxfordian (*Planula* zone, Stam 1986); Kimmeridgian (Said & Barakat 1968). This study: Early - Middle Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Subfamily GLOBOTEXTULARIINAE Cushman, 1927

Genus MARSSONELLA Cushman, 1933

Marssonella kummi Zelder 1961

Plate 3, figs. 15-16

Marssonella kummi Zelder, 1961, p.31, pl. 7, fig.1; Maync, 1970, p. 1086-1087, pl.1, figs.38-39.

Diagnosis and remarks: The test has an early trochospiral stage of 3 to 4 chambers and a conical biserial stage of 6 to 8 pairs of chambers. The sutures are flush or slightly depressed, but indistinct. The apertural face is slightly concave.

Variability is seen in the rate of chamber growth, those with rapid growth approaching the flared conical shape of *M. subtrochus* Bartenstein. Maync (1970) regarded *Marsonella oxycona* and *M. kummi* to be synonymous on the basis of length to breadth ratios. Portuguese specimens have length to breadth ratios of between 1.4:1 and 1.9:1, within the range given by Maync (1970). Bartenstein (1978) placed *M. kummi* in a phylogeny with *Spiroplectammia dorni* and *D.(M) subtrochus* that evolved during the Hauterivian to Barremian. Portuguese specimens may be transitional between the latter forms. Specimens are finely agglutinated from silt.

Size: Maximum height, 0.37mm; maximum width, 0.2mm.

Occurrence: Cabo Espichel, sample M/7, rare; Ericeira, sample H/4, common. Reported widely from Europe.

Stratigraphic age: Barremian-Albian (Maync 1970, DSDP Site 120, Goringe Bank). This study: Late Hauterivian, *Marsonella kummi* zone.

Suborder ROTALIINA Delage & Herouard, 1896

Superfamily NODOSARIACEA Ehrenberg, 1838

Family NODOSARIIDAE Ehrenberg, 1838

Subfamily NODOSARIINAE Ehrenberg, 1838

Genus LENTICULINA Lamark, 1804

Lenticulina muensteri (Roemer, 1839)

Plate 6, fig.1

Robulina muensteri Roemer, 1839, p. 48, pl. 20, fig. 29.

Lenticulina muensteri (Roemer); Seibold & Seibold, 1956, p. 109, pl. 4, figs. a-b, pl. 5, figs. q-r; Gordon, 1962, p. 526-528, text-fig. 2 (1), (2); Stam, 1986, p. 122, pl. 5, figs. 7-8.

Diagnosis and remarks: Test with up to ten chambers in the final whorl, and an umbilical boss of clear calcite. The periphery is often sharp, but lacks a true keel. The sutures are often more depressed in later chambers, and recurved towards the margin. The later stage may uncoil.

Variability within Portuguese specimens is similar to that outlined by Gordon (1962).

Dimensions: Maximum diameter, 0.47mm; maximum thickness, 0.22mm.

Occurrence: Cabo Espichel, samples J/1, J/2, I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/8, I/9, I/10, I/13, I/14, I/15, I/16, I/17, I/18, I/19, I/20, I/21, I/22, L/4, M/8 (rare to common); Ericeira, samples B/1, B/2, MB/6, E/4 (rare to common). Widely reported from Europe.

Stratigraphic age: Callovian (Gordon, 1967); Rhaetian-Portlandian (Coleman *et al.* 1981); Berriasian-Barremian (Hart *et al.* 1981); Hauterivian (Fletcher 1973, Speeton Clay, England). This study: Kimmeridgian-Early Barremian, *Mesoendothyra* sp.A to

Choffatella decipiens zone.

Family POLYMORPHINIDAE d'Orbigny, 1839

Subfamily POLYMORPHININAE d'Orbigny, 1839

Genus EOGUTTULINA Cushman & Ozawa, 1930

Eoguttulina liassica (Strickland)

Plate 6, fig. 2

Polymorphina liassica Strickland, 1846, p. 31, text-fig. b.

Eoguttulina liassica (Strickland); Bartenstein & Brand, 1937, p. 178, pl. 1a, fig. 24a-b; pl. 2a, fig. 23; pl. 2b, fig. 35; pl. 3, fig. 49; pl. 4, fig. 74a-b; pl. 5, fig. 69a-b; Lloyd, 1962, p. 370-372, figs. 1a-d, 2a-c, 3a-c; text-fig. 2a-e.

Diagnosis and remarks: A small species of *Eoguttulina* with a lobate outline. The early chambers are sub-globose while the later chambers are elongate.

Variability is seen in the inflation of the chambers and depression of the sutures, specimens with weakly depressed sutures and small chambers are similar to *Eoguttulina oolithica*.

Size: Maximum length 0.35mm; maximum width, 0.2mm.

Occurrence: Cabo Espichel, samples J/1, J/2, I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/9, I/13, I/17, I/19, I/20, K/4, L/4 (rare to common); Ericeira, samples B/1, B/2, B/7, E/4 (rare to common); Praia Azul, samples A/1, A/2, A/3, A/4, A/5, A/7, A/8, A/9, A/10 (abundant). Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Lloyd 1962, Kimmeridge Clay, England); Valanginian (Bartenstein and Brand, 1937). This study: Kimmeridgian - Valanginian, *Mesoendothyra*

sp.A to *Haplophragmiun inconstans* zone.

Eoguttulina inovroclaviensis (Bielecka & Pozaryski)

Plate 6, fig. 3

Sigmomorphina inovroclaviensis Bielecka & Pozaryski, 1954, p. 192, pl. 9, fig. 47a-c.

Eoguttulina inovroclaviensis (Bielecka & Pozaryski); Lloyd, 1962, p. 372, pl. 1, fig. 7a-c; text-fig. 4a-b; Barnard & Shipp, 1981, p. 14, pl. 3, figs. 6-8.

Diagnosis and remarks: The test has elongate, narrow chambers that are added at about 180 degrees to each other. The species is distinguished from *E. liassica* by the relatively longer test.

Size: Maximum length, 0.37mm; maximum width, 0.17mm.

Occurrence: Cabo Espichel, samples I/13, I/14, I/16, I/17, I/19, I/22, K/4, K/5, M/8 (rare to common); Ericeira, samples B/1, B/2, B/7, E/6 (rare to common). Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Barnard & Shipp 1981). This study: Kimmeridgian - Early Barremian, *Mesoendothyra* sp.A to *Choffatella decipiens* zone.

Eoguttulina metensis (Terquem)

Plate 6, fig. 4

Polymorphina metensis Terquem, 1864, p. 301, pl. 13, fig. 38a-b.

Eoguttulina metensis (Terquem); Lloyd, 1962, p. 372, pl. 1, figs. 6a-c, text-figs. 6a-b.

Diagnosis and remarks: The test is smooth and fusiform with quinqueloculine growth, but

as the sutures are only slightly depressed this is often difficult to see. Lloyd (1962) suggested this species is allied to *E. oolithica* on the basis of the faint sutures and fine, closely set pores.

Size: Maximum length, 0.4mm; thickness, 0.12mm.

Occurrence: Cabo Espichel, samples I/13 (rare), I/16 (common), I/17, I/19, I/20, I/21, I/22, I/23, M/2 and M/6 (rare). Ericeira, samples B/6 and E/4 (rare). Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Lloyd 1962). This study: Middle Kimmeridgian- Late Hauterivian, *Choffatella tingitana* zone to *Marsonella kummi* zone.

Eoguttulina oolithica (Terquem)

Plate 6, fig. 5

Polymorphina oolithica Terquem, 1864, p. 299, pl. 32, figs. 1-5, 8-10.

Eoguttulina oolithica (Terquem); Lloyd, 1962, p. 373, pl. 1, figs. 5a-c, text-fig. 5A,B.

Diagnosis and remarks: The test is ovoid to ellipsoid with a smooth outline. The sutures are slightly depressed and may be obscure.

Lloyd (1962) noted microspheric forms up to 0.44mm in length with 7-8 chambers, and megalospheric forms up to 0.33 mm long with 3-7 chambers in material from southern England. Portuguese specimens, on the basis of their size, are megalospheric.

Size: Maximum length, 0.2mm; thickness, 0.13mm.

Occurrence: Cabo Espichel, sample I/13, I/16, I/17, I/18, I/19, I/21, I/22 and K/5 (rare to

common); Ericeira, B/1 (frequent) B/8 (rare); Praia Azul, A/2, A/3, A/6 (rare). Widely reported from Europe.

Stratigraphic age: Kimmeridgian (Lloyd 1962). This study: Middle-Late Kimmeridgian, *Choffatella tingitana* zone.

Eoguttulina bilocularis (Terquem, 1864)

Plate 6, fig. 6

Polymorphina bilocularis Terquem, 1864, p. 293, pl. 11, figs. 9-32.

Eoguttulina bilocularis (Terquem); Luterbacher, 1970, p. 580, pl. 2, fig. 27; Ruget, 1973, p. 537, pl. 8, figs. 8-10; Stam, 1986, p. 117, pl. 5, fig. 4.

Diagnosis and remarks: A species of *Eoguttulina* with an inflated final chamber that partly overlaps those preceding. The suture at the base of final chamber is clearly depressed whilst those of earlier chambers are weak, resulting in a pseudo- bilocular appearance.

Size: Maximum length, 0.62mm; thickness, 0.17mm.

Occurrence: Ericeira, samples B/1 (common), B/2 (rare).

Stratigraphic age: Callovian (Stam 1986, Portugal). This study: Early-Middle Kimmeridgian, *Mesoendothyra* sp.A zone.

Superfamily DISCORBACAE Ehrenberg, 1838

Family DISCORBIDAE Ehrenberg, 1838

Subfamily DISCORBINAE Ehrenberg, 1838

Genus DISCORBIS Lamark, 1804

Discorbis scutiliformis (Seibold and Seibold, 1960)

Plate 6, fig. 7-9

Conorbina scutiliformis Seibold and Seibold, 1960, p.381, figs. 8c,d.*Discorbis scutiliformis* (Seibold and Seibold); Wernli, 1971, p. 338, pl. 6, figs. 18, 21, 22, 24, pl.7, figs. 11,12.

Diagnosis and remarks: Plano-convex test with 2 to 2.5 whorls visible on the dorsal side and 8 chambers in final whorl. The sutures are limbate and strongly curved. The umbilical side is flat to slightly concave with indistinct sutures. Each chamber on the umbilical side has a flap that extends from its base into the umbilicus. Secondary apertures are on the proximal side of chamber flaps.

This species is distinguished from *D. paraspis* by the final chamber which is broader than high.

Size: Maximum diameter, 0.68mm; thickness, 0.2mm.

Occurrence: Cabo Espichel, sample K/6 (abundant). Common in Europe.

Stratigraphic age: Upper Jurassic: Oxfordian-Kimmeridgian (Stam 1985, Portugal). This study: Late Kimmeridgian-Early Portlandian, *Anchispirocyclina lusitanica* zone, *Discorbis scutiliformis* subzone.

Superfamily ROBERTINACEA Reuss, 1850

Family CERATOBULIMINIDAE Cushman, 1927

Subfamily EPISTOMININAE Wedekind, 1937

Genus EPISTOMINA Terquem, 1883

Epistomina uhligi Mjatluk, 1953

Plate 6, figs. 10-11

Epistomina uhligi Mjatluk, 1953, P. 219, pl. 2, fig. 5; Ohm, 1967, p. 128, text-figs. 22-24; Gradstein, 1978, pl.1, fig. 2; Stam, 1986, p. 120, pl. 1, figs. 7-14; Williamson & Stam, 1987, p. 30, pl. 5, figs. 8-9.

Diagnosis and remarks: A smooth bi-convex epistominid with lateromarginal apertures on the last two chambers only.

Williamson and Stam (1987) noted variability in the convexity of the ventral side and the development of the umbilical boss. Portuguese specimens have small umbilical bosses, and a ventral side slightly more convex than the dorsal side. Specimens are poorly preserved with indistinctive sutures.

Size: Maximum diameter, 0.47mm; maximum thickness 0.33mm.

Occurrence: Cabo Espichel, samples I/2, I/17, I/18, I/22, and K3. Widely reported from Europe.

Stratigraphic age: Kimmeridgian-Tithonian (Williamson & Stam, 1988). This study: Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

8.4: Larger foraminifera taxonomy and thin section morphology:

Subfamily CYCLAMMININAE Marie 1941

Genus MESOENDOTHYRA Dain 1958

Mesoendothyra sp.A

Plate 7, Figs. 1-11.

Description: Test inflated, involute with plectogyral coiling. One and a half to three whorls with 4 to 8 chambers in final whorl. Chambers embrace earlier ones and increase in size gradually as added. The final chamber is often narrower than the penultimate one, and may extend to umbilicus on one side of the test, and half distance to umbilicus on other side. The umbilicus is closed. The sutures are gently curved and slightly depressed. The peripheral outline is subcircular and slightly lobate and the axial profile is ovate to lenticular and broadly rounded. The aperture is an interiomarginal semicircular arch that extends half the distance of the apertural face. The test is finely agglutinated from carbonate grains, as determined from. The inner wall structure is complex, with coarse alveoles extending inwards below an imperforate outer layer. The septa are massive and imperforate.

Remarks: *Mesoendothyra* sp.A is distinguished from globose forms of *Pseudocyclamina* by its inflated test, plectogyral coiling, the semicircular aperture and the coarse alveoles and imperforate septa seen internally. Two forms are recognised in the Portuguese material: a larger lenticular form with an assymetric final chamber; a smaller globose form with a near symmetric final chamber. The larger form is 0.55-0.60 mm in diameter, contains 2.5 to 3 whorls and has a simple proloculus of 0.028-0.05mm diameter, and is interpreted to be the microspheric generation. The smaller form, interpreted as the megalospheric generation, is 0.21-0.38 mm in diameter, contains one to one and a half whorls and has a complex proloculus of 85-130 μ m diameter with a protoconch and a deuterococonch of equal size.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4 (frequent), I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/8 (rare); Ericeira, samples B/1, B/3 (rare); Praia Azul, samples A/7 (rare), A/8 (abundant).

Stratigraphic age: Early Kimmeridgian, *Mesoendothyra* sp.A zone, beds 6 to 26 of Ramalho (1971).

Genus CHOFFATELLA Schlumberger, 1905

Choffatella decipiens Schlumberger 1905

Plate 8, figs. 1-4, 8.

Choffatella decipiens Schlumberger, 1905, p.155-157; Maync, 1950, p. 539; Moullade, 1966, pl. 1, fig.3, pl. 10, fig. 4; Hottinger, 1967, p. 65, text-fig. 32 a-e, pl. 1, fig. 8, pl. 14, figs. 23-27; Rey, 1972, p. 314, pl. X, fig. 3; Jaffrezo, 1980, p. 380, pl. 32, fig. 3.

Emended description (Maync, 1950, p. 539):

"Plasmostracum planispiral, discoidal, generally involute; chambers in the adult arranged in crosier-shape; last whorl composed of 16 to 25 (on an average 18-20) arcuate narrow chambers arranged in a peneroplis-like spire with coils progressively increasing in height (close coiled early chambers); about 8 chambers in straight portion; septa and lumina of chambers of about same breadth; the strongly forward recurved septa systematically pierced by numerous transverse, parallel- running channels which lead to the linear series of pores on the narrow apertural face; septa non-labyrinthic; imperforate epidermal layer composed of both calcareous material and foreign particles in varying proportions, with the extreme of entirely calcareous or almost exclusively sandy tests; subepidermal layer with regular transverse (and subordinately parallel) partitions (delicate alveolar wall structure); the webb-like near surface reticulum which intercommunicates with the septa channels is distinctly displayed in tangential shallow thin sections.

"Some microspheric specimens studied disclose a more irregular, whimsical growth, the systematic forming of regular chambers and delicate septa having periodically been interrupted and given way to an agglutination of coarse quartz grains at random as in primitive lituolid representatives.

"The tendency of uncoiling is often evidenced in microspheric specimens. The microspheric form (B) differs from the megalospheric one by its very small proloculus, its closer coiled spire in the early stages, and its larger size".

Remarks: The microspheric form has 18-25 chambers in the final whorl, and is often more than 2mm in diameter. The proloculus of this form is too small to be measured in thin section. The megalospheric form is generally less than 1.5mm in diameter with 18-20 chambers in the final whorl and a proloculus of 20 - 60 μm diameter. This form is relatively fatter than the microspheric one, with an equatorial : axial ratio of around 3-5, (compared to 6-7 in the microspheric form).

Choffatella is distinguished externally from *Anchispirocyclina* and *Alveosepta* by the linear pores along the apertural face. Distinction of the fatter megalospheric examples from *Pseudocyclamina* is also based on apertural characters and also by the greater number of chambers in the final whorl. Internally, *Choffatella* has simple septa that lack the alveolar layer seen in *Alveosepta* and without the septal buttresses seen in *Anchispirocyclina*. Axial sections show septa pierced by a single row of openings, rather than the multiple pores found in *Pseudocyclamina* and *Alveosepta*. *Choffatella decipiens* is distinguished from *C. tingitana* by its smaller megalospheric proloculus, tighter coil, greater equatorial: axial ratio and smaller number of chambers in the final whorl. Portuguese specimens are finely agglutinated from silt, although specimens from Ericeira contain inclusions of coarse silica that may disrupt growth of the septa.

Occurrence: Cabo Espichel, samples M/2, M/3, M/4, M/6, M/7, M/9 (abundant), M/5 and M/8 (rare); Ericeira, samples F/1, H/2 (rare), H/3, H/4, H/5, H/6 and H/7 (abundant).

Stratigraphic age: Late Hauterivian-Aptian (Rey 1972, Portugal); Barremian-Early Albian (Maync 1950, Caribbean). This study: Late Hauterivian-Early Barremian, *Marsonella*

kummi to *Choffatella decipiens* zone.

Choffatella tingitana Hottinger 1967

Plate 8, figs. 5-7

Choffatella tingitana Hottinger, 1967, p. 65-67, text-fig. 32 f-n, pl. 14, figs. 1-22.

Diagnosis and remarks: Test large, flat, planispirally coiled and partly evolute. In the final whorl there are 16 to 21 chambers visible, with strongly curved sutures. The peripheral margin is lobate and the periphery is round. The equatorial diameter 8 to 12 times the thickness of the test. The aperture consists of a single row of pores. The wall structure is complex, with a subepidermal layer of alveoles at the chamber margins. Septa are simple, and of about the same thickness as chamber lumen, and are pierced by numerous straight pores aligned between successive chambers.

Hottinger (1967) recognised two generations of this species, a microspheric form with a diameter up to 2.0 mm and a sub-microscopic proloculus, and a smaller megalospheric form with a proloculus of 0.05 to 0.085 mm diameter. *Choffatella tingitana* is distinguished from the stratigraphically younger *C. decipiens* by its greater equatorial : axial ratio, looser partly evolute coil, and larger megalospheric proloculus. Portuguese specimens contain both forms. Specimens are finely agglutinated.

Peybernes and Rey (1975) reported a form intermediate to *Choffatella tingitana* and *C. decipiens*, called *C. pyrenaica*, from the Algarve region of southern Portugal. The latter species is not recognised in the Lusitanian Basin.

Size: Microspheric, maximum diameter 1.17mm; Megalospheric, maximum diameter 0.67mm.

Occurrence: Cabo Espichel, samples J/4, I/1, I/2, I/4, I/5, I/6, I/7, I/8, I/9, I/10, I/13,

I/16, I/17. Common to abundant; Ericeira B/1, B/2; Praia Azul, samples A/2, A/4 (common), A/5, A/9 (abundant), A/8 (frequent). Originally reported from north Africa.

Stratigraphic age: Kimmeridgian-Portlandian (Hottinger 1967, Morocco). This study: Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Genus EVERTICYCLAMMINA Redmond 1964.

Everticyclammina virguliana (Koechlin)

Plate 8, figs. 9-14

Pseudocyclammina virguliana Koechlin, 1942, p. 195-199, pl. VI, figs. 1-7.

Pseudocyclammina kelleri , Henson, 1948, pl.IX, Fig. 4,5,7.

Everticyclammina virguliana (Koechlin), Hottinger, 1967, p. 84-86, pl. 9, fig. 10-16, text-fig. 43; Ramalho, 1969, p. 149-150, pl. XIII, fig.3; pl. XVIII, figs. 1-6, 10; Brun and Rey, 1975, p. 15-36, pl. 1, figs. 1-7; pl. II, figs. 1-9; pl. III, figs. 1-4; pl. IV, figs. 1-7.

Diagnosis and remarks: The test has a planispiral involute early stage with 4-6 chambers visible in the final whorl, and an uncoiled later stage of up to 4 chambers. The sutures are incised, the chambers are slightly inflated, but often have a collapsed appearance toward the test periphery. The periphery of the test is lobed, with a sharp profile in the early stage that becomes rounded in later stages. The uncoiled portion when present is usually oval in section. The aperture varies from a short, to elongate slit, depending on the form of the final chamber, and when the test is coarsely agglutinated, may have a crenulated appearance.

In thin section the exoskeleton shows an internal layer of alveoles that are open at their inner ends and often bifurcate distally. Tangential sections of the alveoles reveal a circular section whilst longitudinal sections show that they have bulbous terminations.

The alveoles may be larger and well ordered toward the apertural end of each chamber.

The septa are massive and are pierced in the centre by a single opening up to one third of the test diameter in size. The positioning of the septa on the inner coil result in a stellate appearance.

Microspheric and megalospheric generations are recognised. The microspheric generation has a proloculus of around 30 μm diameter, and a planispiral portion of 2 whorls, the final whorl containing 9-11 chambers. The megalospheric generation has a proloculus of 120-240 μm diameter which communicates directly with the first spiral chamber bearing the exoskeletal alveoles. The planispiral portion of the megalospheric form has 1-2 whorls, with 6-8 chambers in the final whorl. The tendency to uncoil in the megalospheric generation is less than in the microspheric form. On external characters alone it is difficult to distinguish between the two forms.

Everticyclammina was erected by Redmond (1964), with *E. hensoni* as type species. Redmond (1964) distinguished *Everticyclammina* from *Pseudocyclammina* on the basis of its thinner, delicate walls and closure of the subepidermal cellules at their inner end. Hottinger (1967) presented an emended diagnosis of *Everticyclammina* on the basis of 'true rounded and shallow alveoles' seen in the exoskeleton, but noted difficulties distinguishing the genus from other members of the Lituolidae. In their biometric study, Brun and Rey (1975) concluded that *E. hensoni*, *E. contorta*, *E. eccentrica* and *E. elegans* were synonymous with *E. virguliana*, and attributed the wide variation in wall textures within the species to the type of sediment available. *E. greigi* (Henson), described from Lower Cretaceous strata, is distinguished from *E. virguliana* by its smaller size. *E. kelleri* (Henson) may be an evolutionary link between *E. virguliana* and *E. greigi* (F. T. Banner, personal communication 1988). Brun and Rey (1975), however, argued that size as a criteria for discrimination between species of *Everticyclammina* was not valid, and placed *E. greigi* (Henson) and *E. kelleri* in synonymy with *E. virguliana*. The taxonomy of *Everticyclammina* is reviewed in detail by Banner and Heighton (1990, in press).

Portuguese specimens compare well with those illustrated by Ramalho (1971) and are agglutinated from fine calcareous grains, although many tests have inclusions of smaller foraminifera or peloids.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2, I/3, I/4, I/8 (common to frequent), I/9 (abundant), I/10, I/13, I/16, I/17, I/18, I/19, I/20, I/21, I/23, K/4, K/5 (rare to frequent); Ericeira, samples B/1, B/2 (rare), B/3 (frequent), C/8 (rare); Praia Azul, samples A/1 (abundant), A/2, A/8, A/10 (rare to common).

Stratigraphic age: Early Kimmeridgian - Portlandian (Hottinger 1967, Morocco); Late Kimmeridgian - Berriasian (Ramalho 1969, Portugal). This study: Early Kimmeridgian - Berriasian, *Mesoendothyra* sp.A to *Haplophragmium inconstans* zone, *Ammobaculites subcretaceus* subzone.

Genus FEURTILLIA Maync, 1958

Feurtillia frequens Maync 1958

Plate 9, figs. 1-3

Feurtillia frequens Maync, 1958, p. 1-4, pl. 1, figs. 2-5, pl. 2, figs. 1-10; Hottinger, 1967, p. 56-57, pl. 9, figs. 24-29; text fig. 28.

Diagnosis and remarks: Compressed, planispiral involute, later uncoiling; 10 to 12 chambers in final whorl, up to 6 in the rectilinear stage; sutures indistinct, gently curved in the coiled portion, straight in the uncoiled part; peripheral margin polygonal to lobulate; aperture an elongate slit in the plane of coiling on the septal face of the last chamber; wall structure complex, a shallow subepidermal network of polygonal alveoles; septa thick, structureless, often recurve approximately as thick as chamber lumen, pierced by central opening.

This species is distinguished externally from *Everticyclammina* on its compact test and greater number of chambers in the last whorl. *Feurtillia* also lacks the collapsed chamber margins that are characteristic of *Everticyclammina*, and retains a low broad chamber profile throughout growth. Hottinger (1967) noted that the cross section of the alveoles appear circular in *Everticyclammina* and polygonal in *Feurtillia*.

The Portuguese specimens compare well to Maync's (1958) specimens, although uncoiled forms are rare. Specimens are agglutinated from silt.

Size: Maximum diameter of coil 0.4mm; Maximum length of test (including uniserial portion) 0.6mm

Occurrence: Cabo Espichel, rare to common in samples I/2, I/4, I/17, I/18, I/19, I/20, I/21, I/22, M/2; Ericeira, rare in sample B/2.

Stratigraphic age: Portlandian-Late Valanginian (Maync 1958, Swiss Jura). This study: Early Kimmeridgian - Hauterivian, *Mesoendothyra* sp.A to *Marsonella kummi* zone.

