# MARGINAL MARINE FORAMINIFERA AND THECAMOEBIANS IN THE UPPER CRETACEOUS TO EOCENE DEPOSITS OF THE SOUTH-CENTRAL PYRENEES, SPAIN

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# Abstract

The Upper Cretaceous to Eocene marginal marine sediments, in the northeastern Pyrenees of Spain, is a classic area in which to study sequence stratigraphy. Sequence stratigraphy requires strong sea-level control. The lignites found throughout the sequences, once assumed to be freshwater deposits, can provide accurate sea-level markers if microfossils reveal them to be marginal marine. This study uses samples collected around different lignite layers in the Pyrenees and prepared using new techniques developed for the preparation of such samples. The Foraminifera and thecamoebians provide evidence that the lignites and surrounding sediments are marginal marine deposits. Thus the Pyrenean lignites can be used to accurately relocate former sea levels and to supply the vertical limits of the closing of high and low order transgressive cycles. The evidence discussed in this study indicates that the accurate reconstruction of very old paleo sea levels is feasible, and that the methods here developed can be used for a thorough study of the marginal marine sediments of the entire Pyrenean sequence. In addition, the microfaunae from these sequences share similarities with those described in modern day, as well as Cretaceous and Carboniferous estuarine deposits. The similarities suggest two more ideas: i) that microorganisms in highly stressed areas, such as marshes, did not evolve as quickly as more open marine assemblages; and ii) that the methods used in this paper can be routinely applied to establish accurate paleo-sea levels in deposits from the Paleozoic to the Present.

Keywords: Micropaleontology, Sequence Stratigraphy, South-central Pyrenees, Spain, Foraminifera, Thecamoebians, Sea-level, Paleoecology, Marine Lignite

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# CHAPTER 1 INTRODUCTION

## 1.1 Introduction

A sequence is a suite of sedimentary rock units representing a period of continuous deposition. A succession of sequences is typically cyclic and is composed of genetically related stratal units, in which each sequence is bounded by erosional or nondepositional surfaces (Posamentier et al., 1988). Sequences form in response to changes in relative sea-level (i.e., due to changes in ocean basin volume and land movements, etc.) and sediment supply (Posamentier et al., 1988), and they represent “packages” of sediment that can be further subdivided into parasequences, sets, and beds. Sequences can be allostratigraphic (deposition is controlled by factors from outside the basin area) or autostratigraphic (deposition is controlled by factors within the basin). Sequences are subdivisions of the stratigraphic record defined by mappable rock units (NACSN, 1983).

Sequence stratigraphy is the study of relationships between sedimentary units within a chronostratigraphic framework (Posamentier et al., 1988). The basis of sequence stratigraphy is sea-level change but, in most studies, sea level is poorly defined spatially (i.e., vertically and horizontally). Figure 1.1 summarizes the principles of sequence stratigraphy.

A classic area for the study of sequence stratigraphy is the south-central Pyrenees (Figure 1.2). In this area, rock exposure and sequence completeness are exceptionally good, consequently, the area is host to many field trips and guide books relating to sequence stratigraphy. Mutti (1988) documented the sequences of northeastern Spain in detail. Cycles of highstand and lowstand marine deposits occur interbedded with some turbidite sequences. Limestone-rich lignite lenses often mark the tops of the transgressive cycles. These lignite lenses, previously believed to be freshwater, in reality are both marginal marine

Figure 1.1 Generalized flow diagram explaining the principles of sequence stratigraphy. (Adapted for the study area from the original diagram by Mutti *et al.* (1994)). Surfaces with a "U" represent an unconformity.