Genus PSEUDOCYCLAMMINA Yabe & Hanzawa, 1926

Pseudocyclammina lituus (Yokoyama, 1890)

Plate 9, figs. 4-6

Cyclammina lituus Yokoyama, 1890, p. 26, pl. 5, fig. 7.

Pseudocyclammina lituus (Yokoyama); Brun, 1962, p. 93-94, pl. 1, figs. 1-5; pl. 2, figs. 1-15; Hottinger, 1967, p. 57, text-fig. 29 a-b, pl. 10, figs. 11-13.

Diagnosis and remarks: Planispiral early stage with 6 to 7 closely appressed chambers, followed by uncoiled portion of up to 5 chambers, later chambers may be reduced in size; sutures slightly depressed, straight, radiate in coiled portion, horizontal in uncoiled portion; peripheral margin lobate, uniserial portion circular in cross section; aperture areal,

cribrate; wall structure complex, alveolar subepidermal layer; septa approximately as thick as chamber lumen, pierced by numerous pores.

This species is distinguished by the cribrate aperture, uncoiling tendency, and circular chamber cross section in the uncoiled portion. The Portuguese specimens compare well to the Moroccan examples illustrated by Hottinger (1967), and Brun (1962).

Size: 0.6 -3.0 mm in length.

Occurrence: Cabo Espichel, rare in samples I/2, I/4, I/5, I/6, I/10, I/17, I/20, I/23, common in sample I/18; Ericeira, rare in sample B/8. Widely reported from Europe and north Africa.

Stratigraphic age: Callovian to Valanginian (Brun 1962, S.W. Morocco). This study: Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Pseudocyclammia muluchensis Hottinger, 1967

Plate 9, figs. 7-10

Pseudocyclammia muluchensis Hottinger, 1967, p. 61, pl. 11, figs. 1-22

Pseudocyclammia sphaeroidalis Hottinger, 1967, p. 57, pl. 10, figs. 14-17, text fig. 29c.

Pseudocyclammia gr. *parvula* - *muluchensis* Hottinger; Ramalho, 1971, p. 147, pl. XIV, figs. 9-12, pl. XV, fig. 1.

Diagnosis and remarks: Planispiral involute, bilaterally compressed; 13 to 15 chambers in final whorl, equatorial diameter 1.5 to 3 times axial thickness; sutures flush to slightly depressed, curved, peripheral margin smooth to slightly lobate; aperture areal, cribrate; wall structure complex, an alveolar subepidermal layer; septa simple, 1 to 1.5 times the thickness of chamber lumen, pierced by numerous irregular pores across the full width of

the chamber; endoskeletal pillars sometimes developed in the central part of the test.

This species has a variable external morphology resulting from the amount of growth along the coiling axis. The axial profile of this species ranges from compressed lenticular (resembling *Alveosepta* or *Choffatella*), to globose (referred to by Hottinger (1967) as *P. sphaeroidalis*). Distinction of this species from those of similar appearance is based on thin section. The species lacks the broad band of septal pillars seen in *Anchispirocyclus lusitanica*, and the septa are not as strongly arched. *P. muluchensis* is distinguished from *Alveosepta jaccardi* by the absence of the thin layer of alveoles developed at the anterior part of the septa in the latter species. Distinction from species of *Choffatella* is made on the broad zone of septal pores seen in axial section.

Pseudocyclamina muluchensis is thought to have evolved from *P. parvula* through gradual loss of a narrow central zone of pillars that extend through successive chambers (Hottinger 1967).

Hottinger (1967) recognised two generations of this species, a microspheric form with an equatorial diameter of 1.4 to 1.9 mm, and a megalospheric form containing a proloculus of 0.08 to 0.013 mm diameter and an equatorial diameter of 0.7 to 1.2 mm. Both these generations are recognised in the Portuguese material.

Size: Microspheric, maximum diameter 2.0mm, thickness 0.68mm; Megalospheric, maximum diameter 1.17mm, thickness 0.38mm.

Occurrence: Cabo Espichel, samples I/1, I/2, I/3, I/5, I/6, I/7, I/8, I/10, I/15, I/18, I/19, I/21, I/22, I/23, K/1, K/3, K/6. Common to abundant; Ericeira, Samples B/2, B/3, B/5, B/6, B/7, B/8. Common to abundant. Previously reported from north Africa and Portugal.

Stratigraphic age: Kimmeridgian (Hottinger 1967, Tizi n'Tassa, Morocco). This study: Kimmeridgian-Berriasian, *Mesoendothyra* sp.A to *Ammobaculites subcretaceus*

subzone.

Subfamily SPIROCYCLININAE Munier-Chalmas, 1887

Genus ANCHISPIROCYCLINA Jordan & Applin, 1952

Anchispirocyclus lusitanica (Egger, 1902)

Plate 10, figs. 1-7

Orbiculina lusitanica Choffat, 1885, *nomen nudum*, p. 4.

Dicyclina lusitanica Egger, 1902, p.585-586, pl. 6, figs. 3-5.

Anchispirocyclus henbesti Jordan & Applin, 1952, p. 3-5, pl. 2, figs. 1-4, pl. 3, figs.1-3.

Anchispirocyclus cf. *maynci* (Hottinger); Ramalho, 1971, p. 149, pl. XVII, figs. 1-10.

Anchispirocyclus lusitanica (Egger); Ramalho, 1971, p. 148, pl. XV, figs. 4-9, pl. XVI, figs. 1-2; Jansa *et al.*, 1980, pl. 8, figs. 7-8; Rey, 1972, p. 311, pl. VII, figs. 1, 3 & 4.

Diagnosis and remarks: Planispiral, involute and bilaterally compressed; 16 or more chambers in the final whorl, chambers strongly embracing, sutures strongly arched and may be slightly raised, flush, or feintly depressed depending on preservational characteristics; poles slightly depressed; size variable, up to 15mm in diameter; periphery variable from broadly rounded to narrow depending on inflation of the test which tends to be greater in the megalospheric generation. In thin section a fine meshwork of subepidermal alveoles covers the lateral and peripheral sides of the chambers. Septa are simple, 1 - 2 times chamber height in thickness, and pierced by straight pores of approximately half the septa thickness in diameter; the axes of the pores are commonly aligned between successive chambers. The endoskeleton is composed of numerous irregularly placed buttresses that connect the anterior faces to the posterior faces of successive septa through the chamber lumen. The endoskeletal buttresses may be variably

developed across the chamber breadth seen in axial and equatorial thin sections, and are particularly well formed in the later whorls. The interconnections between successive chambers have a characteristically 'labyrinthic' appearance due to the disposition of the buttresses.

The microspheric generation of the species commonly has 24 or more chambers in the last whorl, and may attain a diameter of up to 15mm, when an annular growth stage may be achieved. More commonly it is 5-10 mm in diameter, reniform to discoid in outline, and does not display a true cyclical growth stage. The proloculus is too small to be measured accurately under optical resolution.

The megalospheric generation is of two forms: A1 is characterised by a test diameter of 0.77-2.2mm and a proloculus of 0.06-0.26 mm diameter; A2 has a 0.37-2.0mm diameter test and a 0.14 - 0.45 mm diameter proloculus. The megalospheric forms have between 16 and 24 chambers in the final whorl.

The genus is distinguished externally from *Choffatella* by its strongly recurved septa and cribrate aperture, rather than the single row of pores seen in the latter. The highly compressed microspheric generation is generally larger than the equivalent generation in species of *Choffatella*, and has broader peneropliform chambers in the final whorl. Distinction from *Pseudocyclamina* and *Alveosepta* is similarly made on overall shape, strong curvature of the septae as well as the number of chambers in the final whorl (usually less than 16 in *Pseudocyclamina*, more than 16 in *Anchispirocyclina*). In addition, the reniform to discoid stage of growth sometimes observed in the microspheric generation has so far never been reported for the other Mesozoic genera of Portugal.

In thin section the genus is recognised by the irregular endoskeletal buttresses and labyrinthic interconnections between successive chambers. The species is particularly abundant in marls and also occurs in massive limestones, and more rarely, mudstones. In Ramalho's (1971) units 41 - 43 at the top of the Cabo Espichel, *A. lusitanica* is associated with euryhaline tolerant ostracod assemblages. Also within these units, the

species is found at several horizons in gypsiferous marls where the reniform and discoid growth stage is developed to the fullest and the form attains a maximum diameter of 15mm. In the Ericeira region, *A. lusitanica* is found in dolomites of the 'Dolomies, argiles et gres a cailloux noirs de Porta de Calada' formation where it also displays gigantism. In the silts at the top of this formation, the species attains a smaller diameter. We do not think that the large size of *Anchispirocyclina lusitanica* is of stratigraphic significance, but may be a phenotypic character brought about by a change in salinity.

Occurrence: Cabo Espichel, samples I/19, I/20, I/21, I/22, K/1, K/2, K/3, K/4, K/5 and K/6. Common to abundant. Ericeira, C/3 (common), C/8 (abundant), C/10 (common).

Stratigraphic age: Kimmeridgian-Portlandian (Hottinger 1967, Kerker, Morocco); Berriasian (Rey 1972, Portugal). This study: Middle Kimmeridgian-Berriasian, *Choffatella tingitana* zone to *Anchispirocyclina lusitanica* zone.

Genus RECTOCYCLAMMINA Hottinger, 1967

Rectocyclammia arrabidensis Ramalho 1969

Plate 10, figs 8-9

Rectocyclammia arrabidensis Ramalho, 1969, p. 42, pl. II, figs. 1-4.

Diagnosis and remarks: Planispiral coil of 5-8 chambers followed by rectilinear portion of 5-8 chambers; coil involute with a slight umbilical depression, depressed straight sutures, a slightly lobate periphery and chambers that increase gradually in size as added; uncoiled portion cylindrical to tapering with chambers increasing in size gradually as added, sutures straight, depressed; uncoiled chambers as broad as, or slightly broader than chamber height; aperture round, terminal; wall structure complex with a network of subepidermal alveoles extending into the septa; septa pierced by single opening, and are thickest adjacent

to this opening.

The layer of subepidermal alveoles seen in thin section distinguishes *Rectocyclammina arrabidensis* from otherwise similar species of *Ammobaculites*. Depending on the composition and preservation of the tests, the subepidermal alveoles can be observed in transmitted light aided by glycerine immersion. *Rectocyclammina* is distinguished from *Haurania* on the single rather than multiple aperture, from *Everticyclammina* on the endoskeletal rather than exoskeletal alveoles, and from *Feurtillia* by a circular rather than elongate aperture. Distinction from *Rectocyclammina chouberti* Hottinger is based on size: *R. chouberti* has an uncoiled portion typically 2-3 times broader than that of *R. arrabidensis*, and an overlapping final chamber 2-3 times the external height of the preceeding one.

The Portuguese specimens compare well to figures in Ramalho (1969), and are agglutinated from fine calcareous material.

Occurrence: Cabo Espichel, samples J/1, J/2 (frequent to abundant), J/4, I/1, (rare), I/4 (abundant), I/5, I/7, I/10, I/13, I/16 and I/19 (common to rare); Ericeira, sample B/1 (rare). Praia Azul, samples A/1 (common), A2 (abundant), A/3, A/4, A/5 (common to rare), A/7, A/8 (abundant), A/9 (rare).

Stratigraphic age: Kimmeridgian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Rectocyclammina chouberti Hottinger 1967.

Plate 10, figs. 10-11

Rectocyclammina chouberti Hottinger, 1967, p. 55-56, pl. 9, figs. 19-21, text-figs. 26, 27a-c; Ramalho, 1971, p.144-145, pl. XIV, figs. 1-4.

Diagnosis and remarks: Planispiral coil of 4-8 chambers followed by rectilinear portion of

4-8 chambers; coil involute, slightly depressed at umbilicus with feint sutures depressed slightly at the periphery; rectilinear chambers increasing in size rapidly in early portion where they are broader than high, slowly in later stages where they are higher than broad; sutures in uncoiled stage flush to slightly depressed; final chamber approximately twice the size of preceding one, broadly rounded with a central round terminal aperture; wall structure complex with a subepidermal network of alveoles; septa with subepidermal alveolar layer continuous with the wall, pierced by single opening.

Rectocyclammia chouberti is distinguished by the swollen uniserial portion and small coil. Externally it resembles the small spired variants of *Ammobaculites coprolithiformis* (Schwager), but internally it differs by virtue of the subepidermal alveoles. Hottinger (1967) identifies megalospheric (B) and microspheric (A) generations of this species. The 'B' forms are distinguished by a coil of up to 8 chambers that possess a megalosphere of around 0.08mm diameter. The 'A' forms have a coil of 4-5 chambers. Both generations are recognised in the Portuguese material, which compares closely to the north African forms described by Hottinger (1967). Specimens are finely agglutinated from calcareous material.

Size: maximum length, 2.0mm; thickness, 0.73mm; coil diameter microspheric generation 0.135mm, megalospheric generation, 0.235mm.

Occurrence: Cabo Espichel, samples I/18, I/20, I/21, K/1 (common to rare), K/2 (frequent); Ericeira, sample B/3 (rare).

Stratigraphic age: Early to Middle Kimmeridgian (Hottinger 1967, Bou Haidour Formation, Morocco). This study: Kimmeridgian-EarlyPortlandian, *Mesoendothyra* sp.A to *Choffatella tingitana* zone.

Subfamily PFENDERININAE Smout & Sugden, 1962

Genus KURNUBIA Henson, 1948

Kurnubia palastinensis Henson 1948

Plate 10, figs. 12-14

1948 *Kurnubia palastinensis* Henson, 1948, P. 608, pl. XVI, figs. 8,11; pl. XVIII, figs. 10-11; P. 607, pl. XVI, figs 1-4, 10; pl. XVIII, figs 8-9; Hottinger, 1967, p. 90-93, pl. 19, figs. 30-34, 38-48; text-figs. 45-47; Ramalho, 1971, p. 151, pl. XII, fig.1; pl. XIX, figs. 8-11.

Diagnosis and remarks: Trochospiral early portion becoming uniserial in later stage; trochospiral portion coiled about a central column, with up to 9 whorls, 4-6 chambers in each whorl, sutures depressed; uniserial portion with up to 12 discoid chambers, broader than high, with depressed sutures; primary aperture at the base of the apertural face (interiomarginal), overlain in the trochospiral stage by a finely perforate (cribrate) apertural plate, and in the uniserial stage with an apertural plate pierced by a terminal aperture; exoskeletal wall structure complex, exoskeleton comprising longitudinal and transverse sets of alveoles occupying the central part of the test between the apertural plates and the anterior walls of the corresponding chambers; endoskeleton comprising a massive column occupying the umbilical region of the trochospire, connected to the early chambers through secondary intercameral pores, and expanding in the later chambers to form the apertural plates.

Redmond (1964) emended the diagnosis of the genus *Kurnubia*, and stated (p.252), "the cellular and labyrinthine structures occupying the central part of the test lie between the apertural plates and the anterior walls of the corresponding chambers rather than within the chambers themselves....". Hottinger (1967, p. 92), however, commented, " Je n'ai vu aucun <<dedoublement>> de la paroi anterieure des loges dont l'une serait perforee par de nombreuses ouvertures et l'autre par une seule ouverture

principale...".

While Redmond (1964) did not illustrate the characters he described, the following description in Hottinger (1967, p. 90), "A la peripherie de cette columellaire se forme un passage secondaire (intercameral foramen) perforant les septes successifs au milieu de leur bord interne semi-circulaire....", together with his illustrations indicate that this structure is the same as the one regarded as a primary opening by Redmond (1964). In the original description of the genus, Henson (1948) described the aperture simply as interiomarginal in the early stage, becoming terminal in the later stage.

Hottinger (1967) recognised trimorphism in north African specimens: microspheric form 'B' had a sharp spire with 9 whorls in the first millimeter of growth and a test length: breadth ratio of around 4.5:1; megalospheric form 'A1' possessed a megalosphere of 0.06-0.1mm diameter, 6 whorls in the first millimeter of growth and a test length:breadth ratio of 1.8-2.4:1; megalospheric form 'A2' had a test length to breadth ratio greater than 2.5:1. Portuguese material includes microspheric and megalospheric 'A2' forms closely resembling those figured by Hottinger (1967).

Occurrence: Cabo Espichel, sample J/1 (rare).

Stratigraphic age: Early to Middle Kimmeridgian (Hottinger 1967, Morocco). This study: Early Kimmeridgian, *Mesoendothyra* sp.A zone, *Kurnubia palastiniensis* subzone.

8.5: Ostracoda.

Phylum ARTHROPODA

Class CRUSTACEA

Subclass OSTRACODA Latreille 1806

Order PODOCOPIDA Muller 1894

Suborder PODOCOPINA Sars 1866

Superfamily CYPRIDACEA Baird, 1845

Family CYCLOCYPRIDIDAE Kaufmann, 1900

Genus CETACELLA Martin, 1958

Cetacella armata Martin

Plate 11, figs. 1,3

Cetacella armata Martin, 1958, p. 195, pl. 18, figs. 5-6; Helmdach, 1971, p. 650-652, plates 1-6, text figs. 7-8; Brenner, 1976, p. 197, pl. 8, figs. 10-14.

Diagnosis and remarks: Carapace outline bean shaped, dorsal margin strongly convex, ventral margin straight to slightly concave, anterior and posterior margins asymmetrically rounded, lateral margins moderately inflated. The maximum height is at the mid length (amplete), and the maximum thickness between the valves is just posterior to mid length. The lateral margins have a finely ribbed longitudinal surface ornament, and may possess a posteromedian spine that projects posteriorly. The species is found in a shelly clay, and is believed to be a fresh to brackish water indicator. *Cetacella armata* differs from *C. striata* by the finer surface ornament and the lateral spines.

Dimensions: L: 0.766mm; H: 0.5mm; W: 0.23mm.

Occurrence: Praia Azul, sample A/5. The species has also been reported from the Fastnet Basin, offshore southwest Ireland (Ainsworth, 1985), northwest Germany (Martin, 1958) and Spain (Brenner, 1976).

Stratigraphic age: Late Kimmeridgian (Helmdach 1971, Portugal; Brenner 1976, Spain).

This study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Family CYPRIDIDAE Sars 1866

Genus MANTELLIANA Anderson 1966

Mantelliana cyrton Anderson

Plate 11, Fig. 5

Mantelliana cyrton Anderson, 1971, p.127, pl. 17, fig.9; Anderson, 1985, P.36, pl. 2, fig. 17; pl. 3, fig. 16.

Diagnosis and remarks: Carapace large, sub-triangular in outline with a strongly arched dorsal margin and assymmetrically rounded anterior and posterior margins, the anterior being more broadly rounded than the posterior. The ventral margin is straight to slightly convex, the anterior and posterior portions marked by slight incisures. Maximum height is just anterior to mid length, maximum length is around one-third the height. An ornament of fine pustules is developed over the entire surfaces of the valves.

The Portuguese specimens are partially crushed, but otherwise compare well to those figured in Anderson (1985). The species is distinguished from specimens of *Cypridea* by the absence of the antero-ventral beak and notch.

Dimensions: L: 1.8mm; H: 1.3mm.

Occurrence: Praia Azul sample A/9. The species is originally described by Anderson (1971) from southern England and is subsequently reported from the Isle d'Oleron in SW. France (Anderson 1985).

Stratigraphic age: Late Portlandian-Berriasian (Lower to Middle Purbeck beds, Anderson 1985). This study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Family ILYOCYPRIDIDAE

Genus RHINOCYPRIS Anderson 1940

Rhinocypris jurassica (Martin)

Plate 11, fig. 2

lyocypris jurassica jurassica, Martin, 1940, p. 313, pl.4, figs. 51-54*Rhinocypris jurassica* (Martin); Oertli, 1963, p.18, pl.5, figs. 25-27.*Rhinocypris jurassica spinosa* (Martin), Brenner, 1976, p. 197, pl. 8, figs. 4-6.*Rhinocypris jurassica* (Martin), Anderson, 1985, p. 37, pl. 2, fig. 5.

Diagnosis and remarks: Carapace elongate, sub-elliptical, dorsal margin slightly convex, ventral margin straight to slightly concave, anterior and posterior margins asymmetrically rounded. Maximum height is in the anterior quarter, and the carapace tapers posteriorly. The surfaces of the valves are ornamented with fine spines and small pustules. A small median sulcus is developed on each valve.

The ornament on this species is variable and may consist of a combination of spines, pustules and tubercles. The Portuguese specimens compare well to those in Brenner (1976) and Anderson (1985), but lack the tubercles seen in specimens figured in Kilenyi and Neale (1978).

Dimensions: L: 0.53mm; H: 0.27mm.

Occurrence: Praia Azul, sample A/9. This species has been widely reported from non-marine facies in the U.K. (Kilenyi and Neale, 1978), Germany (Martin, 1940) and Spain (Brenner, 1976).

Stratigraphic age: Portlandian (Lower Purbeck) -Late Hauterivian (Anderson, 1985; Kilenyi and Neale, 1978). This study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Superfamily DARWINULACEA

Family DARWINULIDAE

Genus DARWINULA Brady and Robertson 1885

Darwinula leguminella (Forbes)

Plate 11, Fig. 4

Cypris leguminella Forbes, in Lyell, 1855, p. 294, fig. 334c.

Darwinula leguminella (Forbes); Jones, 1855, pp. 346-7, pl.8, figs. 30-31; Oertli, 1963, p. 20, pl.6. fig. 40; Kilenyi and Allen, 1968, p. 144, pl. 29, fig. 8; Brenner, 1976, p. 198, pl. 10, figs. 23-25; Anderson, 1985, p.34, pl. 11, fig. 8.

Diagnosis and remarks: Carapace elongate, sub-cylindrical, greatest height in the posterior half. Dorsal margin gently convex, anterior margin assymmetrically rounded, bluntly angled ventrally, posterior margin broadly rounded, ventral margin slightly concave in the anterior part. In dorsal view, the carapace is lanceolate, the left valve overlaps the right, and greatest thickness is in the posterior. The valve surfaces are smooth.

Dissarticulated valves in the Portuguese material are in-filled and the hinge and muscle scars cannot be seen. However, in well preserved carapaces, the "rosette" muscle scar pattern typical of the genus may seen externally through the translucent valves when wet. Recent species of *Darwinula* live in slightly brackish to fresh-water. *D. leguminella* differs from *D. oblonga* by its narrower, more pointed anterior margin.

Dimensions: L: 0.96mm; H: 0.26mm; W: 0.23mm.

Occurrence: Praia Azul, samples A/4, A/5, A/6, A/9, rare to common. Widely reported from non-marine deposits in N.W. Europe (eg. Brenner, 1976; Anderson, 1985).

Stratigraphic age: Portlandian (Lower Purbeck beds) to Barremian (S.E. England,

Anderson, 1985). This study: Late Kimmeridgian, *Paranotocythere pustulata* Zone.

Superfamily CYTHERACEA Baird 1850

Family CYTHERIDAE Baird, 1850

Genus FABANELLA Martin 1961

Fabanella boloniensis (Jones)

Plate 11, figs. 6-8

Cythere boloniensis Jones, 1882, p. 616, fig.b.

Fabanella polita polita (Martin), Martin, 1961, p. 186, pl.1, figs. 1-4, 10-12; Ramalho, 1971, p. 161-162, pl. XXII, figs. 11-12.

Fabanella polita ornata (Steghaus); Ramalho, 1971, p. 162, pl XXIII, figs. 1-3.

Fabanella Polita (Martin), Swain, 1987, p.5, figs. 3,4,13.

Fabanella boloniensis (Jones); Kilenyi and Allen, 1968, p. 146-147, pl. 29, figs. 13-21, text fig. 2a-g; Kilenyi, 1978, p. 310, pl. 4, figs. 9,10.

Diagnosis and Remarks: Subrectangular to ovate outline, dorsal margin with a slight concavity just posterior to the anterior cardinal angle, anterior and posterior margins asymmetrically rounded. A slight swelling at the anterior cardinal angle marks the ocular node. The lateral margins are often slightly constricted at about one quarter of the distance from the anterior margin, and are swollen posteriorly, particularly in the larger specimens. Ornamentation is variable from reticulate to smooth, and the ventral margins may be flanked by longitudinal costae.

Much variation is seen in this species ranging from small ovate smooth forms to elongate 'waisted' forms with well developed reticulation. Kilenyi and Allen (1968) also observe similar variation in specimens from the lower part of the Weald Clay of southern England, and consider such variance to be phenotypic in nature. Barker (1963) demonstrated that the size variance in this species is linked to salinity, the smaller forms

being euryhaline. The species occurs predominantly in clays and silts where it is often abundant, and is occasionally found in nodular limestones.

Occurrence: Cabo Espichel, samples I/4, I/5, I/7, I/8, I/9, I/10, I/13, I/14, I/15, I/16, I/19, and I/23; Ericeira, samples B/6, B/7, MB/5, MB/7, E/3, E/4, and E/8; Praia Azul, samples A/4, A/6 and A/9. The species is widely reported from northwest Europe and North America.

Dimensions: L: 1.0mm; H: 0.533mm; W: 0.42mm.

Stratigraphic age: Kimmeridgian to Barremian (Kilenyi 1978). This study: Portlandian to Valanginian, *Fabanella boloniensis* Zone.

Family BRACHYCYTHERIDAE Puri 1954

Genus AMPHICYTHERE Triebel, 1954

Amphicythere aff. *confundens* Oerli

Plate 11, figs, 9-11

Amphicythere confundens Oerli, 1963, p. 37, pl. XLIV, fig. k; Kilenyi, 1969, p. 146, pl. 29, figs. 25, 26; Ramalho, 1971, p. 162-162, pl. XXIII, figs. 4-6.

Diagnosis and remarks: Carapace ovate to sub-rhomboidal with maximum height at the anterior cardinal angle. The dorsal and ventral margins are slightly convex, the anterior margin is symmetrically rounded with a moderate rim and the posterior margin is slightly curved, falling abruptly behind the marked posterior cardinal angle. The anterior cardinal angle has a slight ocular depression and an eye node. The lateral margins are inflated, slightly overhanging the ventral margin. Dorsally the hinge line is straight with slight left valve overlap and maximum thickness posterior to the mid-point. The carapace has

scattered punctae, and sexual dimorphism is apparent, the males being longer.

The Portuguese specimens lack the strong pitting seen in specimens of *Amphicythere confundens* from the Kimmeridge Clay (compare pl.11, figs. 9 and 10), although are otherwise similar to those originally described by Oertli (1963). The species is rare to common in marls and nodular limestones.

Dimensions: L: 0.74mm; H: 0.42mm; W: 0.28mm.

Occurrence: Cabo Espichel, samples I/1, I/9, I/17, I/19, I/21, K/1, K/4, K/5, and K/6; Ericeira, samples B/2, B/3, B/5, and B/6. Previously reported from southern England and western France.

Stratigraphic age: Early Kimmeridgian (Kilenyi 1961, Kimmeridge Clay, *Cymodoce* Zone). This study: Kimmeridgian to Early Portlandian, *Galliaecytheridea* sp.2 to *Schuleridea triebeli* Zone.

Family CYTHERIDEIDAE Sars, 1925

Genus ASCIOCYTHERE Swain, 1952

Asciocythere sp.1 Ramalho

Plate 12, figs. 1-2

Asciocythere sp.1 Ramalho, 1971, p. 163, pl. XXIII, figs. 13-15.

Diagnosis and remarks: Carapace oval to subtriangular in outline with the maximum height in the anterior quarter. The dorsal margin is broadly convex lacking obvious cardinal angles, the ventral margin is straight and the anterior and posterior margins are rounded, the posterior being narrower. The left valve is larger than the right and overlaps it particularly along the dorsal margin.

Portuguese specimens are identical to examples figured in Ramalho (1971). The genus *Asciocythere* is distinguished from *Galliaecytheridea* by its smooth rather than crenulate median hinge element. Disarticulated specimens was not preserved well enough to accurately determine the type of median element, so there may be some question as to the generic affinities of this form. The species is found in marl, shale and nodular limestones.

Dimensions L: 0.43mm; H: 0.3mm; W: 0.23mm.

Occurrence: Cabo Espichel samples I/4, I/5, I/7, I/8, I/9, I/10, I/13, I/14, I/15, I/16, I/17, I/18, I/19, I/20, I/21, I/22, I/23, K/1, K/4 and K/5. Ericeira, samples B/2, B/3, B/5, B/6, B/7 and B/8. Previously reported from Portugal.

Stratigraphic age: Kimmeridgian to Early Portlandian, *Galliaecytheridea* sp.2 to *Schuleridea triebeli* Zone.

Asciocythere sp.3 Ramalho

Plate 12, figs. 3-4

Asciocythere sp.3, Ramalho, 1971, p. 164, pl. XXIV, figs. 4-6.

Diagnosis and remarks: The carapace is oval in outline, with maximum height at in the anterior quarter. The dorsal and ventral margins are gently convex and the anterior and posterior margins are unequally rounded, the posterior being slightly narrower. The hinge line is straight to slightly sinuous and is often slightly depressed. The lateral margins are inflated and the left valve is slightly larger than the right.

Specimens examined are identical to those figured by Ramalho (1971), but due to the poor preservation of the hinge elements there may be some question as to the true affinities of this form. The species approaches *Galliaecytheridea dissimilis* Oertli in its

general shape but is more inflated. The species is rare to common in shales.

Dimensions: L: 0.66mm; H: 0.45mm; W: 0.4mm.

Occurrence: Cabo Espichel samples K/1, K/3, K/4, K/5, M/2 and M/6; Ericeira, samples E/4, H/5 and H/6. Previously reported from Portugal.

Stratigraphic age: Early Portlandian - Late Hauterivian, *Schuleridea triebeli* to *Platycythereis crisminaensis* Zone.

Genus GALLIAECYTHERIDEA Oertli, 1957

Galliaecytheridea postrotunda Oertli

Plate 12, fig.5

Galliaecytheridea postrotunda Oertli, 1957, p. 656. pl. 2, figs. 45-55; Kilenyi, 1969, p. 128-129, pl. 27, figs. 5-14; Jansa, Remane and Ascoli, 1980, pl. 9, figs. 11-12.

Diagnosis and remarks: Carapace ovate, elongate, dorsal margin straight to slightly convex, marked posterior cardinal angle, ventral margin straight to slightly convex, lateral margins moderately inflated, finely punctate.

This species differs from *Galliaecytheridea* sp. 2 Kilenyi in its almost straight dorsal margin, posterior cardinal angle and its larger size. It is difficult, however, to distinguish between juveniles of the two species. The Portuguese specimens have a slightly convex dorsal margin compared to those figured by Oertli (1957), but are identical to those figured by Kilenyi (1969) from the Kimmeridge Clay, and those in Jansa *et al.* (1980) from the Shell Mohican well, offshore eastern Canada. The Portuguese specimens also compare well to Barker's material from Hounstout Cliff, Dorset, housed in the British Museum (B.M. catalog numbers Io. 2164-5)

Dimensions: L: 0.82mm; H: 0.4mm; W: 0.29mm.

Occurrence: Cabo Espichel, samples I/9, I/10, I/13, I/16, I/17 and I/19; Ericeira, samples B/2, B/3 and B/6; Praia Azul, A/2, A/3, A/4 and A/5.

Stratigraphic age: Late Oxfordian-Early Kimmeridgian (Oertli 1963, France); *Baylei* Zone in the Kimmeridge Clay (Kilenyi 1969). This study: Late Kimmeridgian to Early Portlandian, *Paranotacythere pustulata* to *Galliaecytheridea posterotunda* Zone.

Galliaecytheridea sp.2 Kilenyi

Plate 12, figs. 6,8

Galliaecytheridea sp. 2 Kilenyi, 1969, p. 131, pl 27, figs. 1-4.

Diagnosis and Remarks: Carapace elongate, anterior margin round, dorsal margin convex passing into posterior without distinct cardinal angle, ventral margin straight to gently concave, posterior margin often terminating in a short posteroventral spine. The greatest height is in the anterior quarter and the left valve is larger than the right, overlapping around most of the margin.

This species differs from *G. posterotunda* in its slightly concave ventral margin, lack of posterior cardinal angle, and smaller size. Specimens compare well to those from the Kimmeridge Clay (compare pl. 12, figs. 6 and 7), figured by Kilenyi (1969), although the ventral margin is usually concave in both valves. The specimens described in Kilenyi (1969) have a more elliptical right valve. The species is rare to common in shales.

Size: L= 0.55-0.60 mm; H= 0.32-0.35 mm; W= 0.13-0.15mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2 and I/3; Ericeira, sample B/1;

Praia Azul, samples A/1, A/2, and A/8. Previously reported from southern England.

Stratigraphic age: Early Kimmeridgian, (Kilenyi 1969, Kimmeridge Clay, *Cymodoce* Zone). This study: Kimmeridgian, *Galliaecytheridea* sp.2 to *Paranotacythere pustulata* Zone.

Genus SCHULERIDEA Swartz and Swain, 1946

Schuleridea triebeli Steghaus

Plate 13, figs. 1-3

Schuleridea triebeli Steghaus, 1951, p. 205, pl.11, figs. 6-8; Donze, 1960, p. 18-19, pl. III, figs. 31-39; Kilenyi, 1969, p. 118-119, pl. 23, figs. 21-23; Ramalho, 1971, p. 164, pl. XXIV, figs. 7-9; Kilenyi, 1978, p.268, pl.3, figs. 9-12.

Diagnosis and remarks: Large, subovate in lateral outline, maximum height just in front of mid line; anterior and posterior margins asymmetrically rounded, dorsal margin convex with prominent cardinal angles, ventral margin concave; well developed ocular sinus and eye tubercle; left valve strongly overlapping right, particularly along dorsal margin; hinge line straight, maximum thickness between valves posterior to mid point, in posterior third in right valve; lateral margins with well developed punctae; strongly dimorphic, males longer.

This species is distinguished from *S. thoerenensis*, *S. derooi* (Damotte and Grosdidier, 1963) and *S. sp.1* by its prominent left valve overlap and well developed ocular sinus. Kilenyi (1978) reports some variation in the outline of the carapace, and this is true for the Portuguese specimens. The species is common to abundant in marls, nodular and massive limestones.

Dimensions: L: 0.7mm; H: 0.43mm; W: 0.32mm.

Occurrence: Cabo Espichel, samples I/4, I/5, I/7, I/8, I/9, I/10, I/13, I/14, I/15, I/16, I/17, I/18, I/19, I/20, I/21, I/22, I/23, K/1, K/2, K/3, K/4, K/5, and K/6; Ericeira, samples B/2, B/3, B/5, B/6 and B/7. Common in Europe.

Stratigraphic age: Oxfordian - Kimmeridgian (*Mariae -Mutabilis* Zone) (Kilenyi 1978).
This study: Late Kimmeridgian-Early Portlandian, *Paranotacythere pustulata* to *Schuleridea triebeli* Zone.

Schuleridea thoerenensis (Triebel)

Plate 13, figs. 4-6

Cytheridea thoerenensis Triebel, 1938, p. 482-483, pl. 2, figs. 26-29.

Schuleridea thoerenensis (Triebel); Martin, 1961, pl. 14, figs. 13-14; Neale, 1962, pl. 13, figs. 9-12.

Diagnosis and remarks: Carapace ovate to subtriangular in lateral view, maximum height anterior to mid point; forward swing, dorsal margin gently convex, anterior margin asymmetrically rounded, ventral margin straight to slightly concave, posterior margin sharply rounded, narrow; left valve overlaps right by small amount, overlap thins over dorsoventral margin; hinge line straight, maximum thickness between the valves is in the posterior third; valves finely punctate with moderately developed ocular sinus and eye tubercles; strongly dimorphic, males longer.

This species is distinguished by its thin left valve overlap and its narrow posterior. This latter characteristic is more apparent in the male specimens. *Schuleridea thoerenensis* is distinguished from *S. praethoerenensis* by the smooth surface of the valves, the latter having a surface marked with strong pitting. The species is rare to common in nodular limestones and silts.

Dimensions: L: 0.633mm; H: 0.466mm; W: 0.3mm.

Occurrence: Cabo Espichel, samples M/2, M/3 and M/7; Ericeira, samples H/3, H/5 and H/7.

Stratigraphic age: Late Valanginian (Neale, 1962). This study: Berriasian - Early Barremian.

Schuleridea sp.1

Plate 12, figs. 9-10

Description: Carapace sub-rhomboidal in outline, maximum height just in front of mid point; sharp posterior cardinal angle; ventral margin slightly concave, shallow anterior marginal rim; left valve overlaps right an equal amount all round except for the postero-ventral region where the overlap is reduced; Hinge line straight, maximum thickness between valves slightly posterior to mid point, thickness equals half length; carapace ornamented with fine punctae; strongly dimorphic, males longer.

Dimensions: L: 0.55mm; H: 0.38mm; W: 0.26mm.

Remarks: This species differs from *S. triebeli* on the following points: left valve overlap is equal all around except for postero-ventral region, compared to the stronger overlap particularly in the dorsal region of *S. triebeli*, maximum thickness between the valves is only just posterior to the mid point, whereas in *S. triebeli* maximum thickness is further to the posterior and is greater in proportion to the length of the carapace. *Schuleridea* sp.1 is common to abundant in nodular limestones, marls and shales.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, and I/1; Ericeira, sample B/1; Praia Azul, samples A/1, A/3, A/4, A/5, A/8 and A/10.

Stratigraphic age: Kimmeridgian, *Galliaecytheridea* sp.2 to *Paranotacythere pustulata* Zone.

Family CYTHERURIDAE Muller, 1894

Genus CYTHEROPTERON Sars, 1866

Cytheropteron aquitanum Donze

Plate 13, figs. 7-8,10

Cytheropteron aquitanum Donze, 1960, p. 21-22, pl. IV, figs. 48-51; Kilenyi, 1969, p. 141, pl. 28, figs. 8-11.

Diagnosis and remarks: The carapace is roughly ovate, with maximum height anterior to the mid point. The dorsal margin is strongly convex, anterior margin is asymmetrically rounded, and the posterior is produced into a short caudal process. The hinge line is straight, and maximum thickness between the valves is in the posterior third. The lateral margins are drawn out posteroventrally, produced into alae that frequently have a vellate ridge. The ventral margins are flanked by longitudinal costae.

Some variability is noted with respect to the development of the alae, although this is within the range of the specimens figured by Donze (1960) and Kilenyi (1969). The Portuguese specimens are also comparable to R.C. Whatley's examples from the Upper Oxfordian of Dorset, housed in the British Museum (Catalog number Io. 5081). The species is rare to common in marls and nodular limestone facies.

Dimensions: L: 0.53mm; H: 0.36mm; W: 0.3mm.

Occurrence: Cabo Espichel, samples I/3, I/4, I/5, I/7, I/9, I/10, I/13, I/15, I/16, I/17, I/18, I/19, I/23, K/1, K/3 and K/4; Ericeira, samples B/1, B/2, B/3, B/5, B/6 and B/7; Praia Azul, samples A/1, A/2, A/3, A/4, A/5, A/7 and A/8.

Stratigraphic age: Middle Kimmeridgian (Donze 1960), *wheatleyensis* Zone in the Kimmeridge type section (Kilenyi 1969). This study: Kimmeridgian to Early Portlandian, *Galliaecytheridea* sp. 2 to *Schuleridea triebeli* Zone.

Cytheropteron sp. 1

Plate 13, figs. 9,13

Diagnosis and remarks: This form has a broadly rounded dorsal margin and inflated lateral margins that are produced into sharp points in the posterior region. The posterior is drawn into a pronounced caudal process. Dorsally, the maximum thickness between the valves is in the posterior third. The form is distinguished from *C. aquitanum* by the longer caudal process and the sharply pointed lateral margins. The species occurs in low numbers in mud and reefal limestone facies.

Occurrence: Cabo Espichel, samples J/1, J/2 and J/4.

Stratigraphic age: Early Kimmeridgian, *Galliaecytheridea* sp.2 Zone, *Cytheropteron* sp.1 subzone.

Genus METACYTHEROPTERON Oertli 1957

Metacytheropteron sp.59 Damotte and Rey

Plate 14, fig. 1

Metacytheropteron sp. 59 Damotte and Rey, 1980, p. 32, pl. 3, fig. 78.

Diagnosis and remarks: The carapace is elongate-ovate with a bluntly pointed posterior situated at around mid-height of the valves. The anterior margin is broadly rounded, sharply rounded in the anteroventral region. The dorsal margin is gently convex and lacks distinct cardinal angles. Dorsally, the maximum thickness between the valves is posterior to mid length, and the left valve slightly overlaps the right. The lateral margins are drawn out into weak alae that are roughly symmetrical about the mid-length. The valves have an ornament of faint striae that parallel the dorsal, anterior and ventral margins.

The specimens are generally poorly preserved, but appear identical to those referred to as *Metacytheropteron* sp. 59 in Damotte and Rey (1980). *Metacytheropteron* differs from the genus *Cytheropteron* in the overlapping left valve, the weakly developed alae and the blunter posterior. The species is rare to common in bioturbated limestones.

Dimensions: L: 0.5mm; H: 0.3mm.

Occurrence: Cabo Espichel, samples M/6 and M/7. Previously reported from Portugal.

Stratigraphic age: Hauterivian-Barremian (Damotte & Rey 1980). This study: Hauterivian - Early Barremian, *Platycythereis crisminaensis* - *Cythereis ericeirensis* Zone.

Genus CYTHEROPTERINA Mandelstam, 1956

Cytheropterina triebeli Neale

Plate 14, figs. 2-4

Cytheropterina triebeli Neale, 1962, p. 437, pl.3, fig.7; pl. 4, figs. 1-4; pl. 12, fig. 33; Neale, 1978, p. 336, pl. 2, fig. 10.

Diagnosis and remarks: Carapace elongate-oval in outline, with an assymmetrically rounded anterior margin, a broadly rounded dorsal margin, and a posterior drawn into a caudal process. The ventro-lateral margins are drawn out into smoothly curved alae that swing to the posterior. The alae are bordered by a narrow rim which is flanked inboard by a row of shallow depressions or pits. The ventral surface of each valve is marked by three or four curved costae. A faint reticulate ornament may be developed elsewhere on the valves.

The hinge is well developed, the right valve containing anterior and posterior terminal hinge elements, each with eight or nine bifid teeth, separated by a pitted median groove. The left valve contains the corresponding denticulate sockets and median bar. The inner margin coincides with the line of concrescence, and contains 6-7 anterior marginal pore canals.

The Portuguese specimens compare well with those illustrated in Neale (1962), and are generally smooth, glossy and well preserved. The alar pits are difficult to observe in normal light, but become more obvious when the specimens are wet and observed from an angle. The faint reticulation is only occasionally observed.

Dimensions: L: 0.5mm; H: 0.35mm.

Occurrence: Cabo Espichel, samples K/3, K/4, K/5 rare to common; Ericeira, sample B/7, rare. The species was originally reported from N.E. England (Speeton Clay).

Stratigraphic age: Berriasian (Speeton Clay, bed D6A, Berriasian, Neale 1962, 1978). This study: Berriasian, *Cytheropterina triebeli* Zone.

Genus PARANOTACYTHERE (Alexander) 1933

Paranotacythere pustulata (Kilenyi)

Plate 14, figs. 5-9

Orthonotacythere pustulata Kilenyi, 1969, p. 143-144, pl. 28, figs. 32-39.

Paranotacythere pustulata (Kilenyi); Wilkinson, 1983, p. 175, fig. 4.

Diagnosis and remarks: The carapace is elongate-trapezoidal in outline with a straight dorsal margin and a posterior cardinal angle that is rounded in the right valve and sharper in the left. The ventral margin is convex, lacks a posteroventral angle, and continues to the posterior extremity. The posterior is drawn into a point, situated just above the mid-height in the right valve, slightly higher in the left. Dorsally, the hinge is straight and maximum thickness is just posterior to mid length. The left valve is slightly larger than the right, and overlaps it a small amount along the posterodorsal and posteroventral regions. Strong polygonal reticulation ornaments the posterior half of both valves and a narrow Zone parallel to the anterior and ventral margins. A prominent furrow is developed extending from the antero-mid-dorsal region through the anteromedian area of each valve. This furrow yields an elongate central node that is aligned vertically, and is surrounded by a large mid-dorsal, larger ventromedian and smaller anteroventral and anterodorsal nodes. The ventromedian and anteroventral nodes are joined by a sharp ridge parallel to the ventral margin.

Specimens are identical to those figured by Kilenyi (1969) from the Kimmeridge Clay type section of southern England. This species differs from the smaller species *O. interrupta* Triebel in its lack of a posteroventral angle, lower posterior and lack of ridges. Variability is seen in this species through its range, with the later forms being less pustulose and more reticulate.

The Holotype and Paratypes of this species, originally housed in the Department of Geology, Hull University, England, are missing and detailed comparisons could not be made. The Portuguese specimens are abundant in silty clays.

Dimensions: L: 0.6mm; H: 0.28mm; W: 0.23mm.

Occurrence: Cabo Espichel, sample I/4 (rare); Ericeira, samples B/2 and B/3 (rare); Praia Azul, abundant in samples A/1, A/2, A/3, A/5, and A/10. Previously reported from southern England.

Stratigraphic age: Kilenyi (1969) reported the species from the *pectinatus*, *pallasoides* and *rotunda* ammonite zones (Late Kimmeridgian) of the Kimmeridgian type section. This study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Family LOXOCONCHIDAE Sars, 1925

Genus MANDELSTAMIA Lyubimova, 1955

Mandelstamia maculata Neale and Kilenyi

Plate 14, fig. 10

Mandelstamia maculata, Neale and Kilenyi, 1961, p. 444-446, pl. 71, figs. 19-25.

Diagnosis and remarks: The carapace is sub-trapezoid in outline with an asymmetrically rounded anterior margin and a bluntly triangular posterior. The dorsal margin is straight and the ventral margin is straight on the left valve and slightly concave on the right, with a lip. The posterior margin is more angular in the right valve than the left, and the lateral margins overhang the ventral margin slightly. A small ovate eye tubercle marks the anterior cardinal angle. Strong reticulate ornamentation is uniformly developed over the valves. Greatest width is one third the length from the posterior. Internally, the hinge is hemimerodont with small crenulate teeth in the right valve and a smooth median bar in the left. The marginal Zone is broad, and the inner margin coincides with the line of concrescence. Neither the pore canals or the scar field could be seen in the specimens examined.

Mandelstamia maculata differs from the Early Cretaceous form, *M. sexti*, in the development of the latero-ventral overhang, the more pointed posterior and the smaller, more uniformly sized surface reticulations.

The Holotype of this species, housed in the Department of Geology, Hull University (Catalog number HU.2.J.1.24) together with the Paratypes, are currently missing, and direct comparisons could not be made.

Dimensions: L: 0.5mm; H: 0.33mm; W: 0.23mm.

Occurrence: Cabo Espichel, sample I/2. The species has also been reported from southern and eastern England.

Stratigraphic age: Late Kimmeridgian (*Subplanites grandis* subzone Kilenyi, 1961; *Wheatleyensis-Pectinatus* zones, Kilenyi 1978). This Study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Mandelstamia sexti Neale and Kilenyi

Plate 14, figs. 11-13

Mandelstamia sexti Neale and Kilenyi, 1961, p. 446, text-figs. 2-4; Neale, 1978, p. 366, pl.2, fig. 14.

Diagnosis and remarks: Carapace elongate-oval in outline, tapering posteriorly, with straight dorsal and ventral margins and an asymmetric anterior margin which is drawn out ventrally. The Posterior margin is rounded to sub-angular, and straight in the postero-dorsal region. Maximum height is in the anterior quarter, maximum thickness is in the posterior quarter. The cardinal angles are well represented, the anterior one marked by a well developed eye tubercle. The valve ornament consists of a reticulation of deep

concentric pits and ridges. Internally, a small anterior vestibulum is developed bearing a few straight radial pore canals.

In the type description, the species is noted as having a well differentiated hinge with the terminal hinge cusps in the right valve bearing 4 or 5 denticulations. The Portuguese specimens were not preserved well enough for the hinge structure to be examined in detail.

The Portuguese specimens compare well with those illustrated in Neale and Kilenyi (1961), and paratypes deposited in the collections of the Department of Geology, Hull University, England (compare pl. 14, figs 11 and 12).

Dimensions: L: 0.69mm; H: 0.4mm.

Occurrence: Cabo Espichel, samples K/3, K/4, K/5 rare to common. The species was originally described from N.E. England,

Stratigraphic age: Berriasian (Speeton Clay Bed D6A, Neale and Kilenyi, 1961). This study: Berriasian, *Cytheropterina triebeli* Zone.

Family PROGONOCYTHERIDAE Sylvester-Bradley, 1948

Genus EXOPHTHALMOCYTHERE Triebel, 1938

Exophthalmocythere gigantea Schmidt

Plate 15, figs. 9-12

Exophthalmocythere gigantea Schmidt, 1954, P. 96-98, Tab. 6, Fig. 13-15; Tab. 8, Fig. 40-43; Klinger, Malz & Martin, 1962, p. 179-180, tab.26, fig. 18.

Diagnosis and remarks: Sub-rectangular preplete carapace, elongate in outline with straight to slightly convex sub-parallel dorsal and ventral margins and well marked cardinal

angles. The anterior margin is broadly rounded and the posterior margin is obtusely pointed at one third to one half mid-height. Prominent eye nodes are developed on the ends of upward and forward pointing stalks at the anterior cardinal angle of each valve. Dorsally the hinge line is straight and the valves are moderately inflated with maximum thickness at mid length. The left valve is slightly larger than the right. The lateral margins have a primary and a secondary reticulate ornament.

Internally, the hinge is paramphidont with the main positive elements in the right valve. The posterior tooth has three crenulations. The inner margin is coincident with the line of concrescence, and is broadest in the anterior. Marginal pore canal and scar details could not be determined.

The Portuguese specimens compare well to those figured by Klinger *et al.* (1962), and Moo's specimens housed in the British Museum (Catalog number Io. 1703-4).

Occurrence: Cabo Espichel, sample I/15, K/3, rare. Previously reported from Germany.

Stratigraphic age: Kimmeridgian-Portlandian (Schmidt 1954, N.W. Germany); Early-Middle Kimmeridgian (Klinger *et al.* 1962, N.W. Germany).

Exophthalmocythere sp. 1

Plate 16, figs. 1-3

Diagnosis and remarks: This form has the same carapace morphology as *E. gigantea* except that it possesses a blade-like wing along the full length of the ventral margin, and a second one developed around the anterior margin. The anterior wing is closer to the contact Zone than the ventral. These structures are typically developed in *Parexophthalmocythere* together with strong anterior and posterior marginal denticulations, but are absent in *Exophthalmocythere*. This species has characteristics of both genera, but has been placed

in *Exophthalmocythere* because it is otherwise identical to *E. gigantea*.

Occurrence: Cabo Espichel, sample K/4 rare.

Stratigraphic age: Portlandian to Berriasian, *Schuleridea triebeli* to *Cytheropterina triebeli* zones.

Genus PROTOCYTHERE Triebel, 1938

Protocythere hechti Triebel

Plate 17, figs. 1-4

Protocythere hechti, Triebel, 1938, p. 189, pl. 1, figs. 11-16; Bartenstein, 1956, p. 530, pl. 3, figs. 73-75; Neale, 1962, p. 446, pl. 9, figs. 5-7; Kilenyi, 1978, p. 338, pl. 3, fig. 8.

Diagnosis and remarks: The carapace is elongate with a sub-rectangular outline. Ventral and dorsal margins are straight and parallel, the anterior margin is broadly rounded and the posterior margin is bluntly triangular at mid-height. A prominent hinge ear is developed at the anterior cardinal angle of the left valve, and poorly developed in the right. The lateral margins have three straight longitudinal ribs developed, in the dorsal, ventral and central areas. The middle rib has a subdued anterior tubercle. The specimens examined are slightly distorted, giving the impression that the dorsal rib is higher on one valve than on the other. This species is distinguished from *P. triplicata* and other species of *Protocythere* by the straight ribs and less inflated margins.