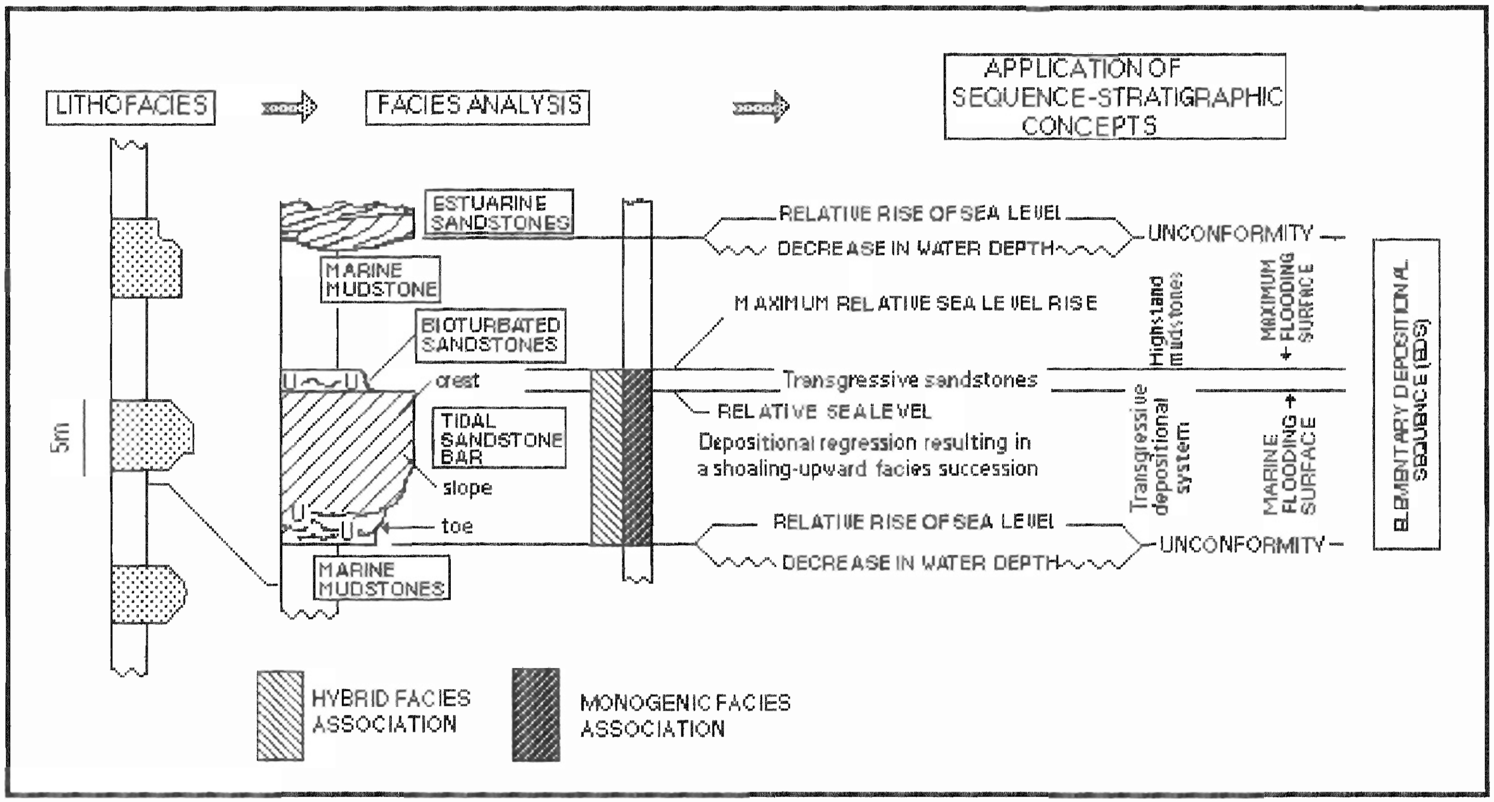