Portuguese specimens compare well to published descriptions of the species, although are somewhat distorted or crushed. Specimens also compare well with one recovered from the Speeton Clay Formation, donated to me by University College London (compare pl. 17, figs. 1-4). Specimens are found in a shale.

Occurrence: Cabo Espichel, sample M/2, M/3, M/6, M/8 (rare). The species has previously been reported from N.W. Germany, France and eastern England (Speeton Clay type section).

Stratigraphic age: Hauterivian to Barremian. (Neale 1962, Speeton Clay, Bed D2, Lower Hauterivian). This study: Hauterivian-Barremian.

Protocythere triplicata (Roemer)

Plate 17, figs. 5-7

Cytherina triplicata Roemer, 1841, p. 104, pl. 16, fig. 16.

Protocythere triplicata (Roemer); Triebel, 1938, p. 20, pl. 1, figs. 1-5; pl. 3, figs. 33-37; Neale, 1962, p. 446, pl. 8, figs. 1-5.

Diagnosis and remarks: Carapace swollen, elongate-ovate with an up-turned posterior. Dorsal margin straight to slightly concave, ventral margin with a slight median concavity, anterior margin broadly rounded and asymmetric. The valves are marked by three strong, thick ribs. The dorsal and ventral ribs are convex, the median rib straight, commencing with an expanded anterior tubercle. The cardinal angles are well represented, the anterior one on the left valve being marked by a strong hinge-ear. The surface of the valves are smooth. Internally, the species has a strong merodont hinge with crenulate anterior and posterior elements in the right valve and corresponding sockets in the left.

The species is distinguished from other species of *Protocythere* by the strongly inflated valves and the thick curved ribs. The Portuguese specimens are somewhat distorted, but otherwise compare well to published figures. Specimens also compare well to examples recovered from the Speeton Clay, donated to me by A.R. Lord, University College London (compare pl. 17, figs. 5-7).

Occurrence: Cabo Espichel samples M/6, M/9, rare. This species is widely reported from N.W. Europe.

Stratigraphic age: Hauterivian-Barremian (Speeton Clay bed D2, Neale 1962, 1978). This study: Hauterivian-Barremian, *Platycythereis crisminaensis* - *Cythereis ericeirensis* Zone

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948

Genus CYTHEREIS Jones 1849

Cythereis ericeiraensis Damotte and Rey

Plate 17, Fig. 9

Cythereis ericeiraensis, Damotte and Rey, 1980, P. 25, pl. 2, figs. 47-50

Diagnosis and remarks: Carapace sub-trapezoidal in outline, with a broadly rounded anterior margin, straight dorsal margin, a triangular posterior and well marked cardinal angles. The anterior cardinal angle is represented by a lobe at around a quarter of the length from the anterior, more prominent on the left valve. The posterior cardinal angle is fairly open, situated at around one quarter the length from the posterior. The posterior is marked by an angle of around 90 degrees, situated at mid-height.

The anterior margin is bordered by a denticulate rim, commencing at the anterior cardinal, passing around to the antero-ventral region, and continuing parallel to but slightly in-board of the ventral margin. The dorso-lateral region is flanked by a ridge bearing around five denticulations. Viewed dorsally, this area broadens in the posterior, which is marked by two or three oblique striations that diverge posteriorly. The lateral margins have an anterior sub-central tubercle, and a postero-median swelling.

The specimens recovered from the Ericeira section are carapaces, and the internal characters can not be determined. Damotte and Rey (1980) assign the species to the

sub-genus *Cornicythereis* Gruendel 1973 on the basis of the denticulate ridges parallel to the ventral and dorsal margins.

Dimensions: L: 0.96mm; H: 0.56mm; W: 0.5mm.

Occurrence: Ericeira samples H/5 and H/6. The species has so far only been reported from the Lusitanian Basin.

Stratigraphic age: Damotte and Rey (1980) report the species from the Lower Aptian. This Study: Late Hauterivian-Early Barremian, *Platycythereis crisminaensis* -*Cythereis ericeirensis* Zone.

Genus REHACYTHEREIS Gruendel 1973

Rehacythereis sp.A

Plate 18, figs. 1-4.

Protocythere sp.1 Ramalho, 1971, p. 166, pl. xxv, figs. 1-4.

Diagnosis and remarks: The heavily sculptured carapace is sub-trapezoidal to sub-rectangular in outline with a prominent frontal lobe, an asymmetrically rounded anterior margin and a bluntly pointed posterior. The dorsal and ventral margins are convex. A small dorsolateral tubercle interrupts dorsal margin at mid point. The lateral margins have a prominent sub-central tubercle and are inflated towards the posterior where they are drawn out into pustulose posterodorsal and posteroventral inflations in the third quarter from the anterior. The cardinal angles are well marked, the anterior ones with large, round eye nodes. The anterior has a prominent bordering denticulated ridge, and the posterior is also marked by denticulations.

Coarse first-order and a finer second-order reticulation covers the valve sides and

extends onto the sub-central tubercle. The first-order reticulation is about 20 times the magnitude of the second. Small pustules pierced by normal pore canals are irregularly scattered over the valves. Viewed dorsally, the left valve is clearly larger than the right and the hinge line swings over to the right in the anterior portion to accommodate the larger hinge ear and eye tubercle in the left valve. The anterior of the carapace is strongly compressed with respect to the posterior, and maximum width is in the posterior third.

Internally, the hinge is weakly developed, hemimerodont with the teeth in the right valve. The anterior tooth is larger than the posterior and is divided into 4 equal crenulations. The median groove (bar in the left valve) is smooth, lightly sub-divided, and widens up to the anterior tooth. The posterior tooth has 3 or 4 crenulations. Height of each crenulation in both anterior and posterior teeth is the same across the full extent of the teeth. A small vestibulum is developed around the anterior margin, and 12 straight marginal pore canals may be seen. Elsewhere the inner margin appears coincident with the line of concrescence. The posterior marginal Zone has 5 or 6 marginal pore canals. Four adductor scars are aligned in the posterior of the scar field, and a horseshoe-shaped mandibular scar lies in front of these and is open towards the dorsal adductor.

The taxonomy of the Trachyleberididae has not been resolved despite Gruendel's (1973) work and subsequent review of the genera by Damotte (1976). The species described above has a hemimerodont hinge which is atypical for the genus *Cythereis* (paramphidont), in that it lacks the anterior socket in the median element of the right valve. The hinge approaches that of *Protocythere* and *Mandocythere* (R. Damotte, pers. comm. 1989), except that the teeth do not increase in height distally from the median element. In this respect, the hinge is closest to that of the *Rehacythereis*.

The ornate sub-central tubercle is typical of *Cythereis*, whereas in *Rehacythereis* this structure is usually smooth. Other features usually found in *Cythereis* include the small dorsolateral spine and the large posterodorsal and posteroventral protuberences. In *Rehacythereis* these structures are continuous, forming dorsolateral and ventral ridges. The

specimens examined have internal features typical of *Rehacythereis*, and the external characteristics of *Cythereis*. This adds credence to Damotte's (1976) treatment of *Rehacythereis* as a sub-genus of *Cythereis*.

The specimens examined are similar to those figured by Ramalho (1971), and also similar externally to '*Cythereis*' gr. sp. C. 307 Oertli. Specimens are common to abundant in shale. The type of hinge is comparable to certain forms recognised in the basal cretaceous (Berriasian to Valanginian) of S.E. France (R. Damotte, pers. comm. 1989).

Occurrence: Cabo Espichel, samples K/3, K/5, K/6, rare.

Stratigraphic age: Berriasian, *Cytheropterina triebeli* Zone.

Genus PLATYCYTHEREIS Triebel, 1940

Platycythereis crisminaensis Damotte and Rey

Plate 17, figs. 10-12

Platycythereis crisminaensis Damotte and Rey, 1980, p. 26-27, pl. 3, figs. 59-64.

Diagnosis and remarks: The carapace is elongate and sub-rectangular with a broadly curved asymmetric anterior margin occupying the anterior quarter of the length of the valves. The dorsal margin is mildly convex, the ventral margin slightly concave and the posterior margin is straight, produced at an angle of 70 degrees to the dorsal margin. The hinge line is straight and the valves are roughly equant and compressed. Two tubercles are developed on the lateral margins, a subcentral one in the anteromedian area and another in the posterodorsal area. The surface of the valves is covered in a coarse reticulate ornament of ovate to polygonal pits separated by flat crested ridges. Three localised thickenings of these ridges are developed: one on the sub-central tubercle and elongated in an anterior-posterior

direction; a second, not so well developed and located on the posterodorsal tubercle aligned parallel to the posterior margin; a third, situated in the posteroventral region parallel to the ventral margin.

Internally, the hinge is a strongly developed hemiamphidont type. The right valve contains a smooth anterior tooth and socket, a smooth median groove and a posterior tooth with four crenulations. The left valve contains the corresponding opposite arrangement of hinge elements. The inner margin is coincident with the line of concrescence along the ventral margin, and is developed into an anterior vestibule, equal in width to the marginal Zone. The anterior marginal Zone has nine marginal pore canals. These structures cannot be clearly determined in the posterior marginal Zone. The scar field is slightly depressed and the four adductor scars are aligned along an axis normal to the dorsal margin.

The specimens differ slightly from those figured by Damotte and Rey (1980), but only in the presence of the thickened dorsoventral ridge. The internal characters of the species are not observed in the specimens described in Damotte and Rey (1980), and there is a question as to the generic affinity of the species. The specimens examined in this study have well developed hemiamphidont hinges and flattened margins with subcentral tubercles. These features are typical of the genus *Platycythereis*. The species is common to abundant in shales.

Occurrence: Cabo Espichel, samples M/6 and M/8. Originally reported from Portugal.

Stratigraphic age: Hauterivian-Barremian (Damotte & Rey 1980). This study: Hauterivian-Barremian, *Platycythereis crisminaensis* - *Cythereis ericeirensis* Zone.

Suborder PLATYCOPINA Sars, 1866

Family CYTHERELLIDAE Sars, 1866

Genus CYTHERELLA Jones, 1849

Cytherella fullonica Jones and Sherborn

Plate 15, figs. 1-2

Cytherella fullonica Jones and Sherborn; Kilenyi, 1978, p.264, pl.1, figs. 1-2.

Diagnosis and remarks: Ovate to subrectangular outline with equally rounded anterior and posterior margins. The dorsal and ventral margins are slightly concave, less so than in *C. pyriformis*. The right valve is larger than the left and overlaps it around the margin, more so at the dorsal and ventral concavities. The carapace is smooth.

Portuguese specimens compare well to Jones and Sherborn's material deposited in the British Museum (catalog number Io. 1857), and specimens from the Kimmeridge Clay section (compare pl. 15, figs. 1 and 3). The species is abundant in shales.

Dimensions: L: 0.72mm; H: 0.39mm; W: 0.27mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2, I/3 and I/4; Ericeira, samples B/1, B/2, B/3 and B/5; Praia Azul, samples A/1, A/2 and A/8. The species has also been reported from the Lower Kimmeridge Clay of southern England.

Stratigraphic age: Callovian (*macrocephalus* Zone) to lower Kimmeridgian (*cymodoce* Zone) (Kilenyi, 1978). This study: Kimmeridgian, *Galliaecytheridea* sp.2 to *Paranotacythere pustulata* Zone.

Cytherella suprajurassica Oertli

Plate 15, figs. 4,6

Cytherella suprajurassica Oertli, 1957, p. 649-650, pl.1, figs. 1-10; Oertli, 1963, pl. XLV, fig. g; Ramalho, 1971, p. 169, pl. XXV, figs. 11-12.

Diagnosis and remarks: Carapace ovate and swollen in the posterior. The right valve is

larger than the left and overlaps it all around the margin. The dorsal margin is concave in the anterior part, convex in the posterior, and the ventral margin is straight. The anterior and posterior margins are symmetrically rounded, maximum height is posterior to mid length (postplete), and maximum thickness is in the posterior quarter.

This form is distinguished from *C. fullonica* and *C. pyriformis* by its strong right valve overlap and swollen posterior. The species is common to abundant in marls and nodular limestones where it is usually autochthonous and represented by later instars.

Dimensions: L: 0.83mm; H: 0.56mm; W: 0.38mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/9, I/10, I/13, I/15, I/16, I/17, I/18, I/19, I/20, I/21, I/22, I/23, K/1, K/2, K/3, K/4 and K/5.

Stratigraphic age: Late Oxfordian-Early Kimmeridgian (Oertli 1963, France). This study: Kimmeridgian, *Galliaecytheridea* sp. 2 to *Schuleridea triebeli* Zone.

Cytherella pyriformis (Corneul)

Plate 15, figs. 5,7

Cythere amygdaloides Corneul, 1846, p.198; pl. 7, fig. 10.

Cytherella pyriformis (Corneul); Neale, 1960, p. 204, pl. 4, figs. 19a-b

Cytherella turgida Donze; Ramalho, 1971, p. 169, pl. XXV, figs. 13-14.

Diagnosis and Remarks: Sub-rectangular ovate carapace with slightly concave dorsal and ventral margins, more so on the anterior part of the dorsal margin, and a pyriform outline in dorsal view. Anterior and posterior of roughly equal height and with equally rounded margins. The right valve overlaps the left by a small amount, equally all around. The form is rare and occurs in nodular and massive limestones.

Dimensions: L: 0.76mm; H: 0.43mm; W: 0.37mm.

Occurrence: Cabo Espichel, samples M/2, M/3, M/4, M/5 and M/7. Ericeira, samples C/10, E/4, H/2 and H/3.

Stratigraphic age: Barremian (Neale 1960). This study: Berriasian-Barremian, *Fabanella boloniensis* to *Platycythereis crisminaensis* Zone.

Genus CYTHERELLOIDEA Alexander, 1929

Cytherelloidea weberi Steghaus

Plate 15, fig. 8

Cytherelloidea weberi Steghaus, p. 207, pl. 14, figs. 4-6; Donze, 1960, p. 10-11, pl. 1, figs. 3-6; Oertli, 1963, pl. XLVI, fig. w; Ramalho, 1971, p. 169, pl. XXV, figs. 15-16.

Diagnosis and remarks: The carapace is sub-rectangular with a straight dorsal margin and a slightly concave ventral margin. The anterior margin is symmetrically rounded and the posterior margin is somewhat square. A strong anterior rib is developed parallel to the anterior margin. The ventral rib commences immediately above the antero-ventral termination of the anterior rib, and continues in a straight line to fuse with the posterior rib. The straight posterior rib continues to one third the posterior height, and joins the posterodorsal rib at right angles. The posterodorsal rib continues for one third of the length before wedging into the lateral margin. A short mid-dorsal ridge commences just posterior to mid length, and swings down towards the mid-anterior region. A weak ventro-median rib parallels the ventral rib, but this is often poorly developed in the Portuguese specimens.

This form differs from *C. weberi* s.s. in its lack of a more or less continuous

peripheral rib, and in the development of the oblique mid-dorsal and ventromedian ribs. It is similarly distinguished from *C. paraweberi*, which bears a curved median rib. The Portuguese specimens are identical to the forms figured by Donze (1960) as *Cytherelloidea weberi* var. *recticostata*. from L'île d'Oleron, France. Neale (1973) identified a phylogenetic lineage of *Cytherelloidea* that evolved from *C. weberi* var. *recticostata* in the Callovian, to *C. planata* Donze in the Berriasian, through progressive reduction of the median rib and gradual enlargement of the dorsal and ventral terminations of the posterior rim into tubercles. These trends are in evidence through the range of the species in the Portuguese sections. The species occurs sporadically in low numbers, predominantly in marl facies.

Dimensions: L: 0.6mm; H: 0.37mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/3, J/4, I/3, I/5, I/14, I/15, I/18, I/19, K/1, K/3 and K/4; Ericeira, samples B/1, B/2, B/3 and B/5; Praia Azul, samples A/1, A/2, A/7 and A/8.

Stratigraphic age: Kimmeridgian-Portlandian, *Gravesia* Zone (Donze 1960, France). This study: Kimmeridgian, *Galliaecytheridea* sp.2 to *Schuleridea triebeli* Zone.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, and I/1; Ericeira, sample B/1; Praia Azul, samples A/1, A/3, A/4, A/5, A/8 and A/10.

Stratigraphic age: Kimmeridgian, *Galliaecytheridea* sp.2 to *Paranotacythere pustulata* Zone.

Family CYTHERURIDAE Muller, 1894

Genus CYTHEROPTERON Sars, 1866

Cytheropteron aquitanum Donze

Plate 13, figs. 7-8,10

Cytheropteron aquitanum Donze, 1960, p. 21-22, pl. IV, figs. 48-51; Kilenyi, 1969, p. 141, pl. 28, figs. 8-11.

Diagnosis and remarks: The carapace is roughly ovate, with maximum height anterior to the mid point. The dorsal margin is strongly convex, anterior margin is asymmetrically rounded, and the posterior is produced into a short caudal process. The hinge line is straight, and maximum thickness between the valves is in the posterior third. The lateral margins are drawn out posteroventrally, produced into alae that frequently have a vellate ridge. The ventral margins are flanked by longitudinal costae.

Some variability is noted with respect to the development of the alae, although this is within the range of the specimens figured by Donze (1960) and Kilenyi (1969). The Portuguese specimens are also comparable to R.C. Whatley's examples from the Upper Oxfordian of Dorset, housed in the British Museum (Catalog number Io. 5081). The species is rare to common in marls and nodular limestone facies.

Dimensions: L: 0.53mm; H: 0.36mm; W: 0.3mm.

Occurrence: Cabo Espichel, samples I/3, I/4, I/5, I/7, I/9, I/10, I/13, I/15, I/16, I/17, I/18, I/19, I/23, K/1, K/3 and K/4; Ericeira, samples B/1, B/2, B/3, B/5, B/6 and B/7; Praia Azul, samples A/1, A/2, A/3, A/4, A/5, A/7 and A/8.

Stratigraphic age: Middle Kimmeridgian (Donze 1960), *wheatleyensis* Zone in the Kimmeridge type section (Kilenyi 1969). This study: Kimmeridgian to Early Portlandian, *Galliaecytheridea* sp. 2 to *Schuleridea triebeli* Zone.

Cytheropteron sp. 1

Plate 13, figs. 9,13

Diagnosis and remarks: This form has a broadly rounded dorsal margin and inflated lateral margins that are produced into sharp points in the posterior region. The posterior is drawn into a pronounced caudal process. Dorsally, the maximum thickness between the valves is in the posterior third. The form is distinguished from *C. aquitanum* by the longer caudal process and the sharply pointed lateral margins. The species occurs in low numbers in mud and reefal limestone facies.

Occurrence: Cabo Espichel, samples J/1, J/2 and J/4.

Stratigraphic age: Early Kimmeridgian, *Galliaecytheridea* sp.2 Zone, *Cytheropteron* sp.1 subzone.

Genus METACYTHEROPTERON Oertli 1957

Metacytheropteron sp.59 Damotte and Rey

Plate 14, fig. 1

Metacytheropteron sp. 59 Damotte and Rey, 1980, p. 32, pl. 3, fig. 78.

Diagnosis and remarks: The carapace is elongate-ovate with a bluntly pointed posterior situated at around mid-height of the valves. The anterior margin is broadly rounded, sharply rounded in the anteroventral region. The dorsal margin is gently convex and lacks distinct cardinal angles. Dorsally, the maximum thickness between the valves is posterior to mid length, and the left valve slightly overlaps the right. The lateral margins are drawn out into weak alae that are roughly symmetrical about the mid-length. The valves have an ornament of faint striae that parallel the dorsal, anterior and ventral margins.

The specimens are generally poorly preserved, but appear identical to those referred to as *Metacytheropteron* sp. 59 in Damotte and Rey (1980). *Metacytheropteron* differs from the genus *Cytheropteron* in the overlapping left valve, the weakly developed alae and the blunter posterior. The species is rare to common in bioturbated limestones.

Dimensions: L: 0.5mm; H: 0.3mm.

Occurrence: Cabo Espichel, samples M/6 and M/7. Previously reported from Portugal.

Stratigraphic age: Hauterivian-Barremian (Damotte & Rey 1980). This study: Hauterivian - Early Barremian, *Platycythereis crisminaensis* - *Cythereis ericeirensis* Zone.

Genus CYTHEROPTERINA Mandelstam, 1956

Cytheropterina triebeli Neale

Plate 14, figs. 2-4

Cytheropterina triebeli Neale, 1962, p. 437, pl.3, fig.7; pl. 4, figs. 1-4; pl. 12, fig. 33; Neale, 1978, p. 336, pl. 2, fig. 10.

Diagnosis and remarks: Carapace elongate-oval in outline, with an asymmetrically rounded anterior margin, a broadly rounded dorsal margin, and a posterior drawn into a caudal process. The ventro-lateral margins are drawn out into smoothly curved alae that swing to the posterior. The alae are bordered by a narrow rim which is flanked inboard by a row of shallow depressions or pits. The ventral surface of each valve is marked by three or four curved costae. A faint reticulate ornament may be developed elsewhere on the valves.

The hinge is well developed, the right valve containing anterior and posterior terminal hinge elements, each with eight or nine bifid teeth, separated by a pitted median groove. The left valve contains the corresponding denticulate sockets and median bar. The inner margin coincides with the line of concrescence, and contains 6-7 anterior marginal pore canals.

The Portuguese specimens compare well with those illustrated in Neale (1962), and are generally smooth, glossy and well preserved. The alar pits are difficult to observe in normal light, but become more obvious when the specimens are wet and observed from an angle. The faint reticulation is only occasionally observed.

Dimensions: L: 0.5mm; H: 0.35mm.

Occurrence: Cabo Espichel, samples K/3, K/4, K/5 rare to common; Ericeira, sample B/7, rare. The species was originally reported from N.E. England (Speeton Clay).

Stratigraphic age: Berriasian (Speeton Clay, bed D6A, Berriasian, Neale 1962, 1978). This study: Berriasian, *Cytheropteryina triebeli* Zone.

Genus PARANOTACYTHERE (Alexander) 1933

Paranotacythere pustulata (Kilenyi)

Plate 14, figs. 5-9

Orthonotacythere pustulata Kilenyi, 1969, p. 143-144, pl. 28, figs. 32-39.

Paranotacythere pustulata (Kilenyi); Wilkinson, 1983, p. 175, fig. 4.

Diagnosis and remarks: The carapace is elongate-trapezoidal in outline with a straight dorsal margin and a posterior cardinal angle that is rounded in the right valve and sharper in the left. The ventral margin is convex, lacks a posteroventral angle, and continues to the posterior extremity. The posterior is drawn into a point, situated just above the mid-height in the right valve, slightly higher in the left. Dorsally, the hinge is straight and maximum thickness is just posterior to mid length. The left valve is slightly larger than the right, and overlaps it a small amount along the posterodorsal and posteroventral regions. Strong polygonal reticulation ornaments the posterior half of both valves and a narrow Zone parallel to the anterior and ventral margins. A prominent furrow is developed extending from the antero-mid-dorsal region through the anteromedian area of each valve. This furrow yields an elongate central node that is aligned vertically, and is surrounded by a large mid-dorsal, larger ventromedian and smaller anteroventral and anterodorsal nodes. The ventromedian and anteroventral nodes are joined by a sharp ridge parallel to the ventral margin.

Specimens are identical to those figured by Kilenyi (1969) from the Kimmeridge Clay type section of southern England. This species differs from the smaller species *O. interrupta* Triebel in its lack of a posteroventral angle, lower posterior and lack of ridges. Variability is seen in this species through its range, with the later forms being less pustulose and more reticulate.

The Holotype and Paratypes of this species, originally housed in the Department of Geology, Hull University, England, are missing and detailed comparisons could not be made. The Portuguese specimens are abundant in silty clays.

Dimensions: L: 0.6mm; H: 0.28mm; W: 0.23mm.

Occurrence: Cabo Espichel, sample I/4 (rare); Ericeira, samples B/2 and B/3 (rare); Praia Azul, abundant in samples A/1, A/2, A/3, A/5, and A/10. Previously reported from southern England.

Stratigraphic age: Kilenyi (1969) reported the species from the *pectinatus*, *pallasoides* and *rotunda* ammonite zones (Late Kimmeridgian) of the Kimmeridgian type section. This study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Family LOXOCONCHIDAE Sars, 1925

Genus MANDELSTAMIA Lyubimova, 1955

Mandelstamia maculata Neale and Kilenyi

Plate 14, fig. 10

Mandelstamia maculata, Neale and Kilenyi, 1961, p. 444-446, pl. 71, figs. 19-25.

Diagnosis and remarks: The carapace is sub-trapezoid in outline with an asymmetrically rounded anterior margin and a bluntly triangular posterior. The dorsal margin is straight and the ventral margin is straight on the left valve and slightly concave on the right, with a lip. The posterior margin is more angular in the right valve than the left, and the lateral margins overhang the ventral margin slightly. A small ovate eye tubercle marks the anterior cardinal angle. Strong reticulate ornamentation is uniformly developed over the valves. Greatest width is one third the length from the posterior. Internally, the hinge is hemimerodont with small crenulate teeth in the right valve and a smooth median bar in the left. The marginal Zone is broad, and the inner margin coincides with the line of concrescence. Neither the pore canals or the scar field could be seen in the specimens examined.

Mandelstamia maculata differs from the Early Cretaceous form, *M. sexti*, in the development of the latero-ventral overhang, the more pointed posterior and the smaller, more uniformly sized surface reticulations.

The Holotype of this species, housed in the Department of Geology, Hull University (Catalog number HU.2.J.1.24) together with the Paratypes, are currently missing, and direct comparisons could not be made.

Dimensions: L: 0.5mm; H: 0.33mm; W: 0.23mm.

Occurrence: Cabo Espichel, sample I/2. The species has also been reported from southern and eastern England.