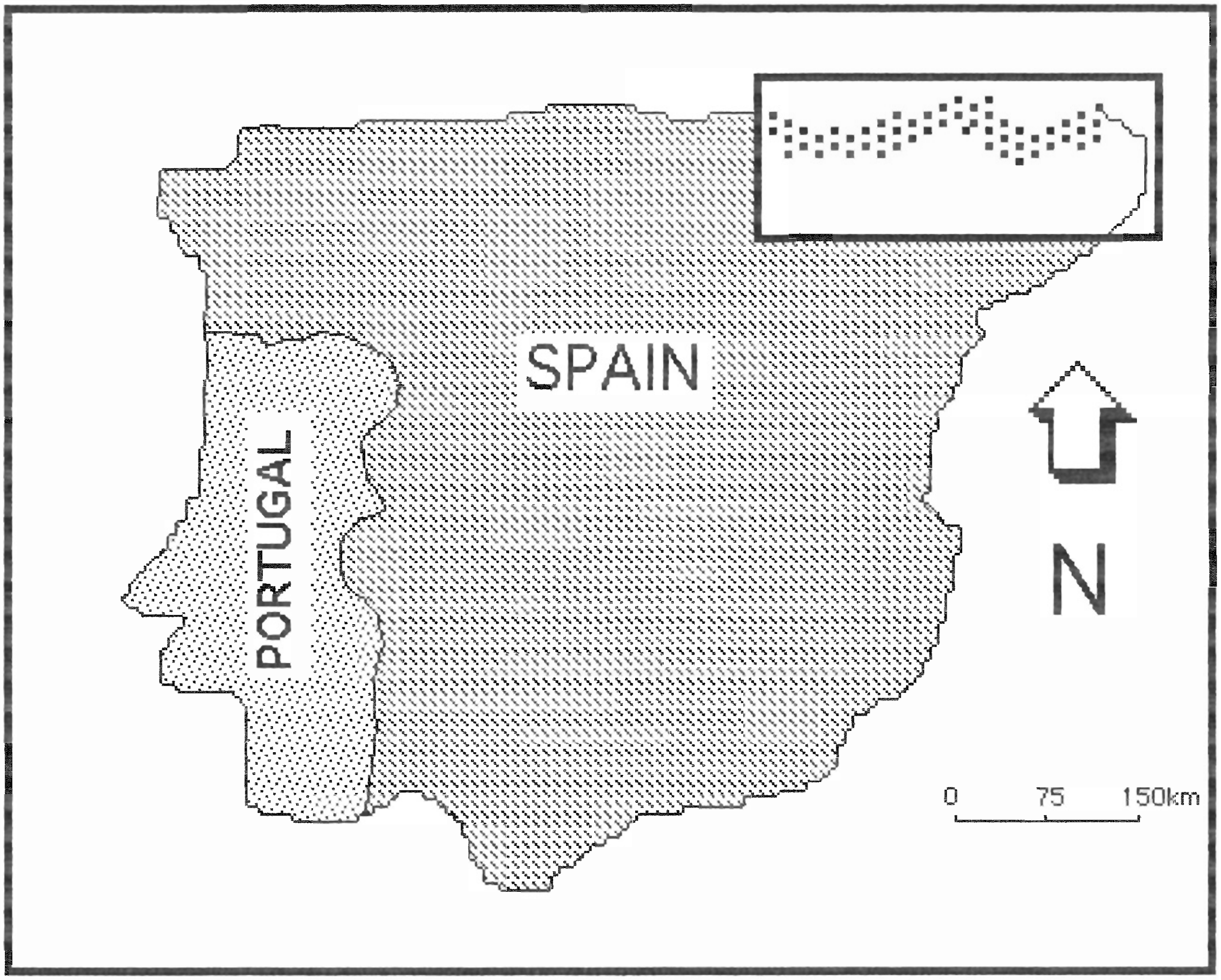

LITHOFACIES
FACIES ANALYSIS
APPLICATION OF SEQUENCE-STRATIGRAPHIC CONCEPTS
5m
ESTUARINE SANDSTONES
MARINE MUDSTONE
BIOTURBATED SANDSTONES
crest
TIDAL SANDSTONE BAR
slope
toe
MARINE MUDSTONES
U
RELATIVE RISE OF SEA LEVEL
DECREASE IN WATER DEPTH
UNCONFORMITY
MAXIMUM RELATIVE SEA LEVEL RISE
Transgressive sandstones
RELATIVE SEA LEVEL
Depositional regression resulting in a shoaling-upward facies succession
RELATIVE RISE OF SEA LEVEL
DECREASE IN WATER DEPTH
UNCONFORMITY
Highstand mudstones
Transgressive depositional system
MAXIMUM FLOODING SURFACE
MARINE FLOODING SURFACE
ELEMENTARY DEPOSITIONAL SEQUENCE (EDS)
HYBRID FACIES ASSOCIATION
MONOGENIC FACIES ASSOCIATION

Figure 1.2 Map of Spain indicating location of the present study.

# INDEX MAP



and freshwater deposits. No previous micropaleontological investigation of these strata exists, and their freshwater origin was never previously demonstrated.

Many studies have shown that organic deposits, especially salt marsh deposits, contain well-defined microfossil assemblages that provide exceptionally accurate markers of former sea level (Scott and Medioli 1978, 1980, 1986), especially along the higher high water (HHW) line. Other work, based on microfossil evidence, has shown that many organic deposits formerly reported as freshwater were marine (e.g., Wightman *et al.* 1993). This study examines microfossils (specifically foraminifera and thecamoebians) from the south-central Pyrenean sequences to determine if they are useful as potential sea-level indicators in this region.

All microfossils in this investigation belong to the kingdom Protista. Foraminifera belong to the subphylum Sarcodina, class Rhizopodea, and are marine (Loeblich and Tappan 1964). Foraminifera possess a test that may be tectinous (organic), calcareous, or agglutinated. Foraminifera may be benthic (bottom-dwelling) or planktonic (free-floating) in lifestyle (Haq and Boersma 1978) and marginal marine forms particularly are very sensitive to environmental factors. Each species lives within a specific range of temperature, salinity, pH, and water depth (Boltovskoy and Wright 1976). In this investigation, benthic, agglutinated marsh foraminifera are of great interest because they not only can be used as a means of determining former sea-levels, they can also be utilized to reconstruct the history of marginal marine and more distal marine paleoenvironments. A large number of older, reworked calcareous foraminifera are also present in the samples under investigation, and their taxonomy and relevance constitute part of this investigation.

The second set of microfossils in this investigation, Thecamoebians, are also protists of subphylum Sarcodina and are spread over two classes: Rhizopodea and Filosia (Medioli and Scott 1987). Thecamoebians are freshwater organisms that can either secrete a siliceous or calcareous test or build one similar to agglutinated foraminifera. Thecamoebians are useful in paleo-limnological reconstructions (McCarthy et al. in press), as well as being good pollution indicators (Scott and Medioli 1983; Asioli and Medioli 1994). This study uses thecamoebians to determine freshwater influence in estuarine paleo-environments.

## 1.2 Purpose

Dr. Emiliano Mutti (University of Parma, Italy) requested the Centre for Marine Geology to perform a feasibility study to apply the accurate (± 5cm) sea-level reconstruction method of Scott and Medioli (1980) to Meso-Cenozoic material. This method has already proven successful on Quaternary deposits worldwide as well as in the Carboniferous Sydney Coal basin of Nova Scotia.

The principal purpose of this investigation is to determine whether foraminifera and thecamoebians are present within the sampled material. Such a determination requires the development of new preparation techniques for the micropaleontological study of the lignites. The following three objectives have been added to this thesis upon discovery of microfossils in and around the lignites: i) to determine if sea-level information is obtainable for this area; ii) to complete, especially since no micropaleontological documentation is available for these strata, the taxonomy of all investigated microfossils; and iii) to determine if some sequences contain freshwater thecamoebians. Thecamoebians and marsh foraminifera are not documented in the Eocene of this area; hence, the completion of a proper taxonomic study is important.

## 1.3 Scope

This study is confined to the Eocene-age rocks of the Tremp-Ager Basin, located in the south-central Pyrenees. A sea-level curve cannot be determined from current data because the areas of study and sample collection are insufficiently detailed, but the genera are described taxonomically for further reference. This study is preliminary and determines the feasibility of continuing a micropaleontological program in the area.

No statistical data are compiled for the microfossil assemblages studied for this thesis. Because of the experimental extraction methods used in this study (Chapter 3), too much destruction of the microfossils has taken place and a statistical analysis would be meaningless. Appendix B contains photomicrograph plates of representative microfossils from the samples discussed in this thesis. Appendix A documents the taxonomy of all the observed and recognized genera. This systematic taxonomy is of importance because most taxa were never before reported in Eocene-aged rocks of the Pyrenees.

Direct discussion of sequence stratigraphy, with respect to sedimentology, is not part of this thesis except where it is of direct consequence to the interpretation of the microfossil assemblage. The nature of the sequence stratigraphic units, in particular the strata associated with the lignite seams, is the focus of this study. Interpretations of the microfossil assemblages are based on comparisons with modern and other known fossil assemblages of the same nature (i.e., marginal marine to freshwater).