Stratigraphic age: Late Kimmeridgian (*Subplanites grandis* subzone Kilenyi, 1961; *Wheatleyensis-Pectinatus* zones, Kilenyi 1978). This Study: Late Kimmeridgian, *Paranotacythere pustulata* Zone.

Mandelstamia sexti Neale and Kilenyi

Plate 14, figs. 11-13

Mandelstamia sexti Neale and Kilenyi, 1961, p. 446, text-figs. 2-4; Neale, 1978, p. 366, pl.2, fig. 14.

Diagnosis and remarks: Carapace elongate-oval in outline, tapering posteriorly, with straight dorsal and ventral margins and an asymmetric anterior margin which is drawn out ventrally. The Posterior margin is rounded to sub-angular, and straight in the postero-dorsal region. Maximum height is in the anterior quarter, maximum thickness is in the posterior quarter. The cardinal angles are well represented, the anterior one marked by a well developed eye tubercle. The valve ornament consists of a reticulation of deep

concentric pits and ridges. Internally, a small anterior vestibulum is developed bearing a few straight radial pore canals.

In the type description, the species is noted as having a well differentiated hinge with the terminal hinge cusps in the right valve bearing 4 or 5 denticulations. The Portuguese specimens were not preserved well enough for the hinge structure to be examined in detail.

The Portuguese specimens compare well with those illustrated in Neale and Kilenyi (1961), and paratypes deposited in the collections of the Department of Geology, Hull University, England (compare pl. 14, figs 11 and 12).

Dimensions: L: 0.69mm; H: 0.4mm.

Occurrence: Cabo Espichel, samples K/3, K/4, K/5 rare to common. The species was originally described from N.E. England,

Stratigraphic age: Berriasian (Speeton Clay Bed D6A, Neale and Kilenyi, 1961). This study: Berriasian, *Cytheropteria triebeli* Zone.

Family PROGONOCYTHERIDAE Sylvester-Bradley, 1948

Genus EXOPHTHALMOCYTHERE Triebel, 1938

Exophthalmocythere gigantea Schmidt

Plate 15, figs. 9-12

Exophthalmocythere gigantea Schmidt, 1954, P. 96-98, Tab. 6, Fig. 13-15; Tab. 8, Fig. 40-43; Klinger, Malz & Martin, 1962, p. 179-180, tab.26, fig. 18.

Diagnosis and remarks: Sub-rectangular preplete carapace, elongate in outline with straight to slightly convex sub-parallel dorsal and ventral margins and well marked cardinal

angles. The anterior margin is broadly rounded and the posterior margin is obtusely pointed at one third to one half mid-height. Prominent eye nodes are developed on the ends of upward and forward pointing stalks at the anterior cardinal angle of each valve. Dorsally the hinge line is straight and the valves are moderately inflated with maximum thickness at mid length. The left valve is slightly larger than the right. The lateral margins have a primary and a secondary reticulate ornament.

Internally, the hinge is paramphidont with the main positive elements in the right valve. The posterior tooth has three crenulations. The inner margin is coincident with the line of concrescence, and is broadest in the anterior. Marginal pore canal and scar details could not be determined.

The Portuguese specimens compare well to those figured by Klinger *et al.* (1962), and Moo's specimens housed in the British Museum (Catalog number Io. 1703-4).

Occurrence: Cabo Espichel, sample I/15, K/3, rare. Previously reported from Germany.

Stratigraphic age: Kimmeridgian-Portlandian (Schmidt 1954, N.W. Germany); Early-Middle Kimmeridgian (Klinger *et al.* 1962, N.W. Germany).

Exophthalmocythere sp. 1

Plate 16, figs. 1-3

Diagnosis and remarks: This form has the same carapace morphology as *E. gigantea* except that it possesses a blade-like wing along the full length of the ventral margin, and a second one developed around the anterior margin. The anterior wing is closer to the contact Zone than the ventral. These structures are typically developed in *Parexophthalmocythere* together with strong anterior and posterior marginal denticulations, but are absent in *Exophthalmocythere*. This species has characteristics of both genera, but has been placed

in *Exopthalmocythere* because it is otherwise identical to *E. gigantea*.

Occurrence: Cabo Espichel, sample K/4 rare.

Stratigraphic age: Portlandian to Berriasian, *Schuleridea triebeli* to *Cytheropterina triebeli* zones.

Genus PROTOCYTHERE Triebel, 1938

Protocythere hechti Triebel

Plate 17, figs. 1-4

Protocythere hechti, Triebel, 1938, p. 189, pl. 1, figs. 11-16; Bartenstein, 1956, p. 530, pl. 3, figs. 73-75; Neale, 1962, p. 446, pl. 9, figs. 5-7; Kilenyi, 1978, p. 338, pl. 3, fig. 8.

Diagnosis and remarks: The carapace is elongate with a sub-rectangular outline. Ventral and dorsal margins are straight and parallel, the anterior margin is broadly rounded and the posterior margin is bluntly triangular at mid-height. A prominent hinge ear is developed at the anterior cardinal angle of the left valve, and poorly developed in the right. The lateral margins have three straight longitudinal ribs developed, in the dorsal, ventral and central areas. The middle rib has a subdued anterior tubercle. The specimens examined are slightly distorted, giving the impression that the dorsal rib is higher on one valve than on the other. This species is distinguished from *P. triplicata* and other species of *Protocythere* by the straight ribs and less inflated margins.

Portuguese specimens compare well to published descriptions of the species, although are somewhat distorted or crushed. Specimens also compare well with examples recovered from the Speeton Clay Formation, donated to me by University College London (compare pl. 17, figs. 1-4). Specimens are found in a shale.

Occurrence: Cabo Espichel, sample M/2, M/3, M/6, M/8 (rare). The species has previously been reported from N.W. Germany, France and eastern England (Speeton Clay type section).

Stratigraphic age: Hauterivian to Barremian. (Neale 1962, Speeton Clay, Bed D2, Lower Hauterivian). This study: Hauterivian-Barremian.

Protocythere triplicata (Roemer)

Plate 17, figs. 5-7

Cytherina triplicata Roemer, 1841, p. 104, pl. 16, fig. 16.

Protocythere triplicata (Roemer); Triebel, 1938, p. 20, pl. 1, figs. 1-5; pl. 3, figs. 33-37; Neale, 1962, p. 446, pl. 8, figs. 1-5.

Diagnosis and remarks: Carapace swollen, elongate-ovate with an up-turned posterior. Dorsal margin straight to slightly concave, ventral margin with a slight median concavity, anterior margin broadly rounded and asymmetric. The valves are marked by three strong, thick ribs. The dorsal and ventral ribs are convex, the median rib straight, commencing with an expanded anterior tubercle. The cardinal angles are well represented, the anterior one on the left valve being marked by a strong hinge-ear. The surface of the valves are smooth. Internally, the species has a strong merodont hinge with crenulate anterior and posterior elements in the right valve and corresponding sockets in the left.

The species is distinguished from other species of *Protocythere* by the strongly inflated valves and the thick curved ribs. The Portuguese specimens are somewhat distorted, but otherwise compare well to published figures. Specimens also compare well to examples recovered from the Speeton Clay, donated to me by A.R. Lord, University College London (compare pl. 17, figs. 5-7).

Occurrence: Cabo Espichel samples M/6, M/9, rare. This species is widely reported from N.W. Europe.

Stratigraphic age: Hauterivian-Barremian (Speeton Clay bed D2, Neale 1962, 1978). This study: Hauterivian-Barremian, *Platycythereis crismaensis* - *Cythereis ericeirensis* Zone

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948

Genus CYTHEREIS Jones 1849

Cythereis ericeiraensis Damotte and Rey

Plate 17, Fig. 9

Cythereis ericeiraensis, Damotte and Rey, 1980, P. 25, pl. 2, figs. 47-50

Diagnosis and remarks: Carapace sub-trapezoidal in outline, with a broadly rounded anterior margin, straight dorsal margin, a triangular posterior and well marked cardinal angles. The anterior cardinal angle is represented by a lobe at around a quarter of the length from the anterior, more prominent on the left valve. The posterior cardinal angle is fairly open, situated at around one quarter the length from the posterior. The posterior is marked by an angle of around 90 degrees, situated at mid-height.

The anterior margin is bordered by a denticulate rim, commencing at the anterior cardinal, passing around to the antero-ventral region, and continuing parallel to but slightly in-board of the ventral margin. The dorso-lateral region is flanked by a ridge bearing around five denticulations. Viewed dorsally, this area broadens in the posterior, which is marked by two or three oblique striations that diverge posteriorly. The lateral margins have an anterior sub-central tubercle, and a postero-median swelling.

The specimens recovered from the Ericeira section are carapaces, and the internal characters can not be determined. Damotte and Rey (1980) assign the species to the

sub-genus *Cornicythereis* Gruendel 1973 on the basis of the denticulate ridges parallel to the ventral and dorsal margins.

Dimensions: L: 0.96mm; H: 0.56mm; W: 0.5mm.

Occurrence: Ericeira samples H/5 and H/6. The species has so far only been reported from the Lusitanian Basin.

Stratigraphic age: Damotte and Rey (1980) report the species from the Lower Aptian. This Study: Late Hauterivian-Early Barremian, *Platycythereis crisminaensis* -*Cythereis ericeirensis* Zone.

Genus REHACYTHEREIS Gruendel 1973

Rehacythereis sp.A

Plate 18, figs. 1-4.

Protocythere sp.1 Ramalho, 1971, p. 166, pl. xxv, figs. 1-4.

Diagnosis and remarks: The heavily sculptured carapace is sub-trapezoidal to sub-rectangular in outline with a prominent frontal lobe, an asymmetrically rounded anterior margin and a bluntly pointed posterior. The dorsal and ventral margins are convex. A small dorsolateral tubercle interrupts dorsal margin at mid point. The lateral margins have a prominent sub-central tubercle and are inflated towards the posterior where they are drawn out into pustulose posterodorsal and posteroventral inflations in the third quarter from the anterior. The cardinal angles are well marked, the anterior ones with large, round eye nodes. The anterior has a prominent bordering denticulated ridge, and the posterior is also marked by denticulations.

Coarse first-order and a finer second-order reticulation covers the valve sides and

extends onto the sub-central tubercle. The first-order reticulation is about 20 times the magnitude of the second. Small pustules pierced by normal pore canals are irregularly scattered over the valves. Viewed dorsally, the left valve is clearly larger than the right and the hinge line swings over to the right in the anterior portion to accommodate the larger hinge ear and eye tubercle in the left valve. The anterior of the carapace is strongly compressed with respect to the posterior, and maximum width is in the posterior third.

Internally, the hinge is weakly developed, hemimerodont with the teeth in the right valve. The anterior tooth is larger than the posterior and is divided into 4 equal crenulations. The median groove (bar in the left valve) is smooth, lightly sub-divided, and widens up to the anterior tooth. The posterior tooth has 3 or 4 crenulations. Height of each crenulation in both anterior and posterior teeth is the same across the full extent of the teeth. A small vestibulum is developed around the anterior margin, and 12 straight marginal pore canals may be seen. Elsewhere the inner margin appears coincident with the line of concrescence. The posterior marginal Zone has 5 or 6 marginal pore canals. Four adductor scars are aligned in the posterior of the scar field, and a horseshoe-shaped mandibular scar lies in front of these and is open towards the dorsal adductor.

The taxonomy of the Trachyleberididae has not been resolved despite Gruendel's (1973) work and subsequent review of the genera by Damotte (1976). The species described above has a hemimerodont hinge which is atypical for the genus *Cythereis* (paramphidont), in that it lacks the anterior socket in the median element of the right valve. The hinge approaches that of *Protocythere* and *Mandocythere* (R. Damotte, pers. comm. 1989), except that the teeth do not increase in height distally from the median element. In this respect, the hinge is closest to that of the *Rehacythereis*.

The ornate sub-central tubercle is typical of *Cythereis*, whereas in *Rehacythereis* this structure is usually smooth. Other features usually found in *Cythereis* include the small dorsolateral spine and the large posterodorsal and posteroventral protuberences. In *Rehacythereis* these structures are continuous, forming dorsolateral and ventral ridges. The

specimens examined have internal features typical of *Rehacythereis*, and the external characteristics of *Cythereis*. This adds credence to Damotte's (1976) treatment of *Rehacythereis* as a sub-genus of *Cythereis*.

The specimens examined are similar to those figured by Ramalho (1971), and also similar externally to '*Cythereis*' gr. sp. C. 307 Oertli. Specimens are common to abundant in shale. The type of hinge is comparable to certain forms recognised in the basal cretaceous (Berriasian to Valanginian) of S.E. France (R. Damotte, pers. comm. 1989).

Occurrence: Cabo Espichel, samples K/3, K/5, K/6, rare.

Stratigraphic age: Berriasian, *Cytheropterina triebeli* Zone.

Genus PLATYCYTHEREIS Triebel, 1940

Platycythereis crisminaensis Damotte and Rey

Plate 17, figs. 10-12

Platycythereis crisminaensis Damotte and Rey, 1980, p. 26-27, pl. 3, figs. 59-64.

Diagnosis and remarks: The carapace is elongate and sub-rectangular with a broadly curved asymmetric anterior margin occupying the anterior quarter of the length of the valves. The dorsal margin is mildly convex, the ventral margin slightly concave and the posterior margin is straight, produced at an angle of 70 degrees to the dorsal margin. The hinge line is straight and the valves are roughly equant and compressed. Two tubercles are developed on the lateral margins, a subcentral one in the anteromedian area and another in the posterodorsal area. The surface of the valves is covered in a coarse reticulate ornament of ovate to polygonal pits separated by flat crested ridges. Three localised thickenings of these ridges are developed: one on the sub-central tubercle and elongated in an anterior-posterior

direction; a second, not so well developed and located on the posterodorsal tubercle aligned parallel to the posterior margin; a third, situated in the posteroventral region parallel to the ventral margin.

Internally, the hinge is a strongly developed hemiamphidont type. The right valve contains a smooth anterior tooth and socket, a smooth median groove and a posterior tooth with four crenulations. The left valve contains the corresponding opposite arrangement of hinge elements. The inner margin is coincident with the line of concrescence along the ventral margin, and is developed into an anterior vestibule, equal in width to the marginal Zone. The anterior marginal Zone has nine marginal pore canals. These structures cannot be clearly determined in the posterior marginal Zone. The scar field is slightly depressed and the four adductor scars are aligned along an axis normal to the dorsal margin.

The specimens differ slightly from those figured by Damotte and Rey (1980), but only in the presence of the thickened dorsoventral ridge. The internal characters of the species are not observed in the specimens described in Damotte and Rey (1980), and there is a question as to the generic affinity of the species. The specimens examined in this study have well developed hemiamphidont hinges and flattened margins with subcentral tubercles. These features are typical of the genus *Platycythereis*. The species is common to abundant in shales.

Occurrence: Cabo Espichel, samples M/6 and M/8. Originally reported from Portugal.

Stratigraphic age: Hauterivian-Barremian (Damotte & Rey 1980). This study: Hauterivian-Barremian, *Platycythereis crisminaensis* - *Cythereis ericeirensis* Zone.

Suborder PLATYCOPINA Sars, 1866

Family CYTHERELLIDAE Sars, 1866

Genus CYTHERELLA Jones, 1849

Cytherella fullonica Jones and Sherborn

Plate 15, figs. 1-2

Cytherella fullonica Jones and Sherborn; Kilenyi, 1978, p.264, pl.1, figs. 1-2.

Diagnosis and remarks: Ovate to subrectangular outline with equally rounded anterior and posterior margins. The dorsal and ventral margins are slightly concave, less so than in *C. pyriformis*. The right valve is larger than the left and overlaps it around the margin, more so at the dorsal and ventral concavities. The carapace is smooth.

Portuguese specimens compare well to Jones and Sherborn's material deposited in the British Museum (catalog number Io. 1857), and specimens from the Kimmeridge Clay section (compare pl. 15, figs. 1 and 3). The species is abundant in shales.

Dimensions: L: 0.72mm; H: 0.39mm; W: 0.27mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2, I/3 and I/4; Ericeira, samples B/1, B/2, B/3 and B/5; Praia Azul, samples A/1, A/2 and A/8. The species has also been reported from the Lower Kimmeridge Clay of southern England.

Stratigraphic age: Callovian (*macrocephalus* Zone) to lower Kimmeridgian (*cymodoce* Zone) (Kilenyi, 1978). This study: Kimmeridgian, *Galliaecytheridea* sp.2 to *Paranotacythere pustulata* Zone.

Cytherella suprajurassica Oertli

Plate 15, figs. 4,6

Cytherella suprajurassica Oertli, 1957, p. 649-650, pl.1, figs. 1-10; Oertli, 1963, pl. XLV, fig. g; Ramalho, 1971, p. 169, pl. XXV, figs. 11-12.

Diagnosis and remarks: Carapace ovate and swollen in the posterior. The right valve is

larger than the left and overlaps it all around the margin. The dorsal margin is concave in the anterior part, convex in the posterior, and the ventral margin is straight. The anterior and posterior margins are symmetrically rounded, maximum height is posterior to mid length (postplete), and maximum thickness is in the posterior quarter.

This form is distinguished from *C. fullonica* and *C. pyriformis* by its strong right valve overlap and swollen posterior. The species is common to abundant in marls and nodular limestones where it is usually autochthonous and represented by later instars.

Dimensions: L: 0.83mm; H: 0.56mm; W: 0.38mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/4, I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/9, I/10, I/13, I/15, I/16, I/17, I/18, I/19, I/20, I/21, I/22, I/23, K/1, K/2, K/3, K/4 and K/5.

Stratigraphic age: Late Oxfordian-Early Kimmeridgian (Oertli 1963, France). This study: Kimmeridgian, *Galliaecytheridea* sp. 2 to *Schuleridea triebeli* Zone.

Cytherella pyriformis (Corneul)

Plate 15, figs. 5,7

Cythere amygdaloides Corneul, 1846, p.198; pl. 7, fig. 10.

Cytherella pyriformis (Corneul); Neale, 1960, p. 204, pl. 4, figs. 19a-b

Cytherella turgida Donze; Ramalho, 1971, p. 169, pl. XXV, figs. 13-14.

Diagnosis and Remarks: Sub-rectangular ovate carapace with slightly concave dorsal and ventral margins, more so on the anterior part of the dorsal margin, and a pyriform outline in dorsal view. Anterior and posterior of roughly equal height and with equally rounded margins. The right valve overlaps the left by a small amount, equally all around. The form is rare and occurs in nodular and massive limestones.

Dimensions: L: 0.76mm; H: 0.43mm; W: 0.37mm.

Occurrence: Cabo Espichel, samples M/2, M/3, M/4, M/5 and M/7. Ericeira, samples C/10, E/4, H/2 and H/3.

Stratigraphic age: Barremian (Neale 1960). This study: Berriasian-Barremian, *Fabanella boloniensis* to *Platycythereis crisminaensis* Zone.

Genus CYTHERELLOIDEA Alexander, 1929

Cytherelloidea weberi Steghaus

Plate 15, fig. 8

Cytherelloidea weberi Steghaus, p. 207, pl. 14, figs. 4-6; Donze, 1960, p. 10-11, pl. 1, figs. 3-6; Oertli, 1963, pl. XLVI, fig. w; Ramalho, 1971, p. 169, pl. XXV, figs. 15-16.

Diagnosis and remarks: The carapace is sub-rectangular with a straight dorsal margin and a slightly concave ventral margin. The anterior margin is symmetrically rounded and the posterior margin is somewhat square. A strong anterior rib is developed parallel to the anterior margin. The ventral rib commences immediately above the antero-ventral termination of the anterior rib, and continues in a straight line to fuse with the posterior rib. The straight posterior rib continues to one third the posterior height, and joins the posterodorsal rib at right angles. The posterodorsal rib continues for one third of the length before wedging into the lateral margin. A short mid-dorsal ridge commences just posterior to mid length, and swings down towards the mid-anterior region. A weak ventro-median rib parallels the ventral rib, but this is often poorly developed in the Portuguese specimens.

This form differs from *C. weberi* s.s. in its lack of a more or less continuous

peripheral rib, and in the development of the oblique mid-dorsal and ventromedian ribs. It is similarly distinguished from *C. paraweberi*, which bears a curved median rib. The Portuguese specimens are identical to the forms figured by Donze (1960) as *Cytherelloidea weberi* var. *recticostata*. from L'île d'Oleron, France. Neale (1973) identified a phylogenetic lineage of *Cytherelloidea* that evolved from *C. weberi* var. *recticostata* in the Callovian, to *C. planata* Donze in the Berriasian, through progressive reduction of the median rib and gradual enlargement of the dorsal and ventral terminations of the posterior rim into tubercles. These trends are in evidence through the range of the species in the Portuguese sections. The species occurs sporadically in low numbers, predominantly in marl facies.

Dimensions: L: 0.6mm; H: 0.37mm.

Occurrence: Cabo Espichel, samples J/1, J/2, J/3, J/4, I/3, I/5, I/14, I/15, I/18, I/19, K/1, K/3 and K/4; Ericeira, samples B/1, B/2, B/3 and B/5; Praia Azul, samples A/1, A/2, A/7 and A/8.

Stratigraphic age: Kimmeridgian-Portlandian, *Gravesia* Zone (Donze 1960, France). This study: Kimmeridgian, *Galliaecytheridea* sp.2 to *Schuleridea triebeli* Zone.

PLATE 1

- Figs. 1, 2 *Reophax horridus* (Schwager), Ericeira, sample C-10, *Choffatella tingitana*-*Marssonella kummi* zones (Upper Kimmeridgian - Hauterivian) x150 (fig.1), x145 (fig.2).
- Figs. 3, 4 *Reophax aff. scorpiurus* Montfort, Ericeira, sample E-5, *Mesoendothra sp.A*-*Marssonella Kummi* zones (Kimmeridgian -Hauterivian), x97 (fig.3), x112 (fig.4).
- Figs. 5, 6 *Haplophragmoides concavus* (Chapman), Cabo Espichel, sample I-17, *Mesoendothra sp.A*-*Marssonella kummi* zones (Upper Kimmeridgian-Lower Hauterivian), x250 (fig.5), x270 (fig.6).
- Fig. 7 *Haplophragmoides concavus* (Chapman), Speeton Clay, bed LB6, x225.
- Figs. 8, 9 *Haplophragmoides minor* Nauss, Ericeira sample C-10, *Ammobaculites subcretaceus*-*Anchispirocyclina lusitanica* zone (Berriasian) x150 (fig.8), x105 (fig. 9). Fig. 9 in plain light, immersed in glycerine.
- Figs.10-13 *Haplophragmoides nonionoides* (Reuss), Ericeira, sample D-6 (figs. 10-11), Cabo Espichel, sample I-14 (figs. 12-13), *Mesoendothra sp.A*-*Choffatella decipiens* zone (Kimmeridgian-Lower Barremian), x226 (fig.10), x207 (fig.11), x245 (figs. 12-13). Specimen in figs. 12-13 with angular periphery.
- Fig.14 *Freixialina planispiralis* Ramalho, Praia Azul, sample A-7, *Mesoendothra sp.A*- *Anchispirocyclina lusitanica* zones (Kimmeridgian - Portlandian), x162



Plate 1

PLATE 2

- Figs. 1-3 *Ammobaculites agglutinans* (d'Orbigny), Cabo Espichel, samples I-4 (fig. 1), I-17 (figs. 2-3), *Mesoendothyra* sp.A - *Ammobaculites* sp.A zones (Kimmeridgian-Hauterivian), x225 (fig.1), x180 (fig. 2), x175 (fig. 3).
- Figs. 4-5 *Ammobaculites coprilithiformis* (Schwager), Cabo Espichel sample I-17 (fig. 4), Ericeira sample E-9 (fig. 5), *Mesoendothyra* sp.A - *Choffatella decipiens* zone (Kimmeridgian-Barremian), x 46 (fig. 4), x48 (fig. 5). Specimen in fig. 4 is a form with a large coil, specimen in fig. 5 is a small-coiled form.
- Figs. 6-7 *Ammobaculites euides* Loeblich and Tappan, Ericeira, sample E-6, *Haplophragmium inconstans*-*Marssonella kummi* zones (Upper Valanginian- Lower Hauterivian), x214 (Fig.6), x208 (Fig.7)
- Fig. 8 *Ammobaculites godmani* (Barnard), Cabo Espichel, sample I-16, *Choffatella tingitana* - *Anchispirocyclina lusitanica* zones (Kimmeridgian-Portlandian, x200.
- Figs. 9-10 *Ammobaculites obliquus* Loeblich and Tappan, Ericeira, sample E-8, *Haplophragmoides inconstans* - *Marssonella kummi* zones, *Ammobaculites obliquus* subzone (Upper Valanginian-Hauterivian), x130 (fig. 9), x200 (fig.10).
- Figs. 11-12 *Ammobaculites reophacoides*, Bartenstein, Ericeira sample H-3, *Marssonella kummi* zone, *Ammobaculites obliquus* subzone (Middle-Upper Hauterivian), x76 (fig. 11), x126 (fig. 12).
- Figs.13-14 *Ammobaculites subcretaceus* Cushman and Alexander, large coiled variants, Ericeira sample C-10 (Fig. 13), *Anchispirocyclina lusitanica*-*Marssonella kummi* zones (Berriasian - Middle Hauterivian), Speeton Clay bed C9-1 (Fig. 14), x225 (Fig. 13), x185 (Fig. 14).
- Figs.15-16 *Ammobaculites subcretaceus* Cushman and Alexander, small coiled variants with well developed uniserial stage, Ericeira, sample C-10 (Fig. 15), *Anchispirocyclina lusitanica* - *Marssonella kummi* zones (Berriasian - Middle Hauterivian), Speeton Clay bed LB3(4-5) (Fig.16), x115 (Fig.15), x 160 (Fig. 16).