## 1.4 The Marginal Marine Environment

For the purpose of this thesis, the term "marginal marine environment" indicates all coastal areas starting from the deepest point affected by waves up to the highest high water (HHW) mark, and includes marshes, estuaries, and beaches. Diurnal changes in water temperature, salinity, and sunlight make this environment an inhospitable place for most marine flora and fauna (Bradshaw and Phleger 1966). This marginal marine area has a high productivity despite the harsh environmental conditions. Organisms occupying the marginal marine environment have evolved to live in brackish waters, and are able to withstand periods of desiccation.

An estuary is a partly enclosed body of water subject to tidal activity and significantly diluted by freshwater runoff. It includes river mouths, bays and inlets (lower estuary) and, through the tidal phenomenon, it can show the distal influences of the marine environment upstream for many kilometers.

## 1.5 Previous Work

Until now, few studies covering ancient marginal marine foraminifera and thecamoebians have been published. Modern analogues are discussed in a long series of papers (Medioli and Scott 1983, 1987; Medioli et al. 1990a, 1990b; Scott and Medioli 1978, 1980, 1983; Scott et al. 1981, 1990, 1991) produced by staff and students of the Centre for Marine Geology (Department of Earth Sciences, Dalhousie University). Table 1.1 summarizes their results.

Ancient marginal marine and fresh water deposits are covered by very few papers. Wall's (1976) is the first study to clearly document marginal marine forms in the Mesozoic. Wall (1983) deals with the biostratigraphy of the Jurassic and Cretaceous series in the Sverdrup Basin, Canadian Arctic (Figure 1.3). In his study, marginal marine and deltaic associations of Foraminifera are identified and illustrated. Many aspects of Wall's study, such as the cyclicity of sedimentation and the presence of marginal marine and freshwater deposits are common to the Pyrenean sequences. Indeed, the two studies, despite the

| | **Estuary** | **Lower salt marsh** | **Upper salt marsh** | **Fresh water** |
|---|---|---|---|---|
| Tidal range | Sub- and intertidal | 0 - 70cm above MSL | 70 - 110 cm above MSL | |
| Salinity ‰ | 1 - 35 | 15 - 32 | 1 - 25 | 0 |
| Fauna | Agglutinated Foraminifera | Agglutinated Foraminifera | Agglutinated Foraminifera | Thecamoebian |
| Genera | *Miliammina*<br>*Ammotium*<br>*Ammobaculites*<br>*Reophax*<br>*Eggerella* | *Ammotium*<br>*Miliammina*<br>*Ammobaculites* | *Trochammina*<br>*Tiphotrocha*<br>*Haplophragmoides* | *Centropyxis*<br>*Nebela*<br>*Difflugia*<br>etc. |

Table 1.1 Physico-chemical characteristics and generalized distribution of agglutinated Foraminifera and thecamoebians of modern estuaries, salt marshes and fresh water environments. (Compiled from various authors)

obvious differences of age and location, contain a number of common genera (e.g.: *Ammobaculites, Eponides, Glomospira, Haplophragmoides, Quinqueloculina, Reophax, Saccammina, Trochammina, Verneulinoides, Spiroplectammina* ).

Thibaudeau (1993) and Wightman et al. (1993) reported marginal marine Foraminifera and thecamoebians from the cyclothems of the coal-bearing strata of the Sydney Basin, Nova Scotia (Figure 1.4), and subsequently Wightman et al. (1994) elaborated on the paleoecological and paleogeographical implications of the same material. Despite a difference of more 300 million years in time and the geographic distance separating the Sydney Basin from the Pyrenees, the genera *Ammotium, Glomospira, Haplophragmoides, Trochammina* and thecamoebians still dominate both assemblages. Wightman et al. (1994) recognized four main assemblages, three based on the dominant foraminiferal genera and one based on the presence of thecamoebians only: i) *Ammobaculites-Ammotium* ; ii) mixed *Trochammina-Ammobaculites-Ammotium;* iii) *Trochammina*-dominated assemblages (may contain reworked thecamoebians); and iv) thecamoebians only. I interpret the above

Figure 1.3 Index map of the Sverdrup area, Northwest Territories, Canada. Boxed area indicates Wall's (1983) study area.