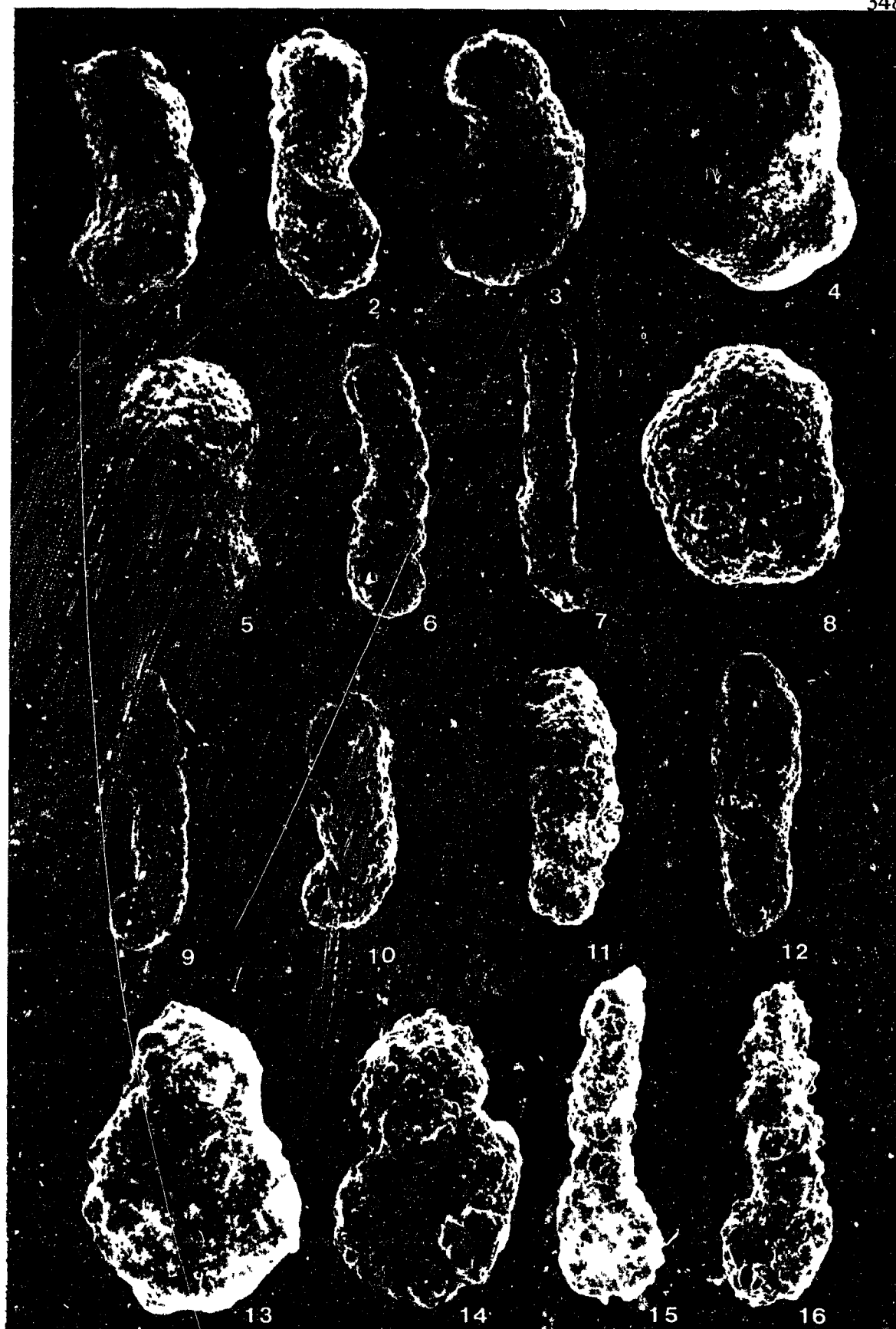


Plate 2

PLATE 3

- Fig. 1 *Ammobaculites subcretaceus* Cushman and Alexander, pseudo-biserial form, Ericeira sample C-10, *Anchispirocyclina lusitanica* - *Marssonella kummi* zones (Berriasian - Middle Hauterivian), x166
- Figs. 2, 4 *Ammobaculites subcretaceus* Cushman and Alexander, in plain light, glycerine immersion showing 'reverse' coiling and pseudo-biseriality in the early stages of the uncoiled portion. Ericeira sample C-10, *Anchispirocyclina lusitanica* - *Marssonella kummi* zones (Berriasian-Middle Hauterivian), x142 (Fig. 2), x135 (Fig. 4).
- Fig. 3 *Ammobaculites subcretaceus* Cushman and Alexander, in plain light, glycerine immersion. 'Reverse' coiling not as strongly developed, pseudo-biseriality apparent in the early uncoiled portion. Speeton Clay, bed LB3 (4-5), x142
- Fig. 5 *Ammobaculites subcretaceus* Cushman and Alexander, in plain light, glycerine immersion. Large coiled variant, Ericeira sample C-10. *Anchispirocyclina lusitanica* - *Marssonella kummi* zones (Berriasian-Middle Hauterivian), x93
- Figs. 6-8 *Haplophragmium inconstans* Bartenstein and Brand, Ericeira sample C-10. *Anchispirocyclina lusitanica* - *Marssonella kummi* zones (Berriasian-Middle Hauterivian) (Figs. 6), Speeton Clay bed LB4B (Fig. 7), Cabo Espichel sample L-5 (Fig. 8), x95 (Fig. 6), x164 (Fig. 7), x130 (Fig. 8)
- Fig. 9 *Flabellammina vitrea* Crespin, Ericeira sample E-7, *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Lower Hauterivian), x91
- Figs. 10-11 *Spiroplectammina ammovitrea* Tappan, Ericeira sample E-7, *Marssonella kummi* zone (Hauterivian), x162 (Fig. 10), x152 (Fig. 11)
- Fig. 12 *Spiroplectammina dorni* Zelder, Cabo Espichel sample M-7, *Marssonella kummi* zone (Hauterivian), x178
- Figs. 13-14 *Verneulinoides minuta* Said and Barakat, Cabo Espichel sample I-5, *Mesoendothyra* sp.A - *Choffatella tingitana* zones (Kimmeridgian), x 226 (Fig. 13), x220 (Fig. 14)
- Figs. 15-16 *Marssonella kummi* Zelder, Cabo Espichel sample M-7 (Fig. 15), Ericeira sample H-4 (Fig. 16), *Marssonella kummi* zone (Upper Hauterivian), x202 (Fig. 15), x180 (Fig. 16)
- Fig. 17 *Trochammina globigeriniformis* (Parker and Jones), Ericeira sample E-7, *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Hauterivian), x380.



Plate 3

Plate 4

- Figs. 1-3 *Trochammina depressa* Lozo, Ericeira sample E-7 (Figs. 1,3), *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Hauterivian), Speeton Clay bed LB4B (Fig. 2), x222 (Fig. 1), x225 (Fig. 2), x224 (Fig. 3)
- Figs. 4-6 *Trochammina* aff. *quineloba* Geroch, Ericeira sample E-5, *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Hauterivian), x254 (Fig. 4), x278 (Fig. 5), x229 (Fig. 6)
- Figs. 7-9 *Trochammina* aff. *ragatti* Crespín, Ericeira sample E-6, *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Hauterivian), x120 (Fig. 7), x125 (Fig. 8), x120 (Fig. 9)
- Figs. 10-12 ?*Tiphotrocha* sp. Ericeira sample E-7, *Marssonella kummi* zone, *Trochammina depressa* sub-zone (Hauterivian), x267 (Fig. 10), x244 (Fig. 11), x263 (Fig. 12)

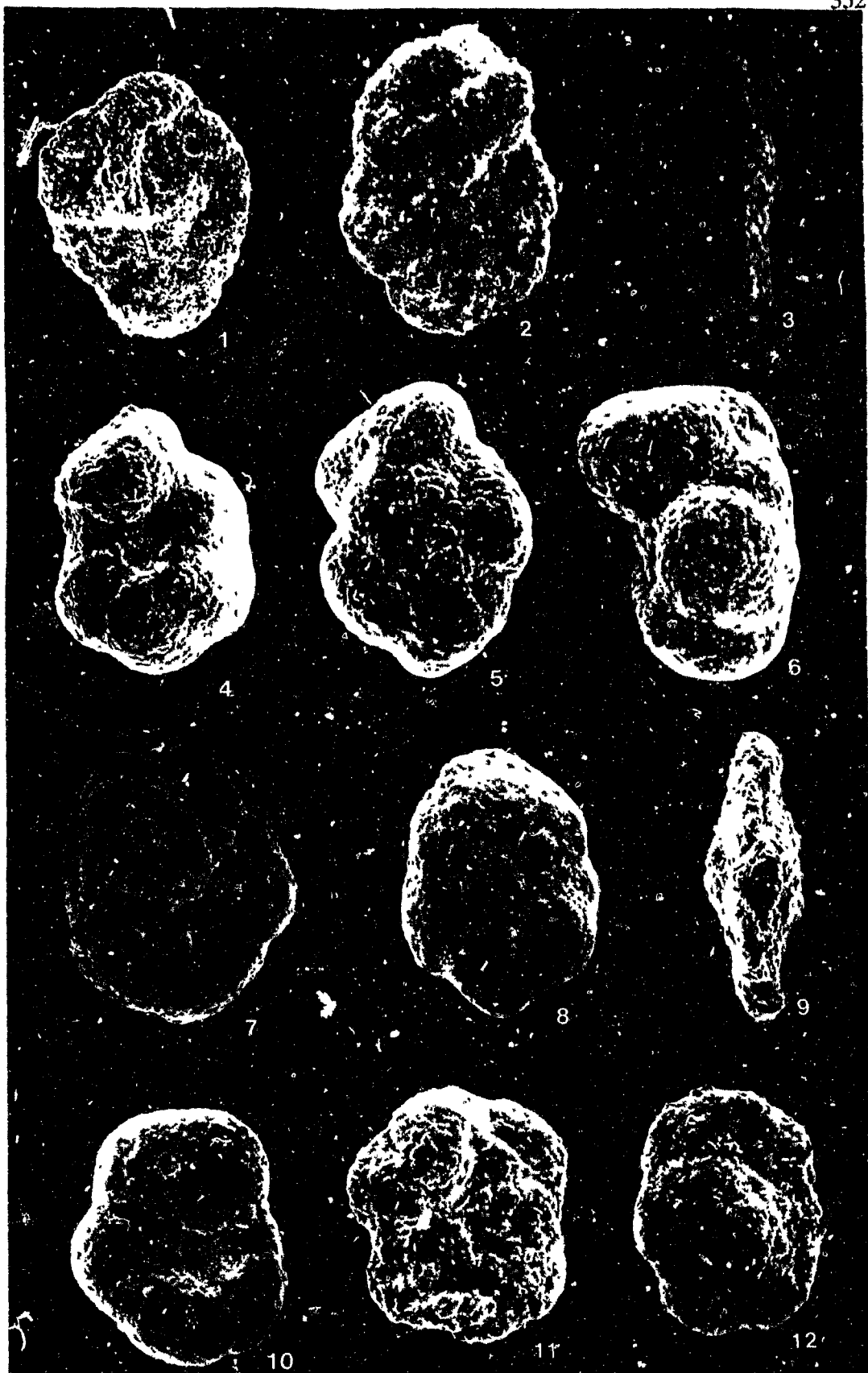


Plate 4

PLATE 5

Figs. 1-7 *Ammobaculites* sp.A. Ericeira sample E.6, *Ammobaculites* sp.A zone (Upper Valanginian). Fig. 1, x175; Fig. 2 view of aperture, x 175; Fig. 3, x240; Figs 4-7, camera lucida drawings of Fig. 1, x112.

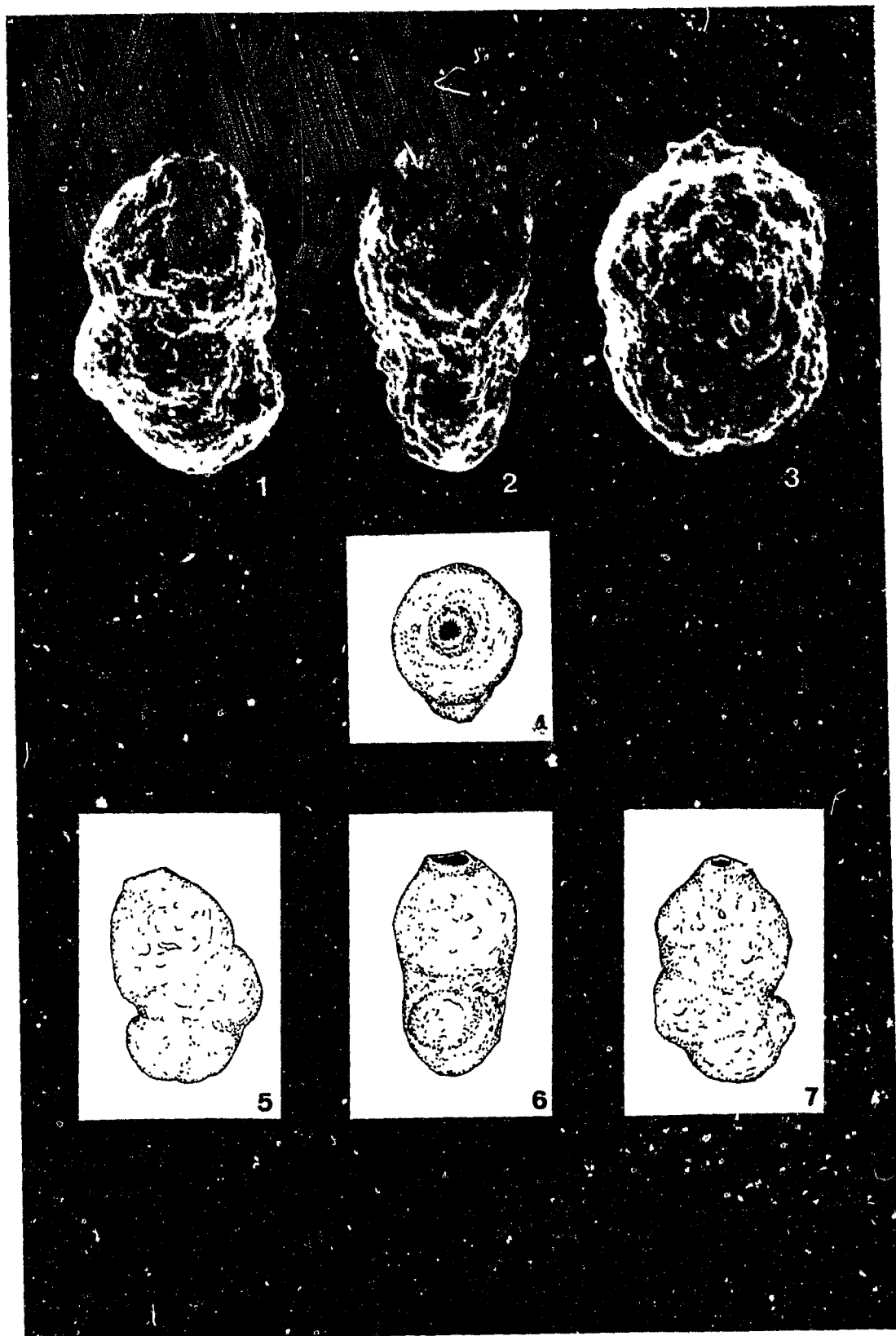


Plate 5

PLATE 6

- Fig. 1 *Lenticulina muensteri* (Roemer), Cabo Espichel sample I-19, *Mesoendothyra* sp.A- *Choffatella decipiens* zones (Kimmeridgian-Barremian), x140
- Fig. 2 *Eoguttulina liassica* (Strickland), Praia Azul sample A-7, *Mesoendothyra* sp.A-*Haplophragmium inconstans* zones (Kimmeridgian-Valanginian), x285
- Fig. 3 *Eoguttulina inovroclaviensis* (Bielecka and Pozaryski), Ericeira sample B-1, *Mesoendothyra* sp.A-*Choffatella decipiens* zones (Kimmeridgian-Barremian), x196
- Fig. 4 *Eoguttulina metensis* (Terquem), Cabo Espichel sample I-17, *Mesoendothyra* sp.A-*Marssonella kummi* zones (Kimmeridgian- Upper Hauterivian), x145
- Fig. 5 *Eoguttulina oolithica* (Terquem), Ericeira sample B-1, *Choffatella tingitana* - *Choffatella decipiens* zones (Kimmeridgian - Lower Barremian), x444
- Fig. 6 *Eoguttulina bilocularis* (Terquem), Ericeira sample B-1, *Mesoendothyra* sp.A zone (Kimmeridgian), x186
- Figs. 7-9 *Discorbis scituliformis* (Seibold and Seibold), Cabo Espichel sample K-6, *Anchispirocyclina lusitanica* zone, *Discorbis scituliformis* sub-zone (Berriasian), x98 (Fig. 7), x96 (Fig. 8), x98 (Fig. 9).
- Figs. 10-11 *Epistomina uhligi* Mjatliuk, Cabo Espichel sample J-2, *Mesoendothyra* sp.A zone, *Kurnubia palastiniensis* sub-zone (Kimmeridgian), x162 (Fig. 10), x225 (Fig. 11)

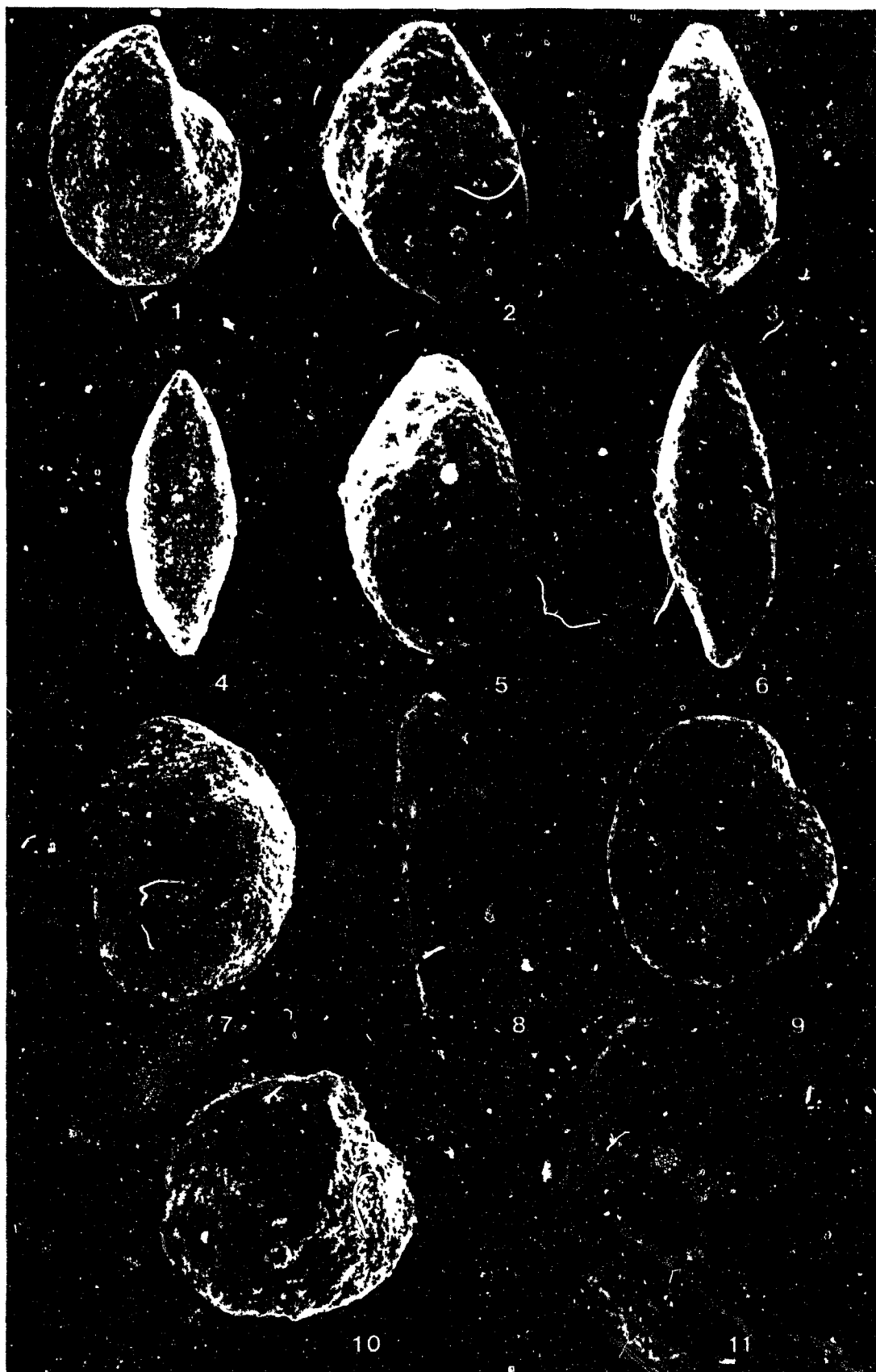


Plate 6

PLATE 7

- Figs. 1-11 *Mesoendothyra* sp.A, Cabo Espichel sample J-1, *Mesoendothyra* sp.A zone (Kimmeridgian). Fig.1: microspheric form, lateral view, x 78; Fig. 2: apertural view showing asymmetric final chamber, x100; Fig. 3: microspheric form, equatorial thin-section, x45; Fig. 4: microspheric form, axial thin-section, x54. Fig. 5: microspheric form, equatorial thin-section, x56; Fig. 6: megalospheric form, lateral view, x158; Fig. 7, megalospheric form, apertural view, x176; Fig.8: megalospheric form, equatorial thin-section, x 96; Fig. 9: megalospheric form, axial thin-section, x 32; Fig. 10: megalospheric form, equatorial thin-section, x 75; Fig. 11: megalospheric form, equatorial thin-section, x 89.

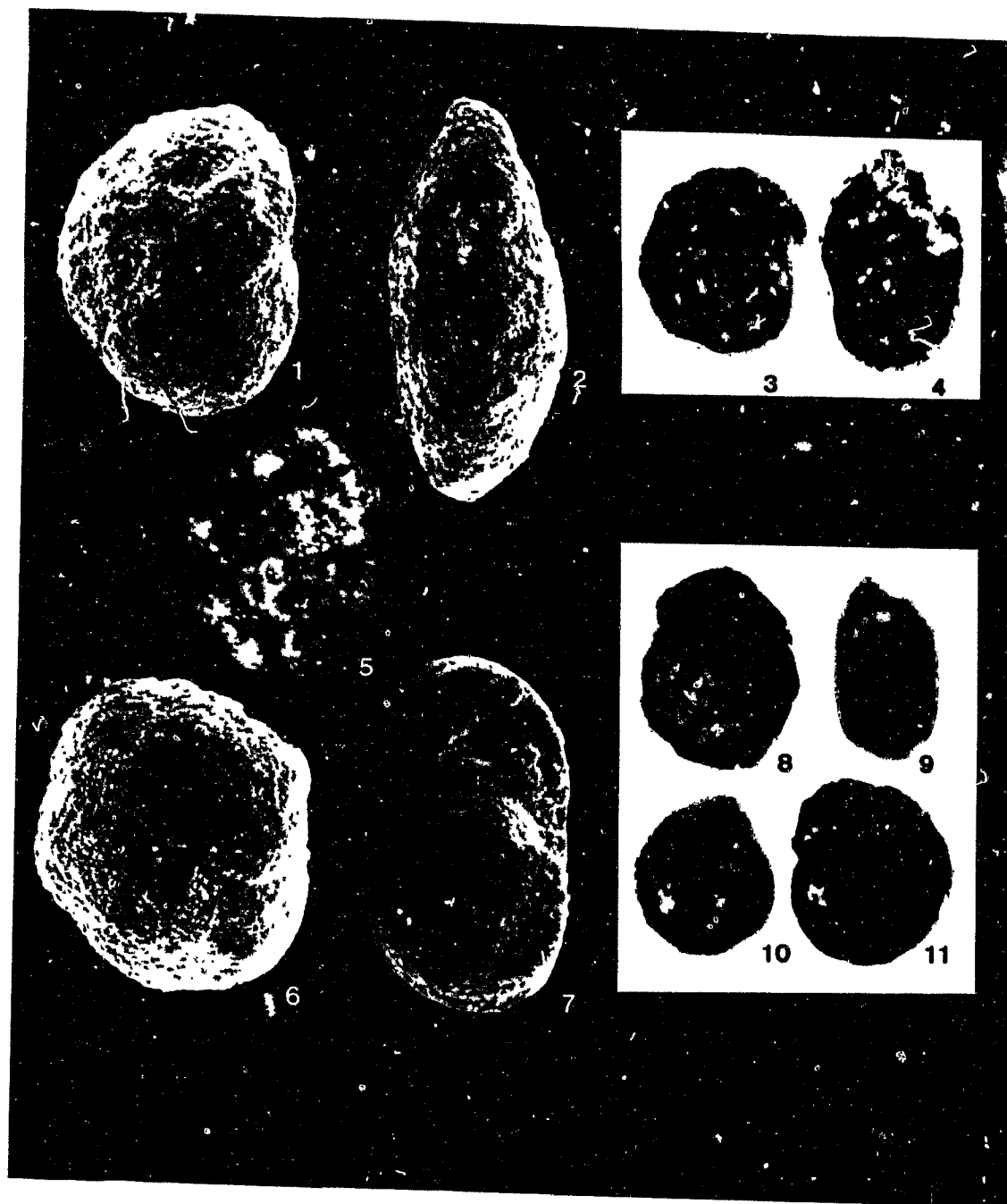


Plate 7

PLATE 8

- Figs. 1-2 *Choffatella decipiens* Schlumberger, Cabo Espichel, sample M-4, *Marssonella kummi* to *Choffatella decipiens* zone (Hauterivian-Lower Barremian). Fig. 1: lateral view, x90; Fig. 2: axial view showing details of apertural face, x103
- Fig. 3-4, 8 *Choffatella decipiens* Schlumberger, Ericeira sample H-6, *Marssonella kummi* to *Choffatella decipiens* zone (Hauterivian - Lower Barremian). Fig. 3: equatorial thin section showing septae pierced by numerous pores, x102; Fig. 4: axial thin section showing single row of pores piercing septae, x75; Fig. 8, equatorial section, x74.
- Figs. 5-6 *Choffatella tingitana* Hottinger, Praia Azul sample A-5, *Mesoendothyra* sp.A to *Choffatella tingitana* zone (Kimmeridgian). Fig. 5: side view showing strongly curved septae and lobate outline, x99; Fig. 6: axial view, x103
- Fig. 7 *Choffatella tingitana* Hottinger, Praia Azul sample A-5, *Mesoendothyra* sp.A to *Choffatella tingitana* zone (Kimmeridgian). Thin section, x100
- Figs. 9-10 *Everticyclammina virguliana* (Koechlin), Cabo Espichel sample J2, *Mesoendothyra* sp.A to *Anchispirocyclina lusitanica* zone (Kimmeridgian to Berriasian), x 74 (Fig.9), x159 (Fig. 10)
- Figs. 12-14 *Everticyclammina virguliana* (Koechlin) Cabo Espichel sample J-2 (Fig. 12), I-20 (Figs. 13-14), *Mesoendothyra* sp.A to *Anchispirocyclina lusitanica* zone (Kimmeridgian to Berriasian), x75 (Fig. 12); x72 (Fig.13); x 155 (Fig.14).



Plate 8

PLATE 9

- Figs. 1-3 *Feurillia frequens* Maync, Cabo Espichel sample I-18, *Mesoendothyra* sp.A to *Marssonella kummi* zone (Kimmeridgian to Hauterivian), Fig. 1: side view, x116; Fig. 2: side view, x 120; Fig. 3: thin section x95.
- Figs. 4-6 *Pseudocyclammia lituus* (Yokoyama), Cabo Espichel sample I-18, *Mesoendothyra* sp.A to *Choffatella tingitana* zone (Kimmeridgian). Fig. 4: uncoiled form, x 83; Fig. 5, coiled form, axial view, x 118; Fig. 6: coiled form, thin section, x126.
- Figs. 7-10 *Pseudocyclammia muluchensis* Hottinger, Cabo Espichel sample I-22, *Mesoendothyra* sp.A to *Anchispirocyclina lusitanica* zone (Kimmeridgian to Berriasian). Fig. 7: side view, x67; Fig. 8: axial thin section, x 65; Fig. 9: equatorial thin section, x 70; Fig. 10: equatorial thin section, x 73.

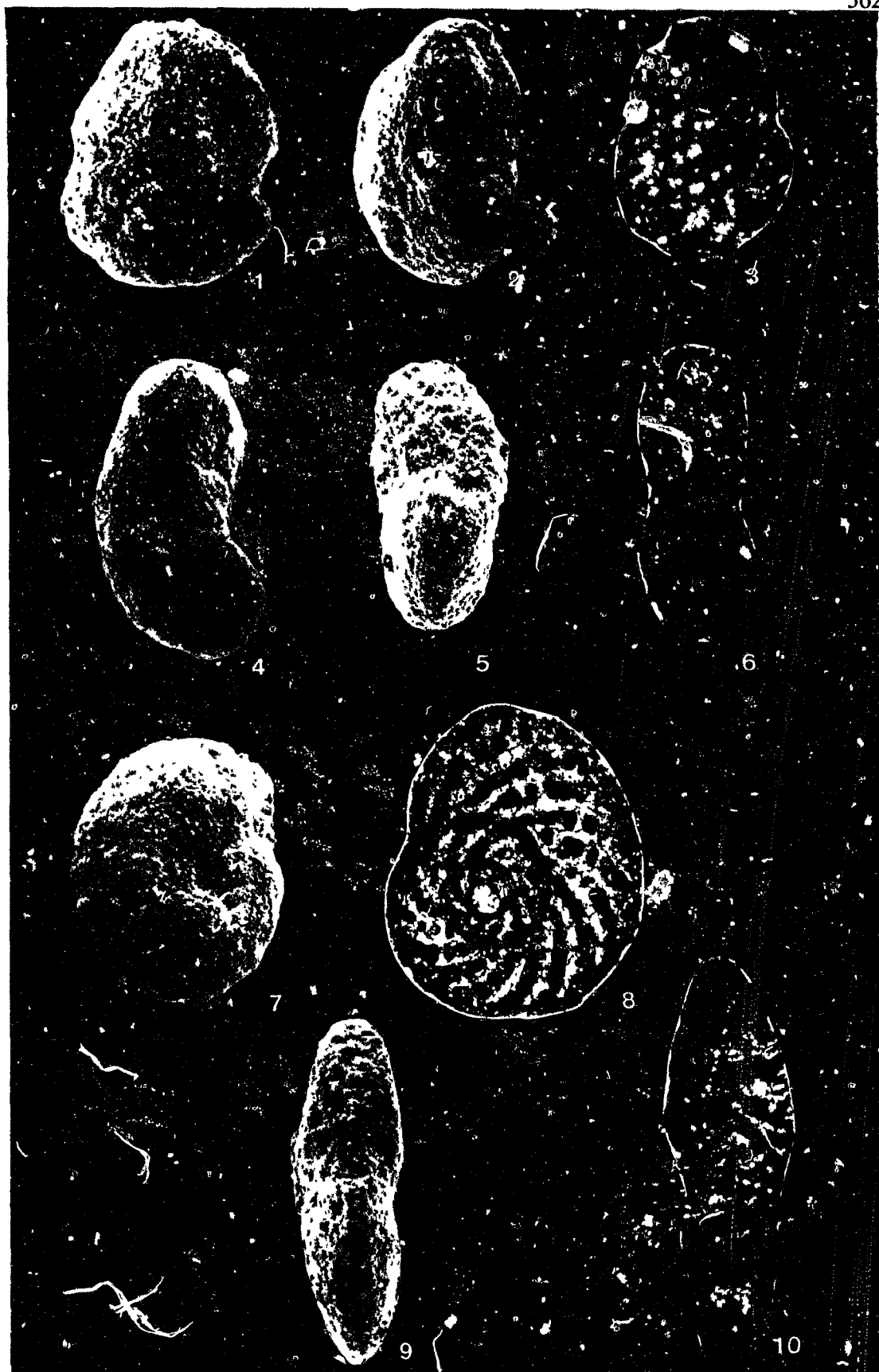


Plate 9

PLATE 10

- Figs. 1-7 *Anchispirocyclina lusitanica* (Egger), Cabo Espichel samples I-19 (Figs. 1,-4), K-2 (Figs. 4-7), *Anchispirocyclina lusitanica* zone (Portlandian to Berriasian). Fig. 1: side view, x42; Fig. 2: apertural view, x53; Fig. 3: equatorial thin section, x 40; Fig. 4: equatorial thin section, x40; Fig. 5: un-coiled form, incomplete specimen, x25; Fig. 6: equatorial thin section of an un-coiled form, *Anchispirocyclina lusitanica* var. *maynci*, x27.5; Fig. 7: axial thin section of *Anchispirocyclina lusitanica* var. *maynci*, showing restriction of endoskeletal pillars to the central zone of the test, x31.5.
- Figs. 8-9 *Rectocyclammina arrabidensis* Ramalho, Cabo Espichel sample J-2, *Mesoendothyra* sp.A to *Choffatella tingitana* zone (Kimmeridgian), Fig. 8: S.E.M. external view, x143; Fig. 9: thin section, x 105.
- Figs. 10-11 *Rectocyclammina chouberti* Hottinger, Cabo Espichel sample K-2, *Choffatella tingitana* to *Anchispirocyclina lusitanica* zone (Kimmeridgian to Portlandian), Fig. 10: S.E.M. external view, x60; Fig. 11: thin section, x76.
- Figs. 12-14 *Kurnubia palastiniensis* Henson, Cabo Espichel sample J-2, *Mesoendothyra* sp.A zone, *Kurnubia palastiniensis* sub-zone (Lower Kimmeridgian). Fig. 12: external view, form with well developed uniserial stage, x 151; Fig. 13: external view, specimen with well developed uniserial stage, x 110; Fig. 14: thin section, specimen lacking development of uniserial stage, x89.

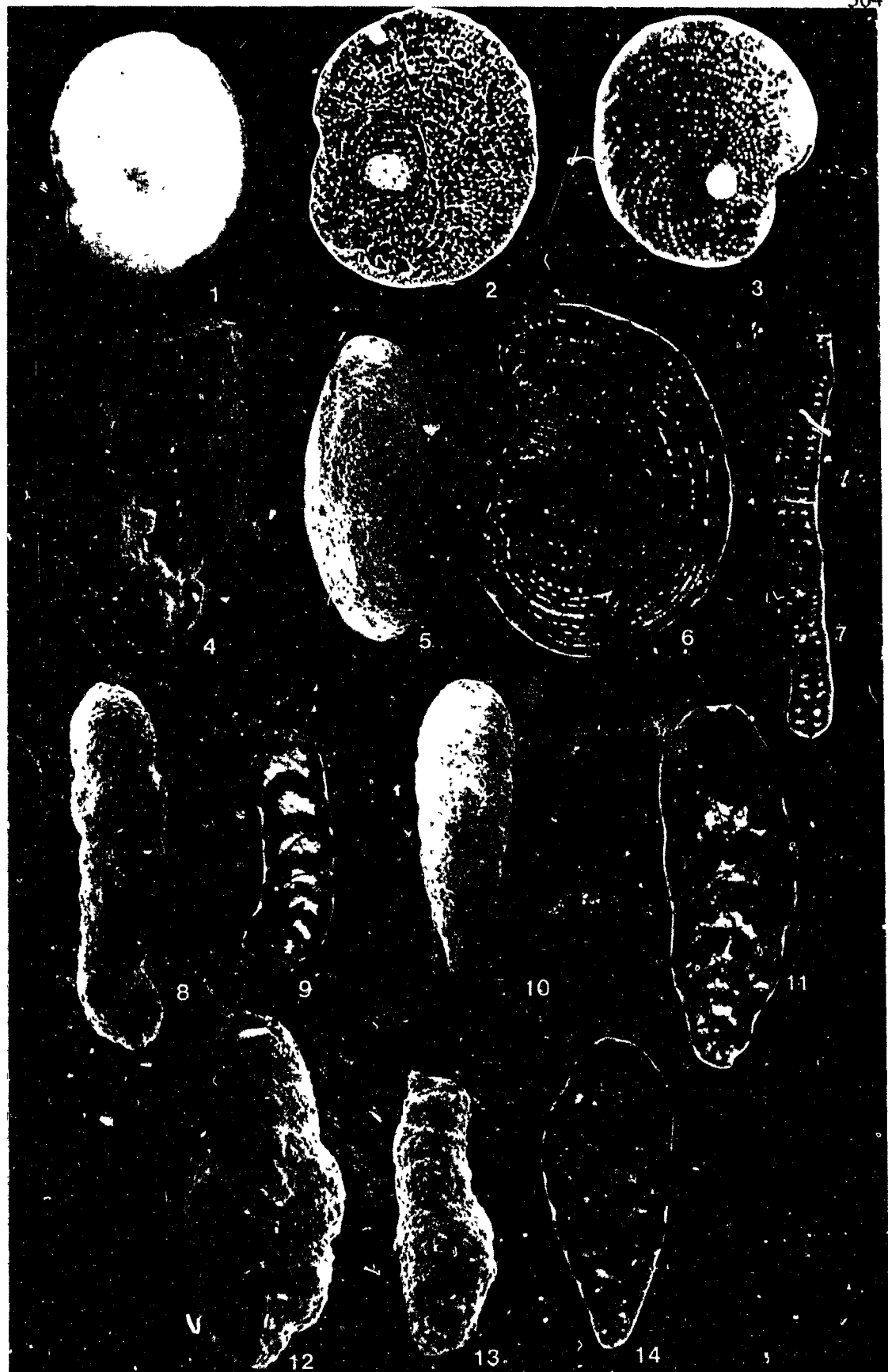


Plate 10

PLATE 11

- Fig. 1 *Cetacella armata* Martin, Praia Azul sample A-5, *Paranotacythere pustulata* zone (Kimmeridgian), carapace has a well developed median spine, x117
- Fig. 2 *Ilyocypris jurassica* (Martin), Praia Azul sample A-9, *Paranotacythere pustulata* zone (Kimmeridgian), x142
- Fig. 3 *Cetacella armata* Martin, Praia Azul sample A-5, *Paranotacythere pustulata* zone (Kimmeridgian), x132
- Fig. 4 *Darwinula leguminella* (Forbes), Praia Azul sample A-9, *Paranotacythere pustulata* zone (Kimmeridgian), x134
- Fig. 5 *Mantelliana cyrton* Anderson, Praia Azul sample A-9, *Paranotacythere pustulata* zone (Kimmeridgian), x44
- Figs. 6-8 *Fabanella boloniensis* (Jones), Praia Azul sample A-6, *Paranotacythere pustulata* zone (Kimmeridgian), x94
- Fig. 9 *Amphicythere* aff. *confundens* Oertli, Ericeira sample B-2, *Galliaecytheridea* sp.2-*Schuleridea triebeli* zone (Kimmeridgian-Portlandian), x123
- Fig. 10 *Amphicythere confundens* Oertli, Kimmeridge Clay sample DoBa 1a, Kimmeridgian, *Baylei* zone, x122
- Fig. 11 *Amphicythere* aff. *confundens* Oertli, Ericeira sample B-2, *Galliaecytheridea* sp.2-*Schuleridea triebeli* zone (Kimmeridgian-Portlandian), x109

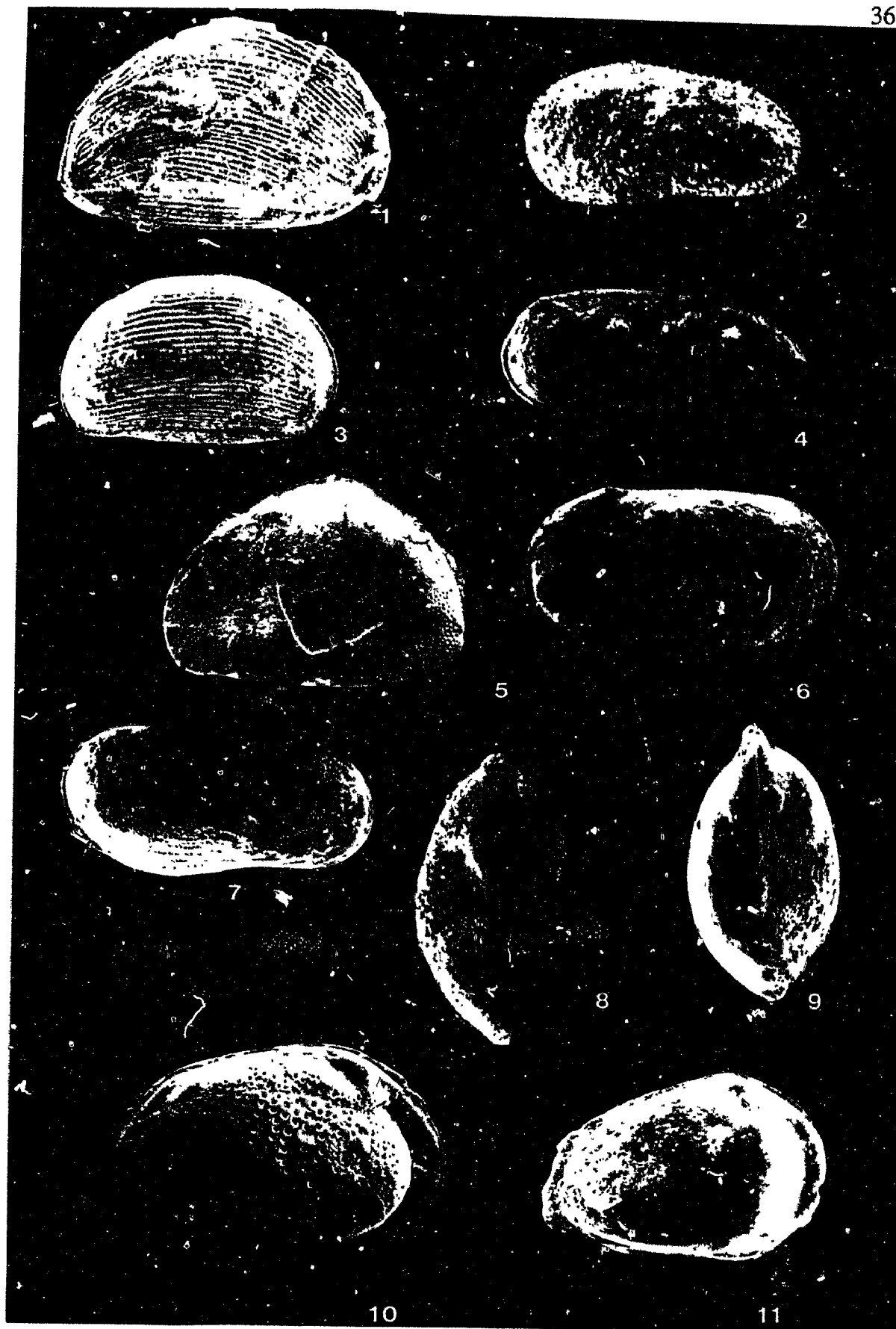


Plate 11

PLATE 12

- Figs. 1-2 *Asciocythere* sp.1 Cabo Espichel sample I-16, *Galliaecytheridea* sp.2 to *Schuleridea triebeli* zones (Kimmeridgian - Berriasian), x193 (Fig. 1), x186 (Fig. 2)
- Figs. 3-4 *Asciocythere* sp.2 Cabo Espichel sample K-1, *Schuleridea triebeli*-*Platycythereis crismaensis* zones (Portlandian - Upper Hauterivian), x140 (Fig. 3), x135 (Fig. 4)
- Fig. 5 *Galliaecytheridea posterotunda* Oertli, Praia Azul sample A-3, *Paranotacythere pustulata* zone (Kimmeridgian), x129
- Figs. 6,8 *Galliaecytheridea* sp.2, Praia Azul sample A-8, *Paranotacythere pustulata* zone (Kimmeridgian), x 128 (Fig. 6), x135 (Fig. 8)
- Fig. 7 *Galliaecytheridea* sp.2 Kilenyi, Kimmeridge Clay sample DoBa 1a, Kimmeridgian (*Baylei* zone), x136
- Fig. 9 *Schuleridea* sp.1 Praia Azul, sample A-5, *Paranotacythere pustulata* zone (Kimmeridgian) x171
- Fig. 10 *Schuleridea* sp.1 Praia Azul, sample A-5, *Paranotacythere pustulata* zone (Kimmeridgian), x150

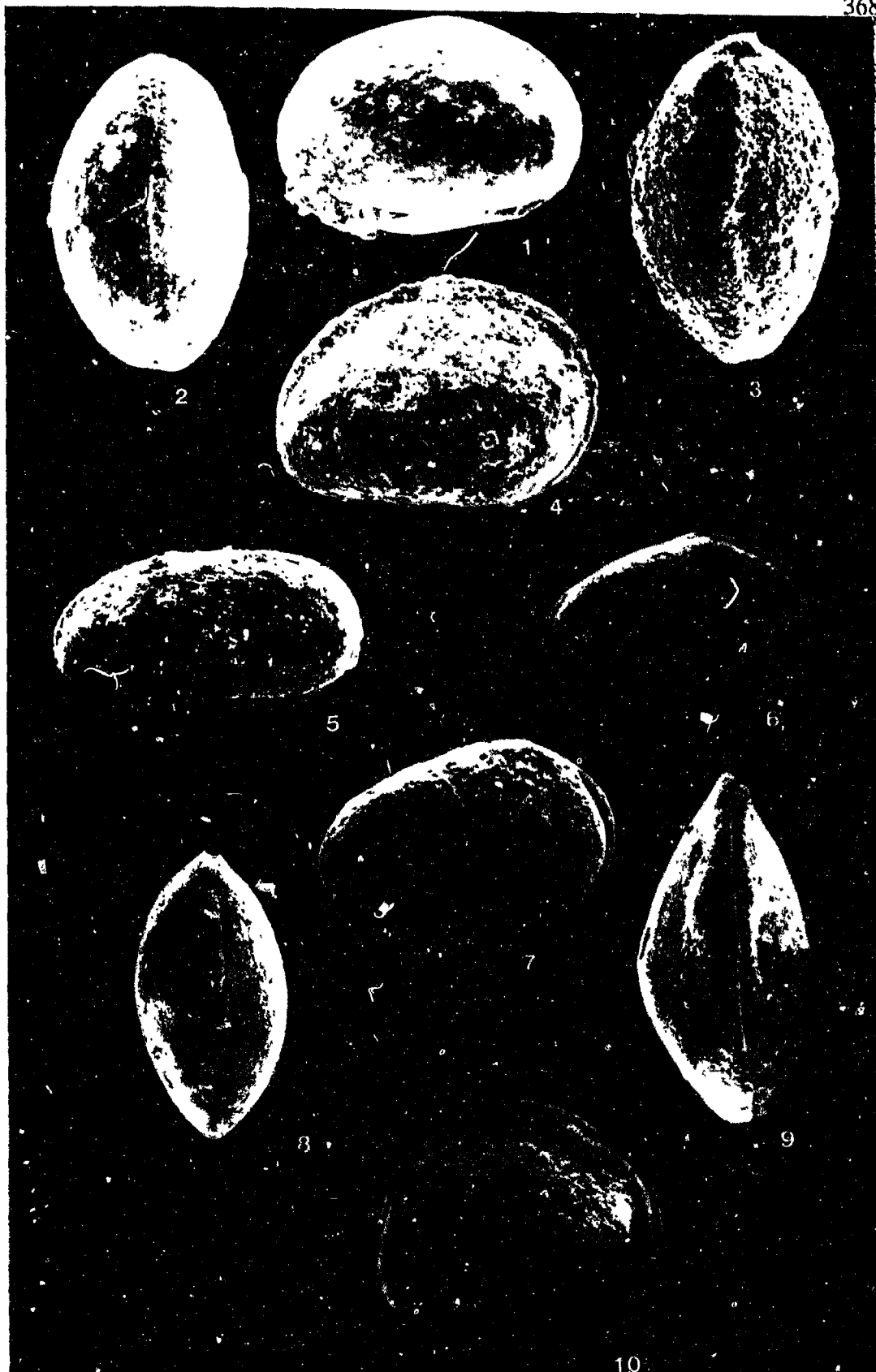
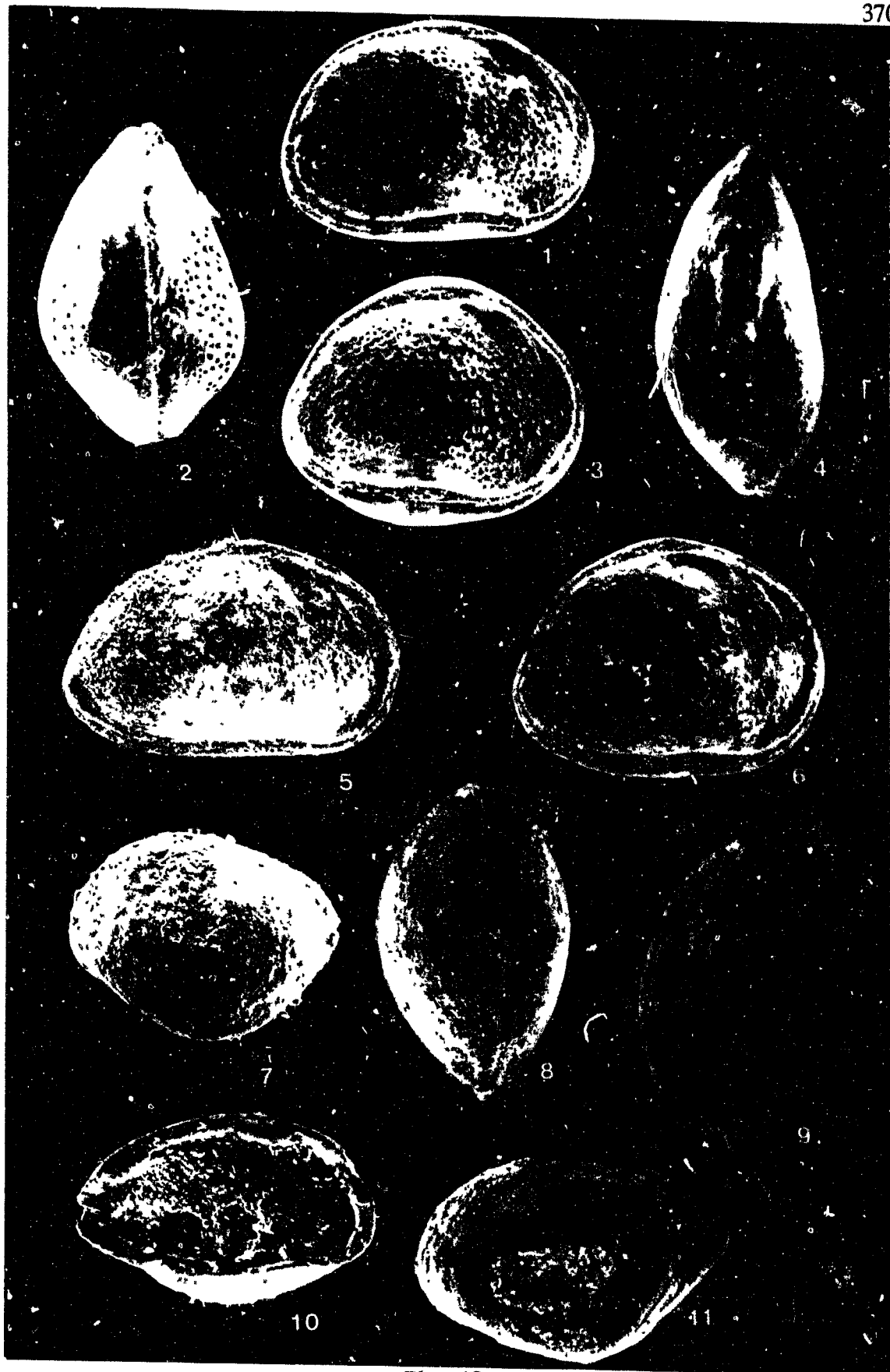


Plate 12

PLATE 13

- Figs. 1-3 *Schuleridea triebeli* (Stegh us 1951) Cabo Espichel, sample I-8, *Paranotacythere pustulata* to *Cytheropterina triebeli* zones (Kimmeridgian-Berriasian), x155 (Fig. 1), x165 (Fig. 2), x116 (Fig. 3).
- Figs. 4-6 *Schuleridea thoerenensis* (Triebel) Cabo Espichel, sample K-4, *Cytheropterina triebeli* to *Platycythereis crisminaensis* zones (Berriasian to Kimmeridgian), x147 (Fig. 4), x142 (Fig. 5), x105 (Fig. 6).
- Figs. 7,8,10 *Cytheropteron aquitanum* Donze, Praia Azul, sample A-3, *Paranotacythere pustulata* zone (Kimmeridgian), x175 (Fig. 7), x220 (Fig. 8), x166 (Fig.10).
- Figs. 9-10 *Cytheropteron* sp.1, Cabo Espichel, sample J/2, *Galliaecytheridea* sp.2 zone (Kimmeridgian) x230 (Fig. 9), x218 (Fig. 10)



Pla. 13

PLATE 14

- Fig. 1 *Metacytheropteron* sp. Cabo Espichel sample M/6, *Platycythereis crisminaensis* zone (Upper Hauterivian-Lower Barremian), x186
- Figs. 2-3 *Cytheropteron triebeli* Neale, Ericeira sample B/7 (Figs. 2-3), Cabo Espichel sample K/5 (Fig. 4), *Cytheropteron triebeli* zone (Berriasian), x214 (Fig.2), x 176 (Fig.3), x224 (Fig.4).
- Fig. 5 *Paranotacythere pustulata* Kilenyi, Praia Azul sample A/10 (Figs. 5-7), sample A/2 (Figs. 8-9), *Paranotacythere pustulata* zone (Kimmeridgian) x162 (Fig.5), x153 (Figs.6-7), x232 (Fig. 8), x187 (Fig. 9).
- Fig. 10 *Mandelstamia maculata* Kilenyi, Cabo Espichel, sample I/2, *Galliaecytheridea* sp.2 zone (Kimmeridgian), x240
- Fig. 11 *Mandelstamia sexti* Neale, Speeton Clay Bed D6A (Berriasian), x124
- Figs. 12-13 *Mandelstamia sexti* Neale, Cabo Espichel, sample K/3, *Cytheropterina triebeli* zone (Berriasian) x182 (Fig. 12), x185 (Fig. 13).

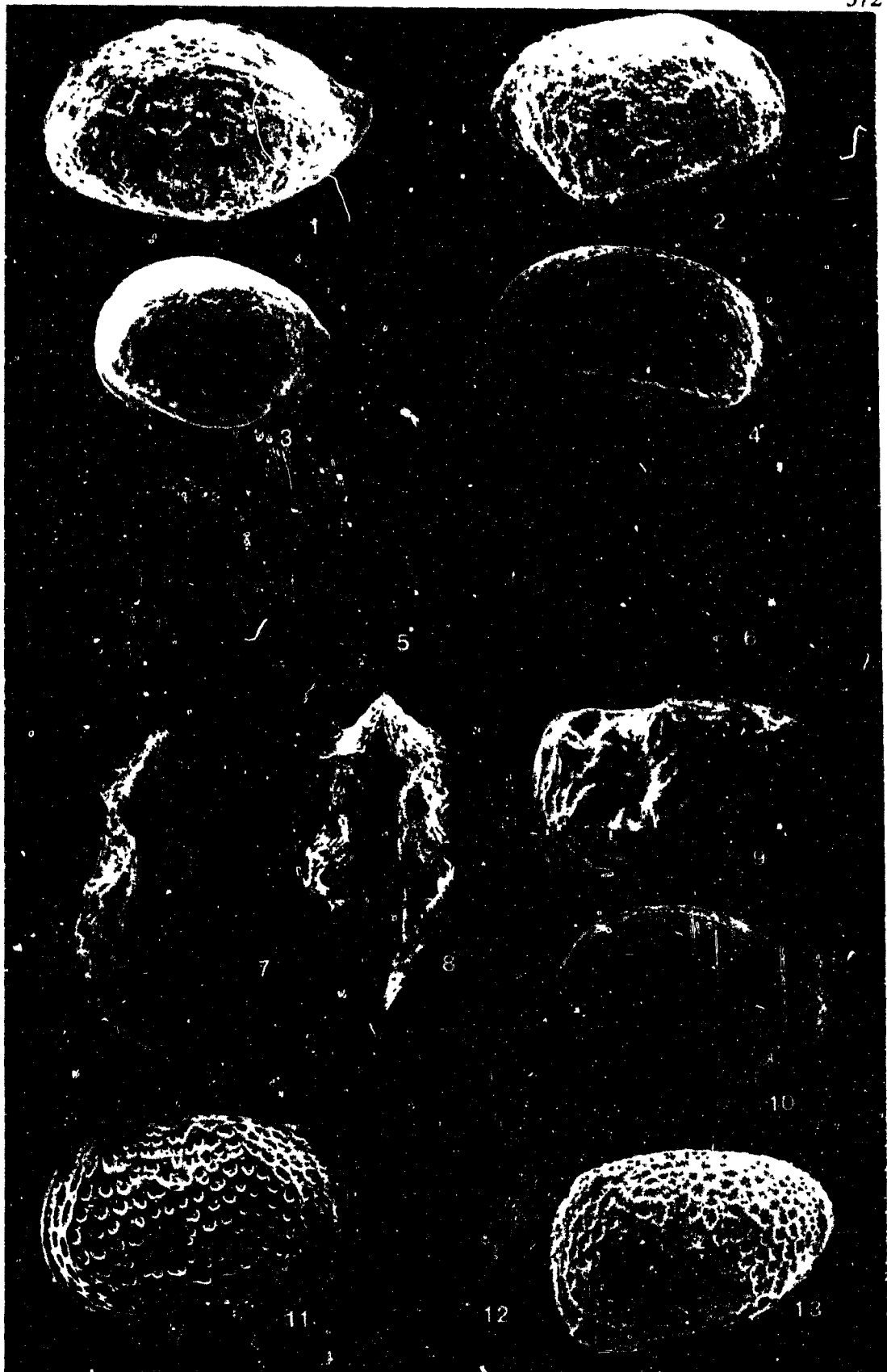


Plate 14

Plate 15

- Fig. 1 *Cytherella fullonica* Jones and Sherborn, Cabo Espichel sample J/2, *Galliaecytheridea* sp.2 zone (Kimmeridgian), x118 (Fig. 1), x114 (Fig. 2).
- Fig. 3 *Cytherella fullonica* Jones and Sherborn, Kimmeridge Clay sample DoBa1, Kimmeridgian *Baylei* zone, x124
- Figs. 4-6 *Cytherella suprajurassica* Oertli, Cabo Espichel sample I-9, *Galliaecytheridea postrotunda*- *Cytheropterina triebeli* zones (Kimmeridgian-berriasian) x103 (Fig. 4), x122 (Fig.6)
- Figs. 5-7 *Cytherella pyriformis* (Corneul), Cabo Espichel sample M/7, *Fabanella boloniensis* to *Platycythereis crisminaensis* zones (Berriasian- Barremian), x107 (Fig.5), x110 (Fig.7)
- Fig. 8 *Cytherelloidea weberi* Steghaus var. *recticostata* Donze, Cabo Espichel, sample K/3, *Galliaecytheridea* sp.2- *Cytheropterina triebeli* zones (Kimmeridgian to Berriasian), x151
- Figs. 9-12 *Exophthalmocythere gigantea* Schmidt, Cabo Espichel, sample K/4, *Galliaecytheridea postrotunda* to *Cytheropterina triebeli* zones (Kimmeridgian- Berriasian), x102 (Fig. 9), x110 (Fig. 10), x114 (Fig. 11), x 108 (Fig. 12).

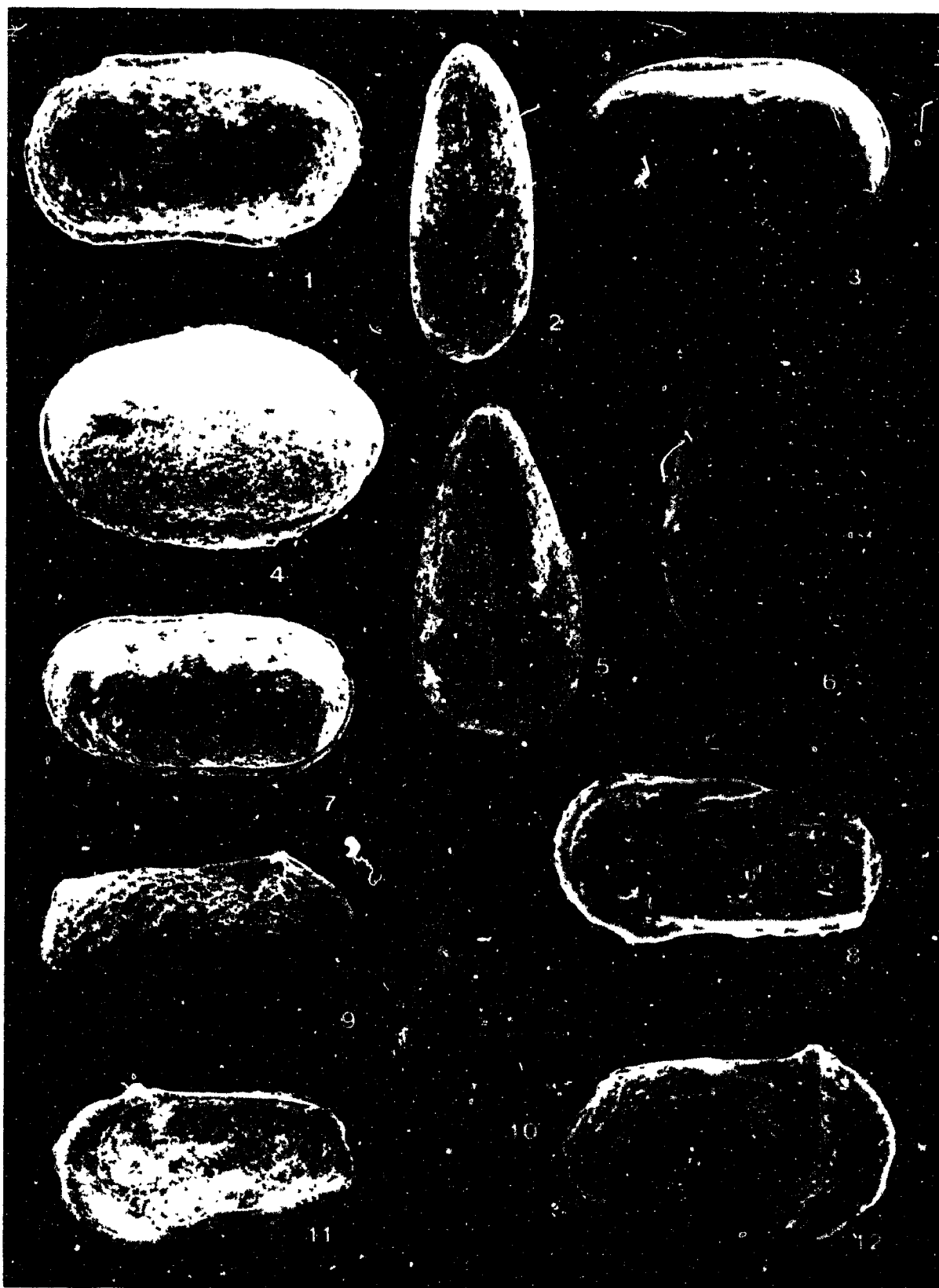


Plate 15

PLATE 16

Figs. 1-3 *Exophthalmocythere* sp.1, Cabo Espichel, sample K/3, *Cytheropteria*
triebelsi zone (Berriasian), x110 (Fig.1), x105 (Fig. 2), x 112 (Fig. 3).

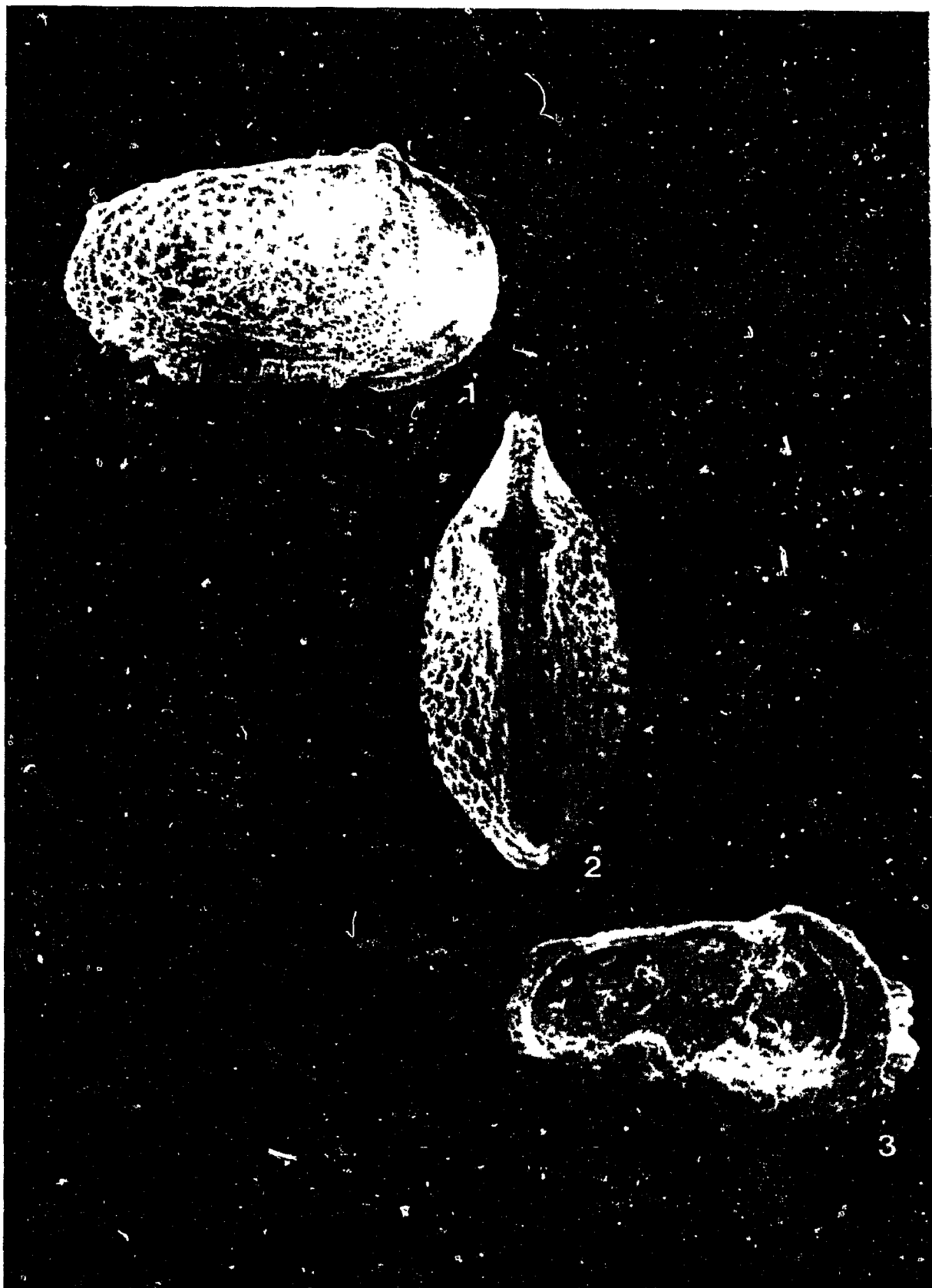


Plate 16

PLATE 17

- Figs. 1-4 *Protocythere hechti* Triebel, Cabo Espichel, sample M/3 (Figs. 1-3), Speeton Clay Bed C8 (Hauterivian) (Fig. 4), *Fabanella boloniensis* to *Platycythereis crisminaensis* zones (Hauterivian- Lower Barremian) x103 (Fig. 1), x125 (Fig. 2), x121 (Fig. 3), x144 (Fig. 4).
- Figs. 5-7 *Protocythere triplicata* (Roemer), Cabo Espichel, sample M/6 (Figs. 5,7), Speeton Clay Bed D3 (Hauterivian), *Platycythereis crisminaensis* zone (Hauterivian - Lower Barremian), x84 (Fig. 5), x93 (Fig. 6), x95 (Fig. 7)
- Fig. 8, 10-12 *Platycythereis crisminaensis* Damotte and Rey, Cabo Espichel, sample M/8, *Platycythereis crisminaensis* zone (Hauterivian- Lower Barremian) x94 (Fig. 8), x92 (Fig. 10), x94 (Fig. 11), x93 (Fig. 12).
- Fig. 9 *Cythereis ericeirensis* Damotte and Rey, Ericeira sample H/5, *Platycythereis crisminaensis* zone (Hauterivian- Lower Barremian) x107

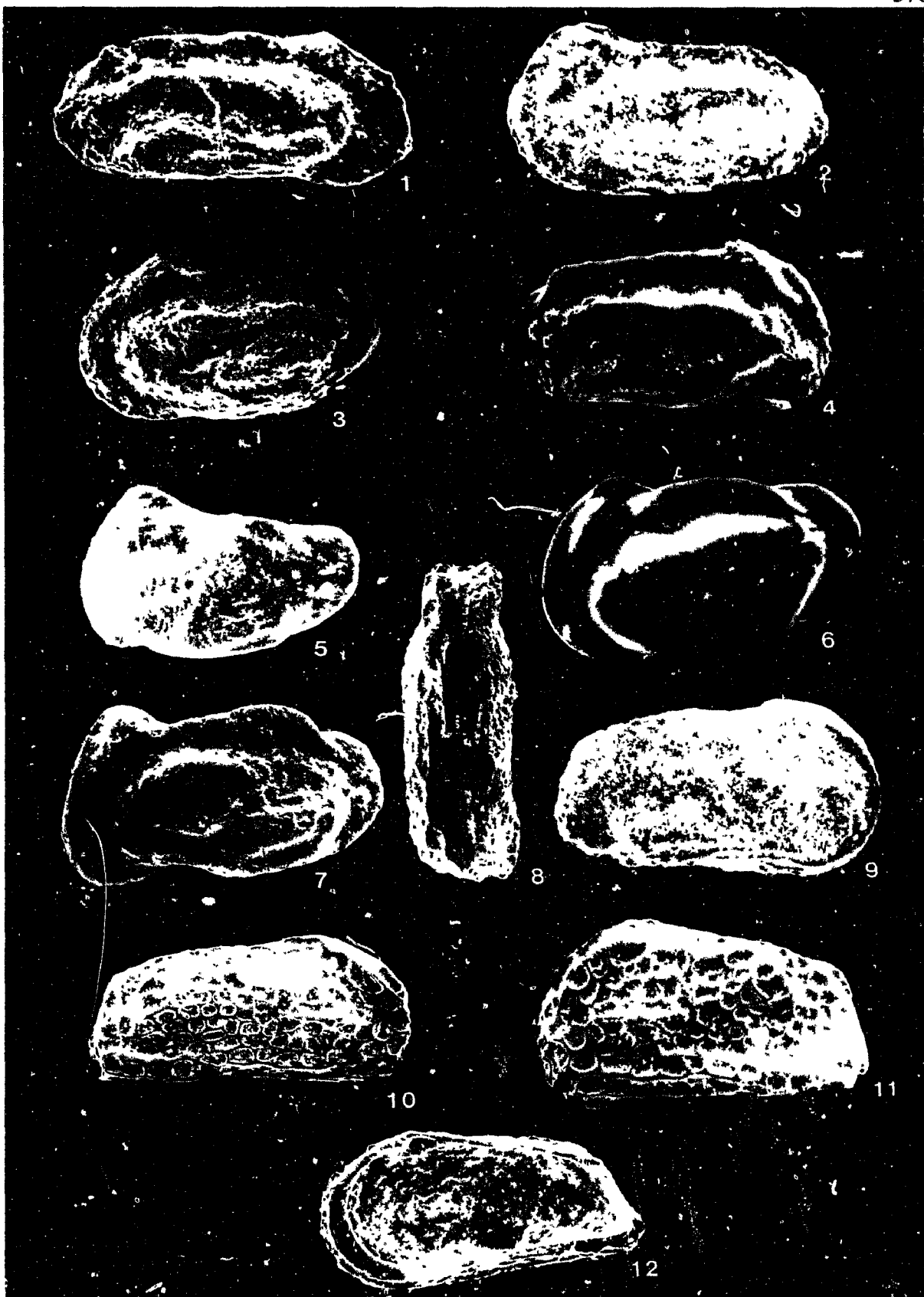


Plate 17

PLATE 18

Figs. 1-4 *Rehacythereis* sp.A Cabo Espichel, sample K/3, *Cytheropterina triebeli*
zone (Berriasian) x114 (Fig. 1), x101 (Figs. 2,3), x225 (Fig. 4).

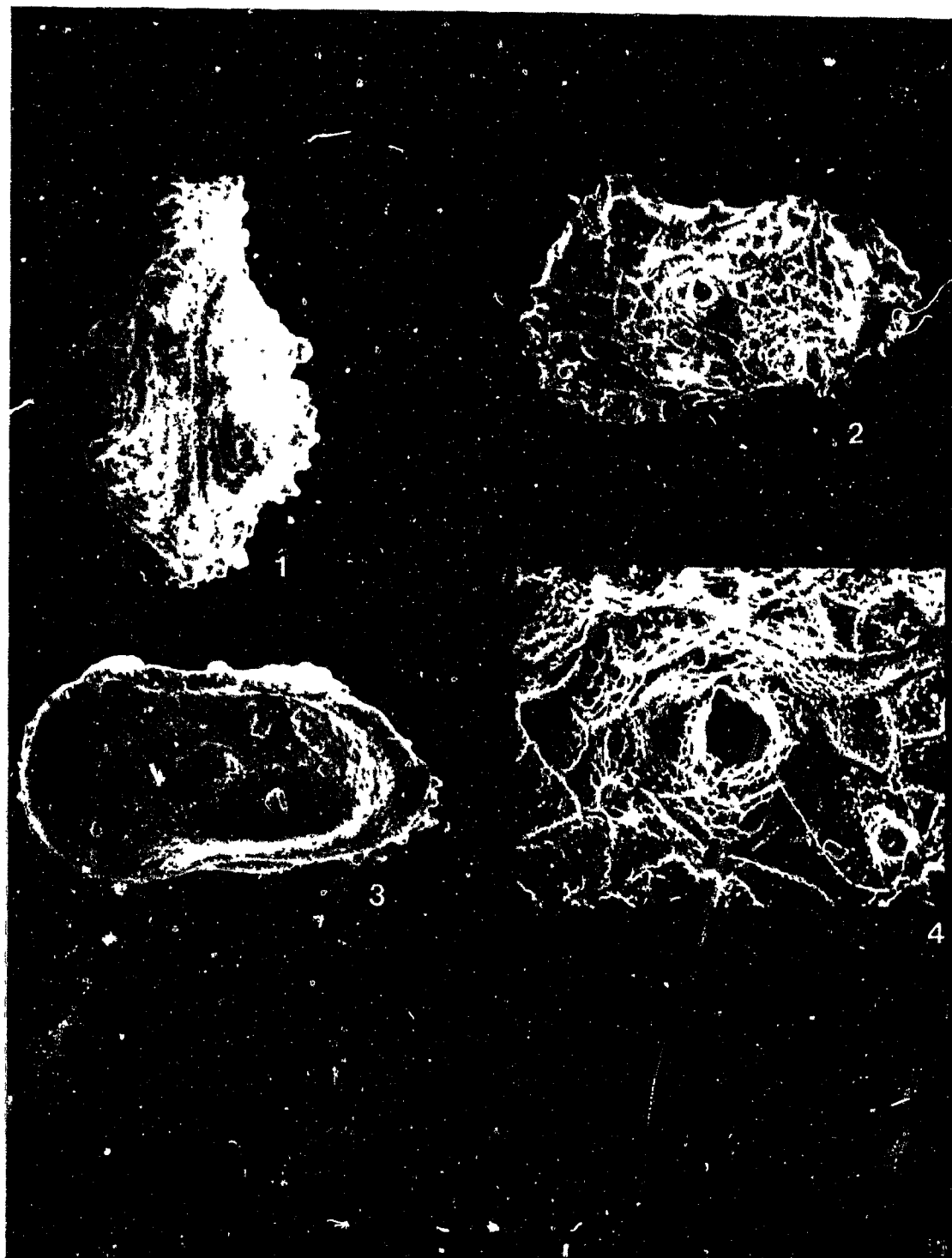


Plate 18

PLATE 19

- Figures 1-3 *Anchispirocyclus lusitanica* (Egger); Fig.1: megalospheric form, lateral view, x55; Fig.2: equatorial thin-section of specimen in Fig.1, x53; Fig.3: thin-section fragment showing wall structure, x70; Specimens from Hibernia I-46 well, 2380m.
- Figures 4, 5: *Pseudocyclammia muluchensis* Hottinger; Fig.4: microspheric form, lateral view, x29; Fig. 5: equatorial thin-section of specimen in Fig. 4, x 31.specimens from Hibernia I-46 well, 2830m.
- Figures 6-8: *Ammobaculites subcretaceus* Cushman and Alexander; Fig. 6: x80; Fig. 7: x 100; Fig. 8: x 125. Specimens photographed immersed in glycerine. Hibernia I-46 well, 2380m.



Plate 19

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