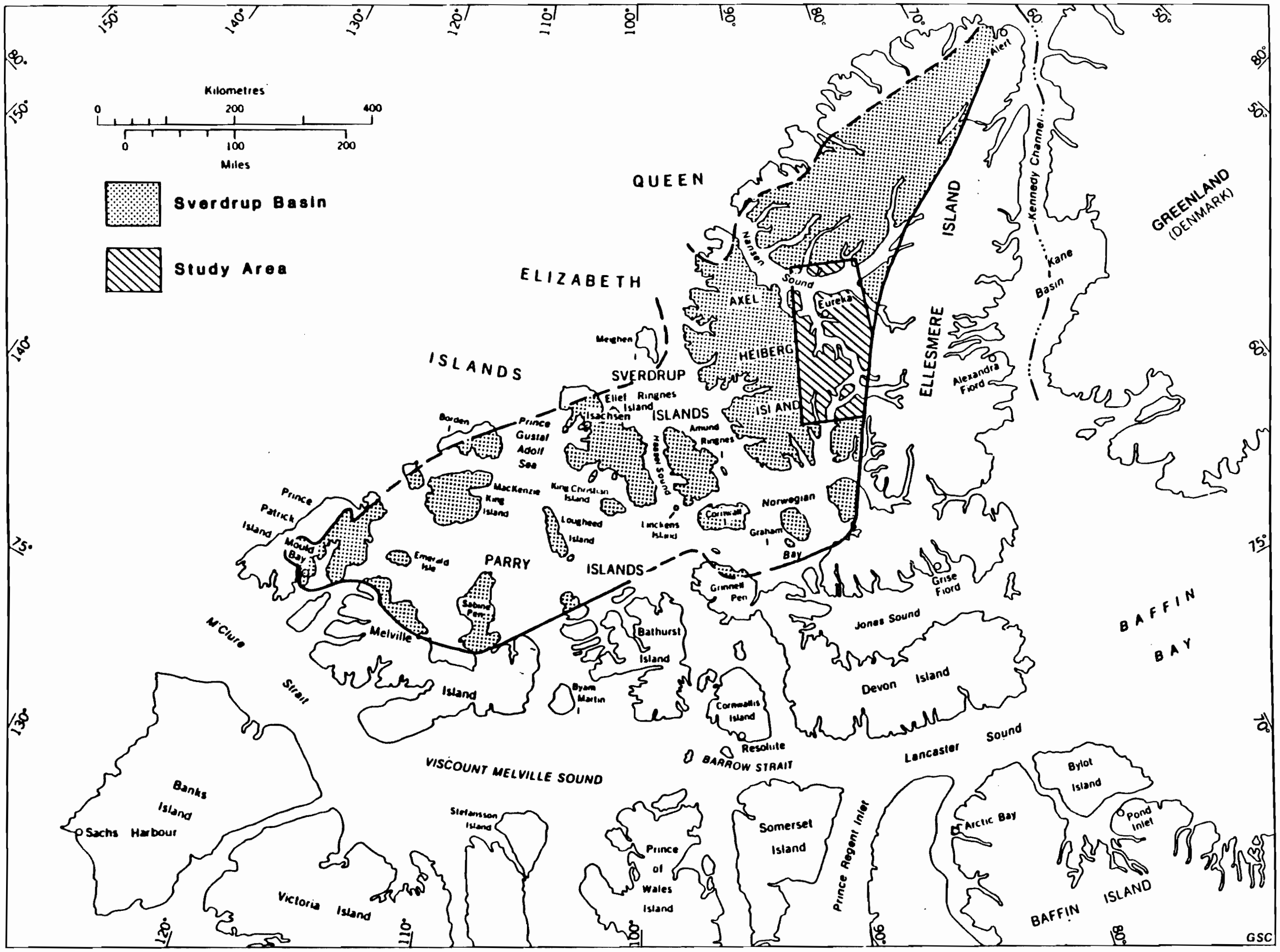
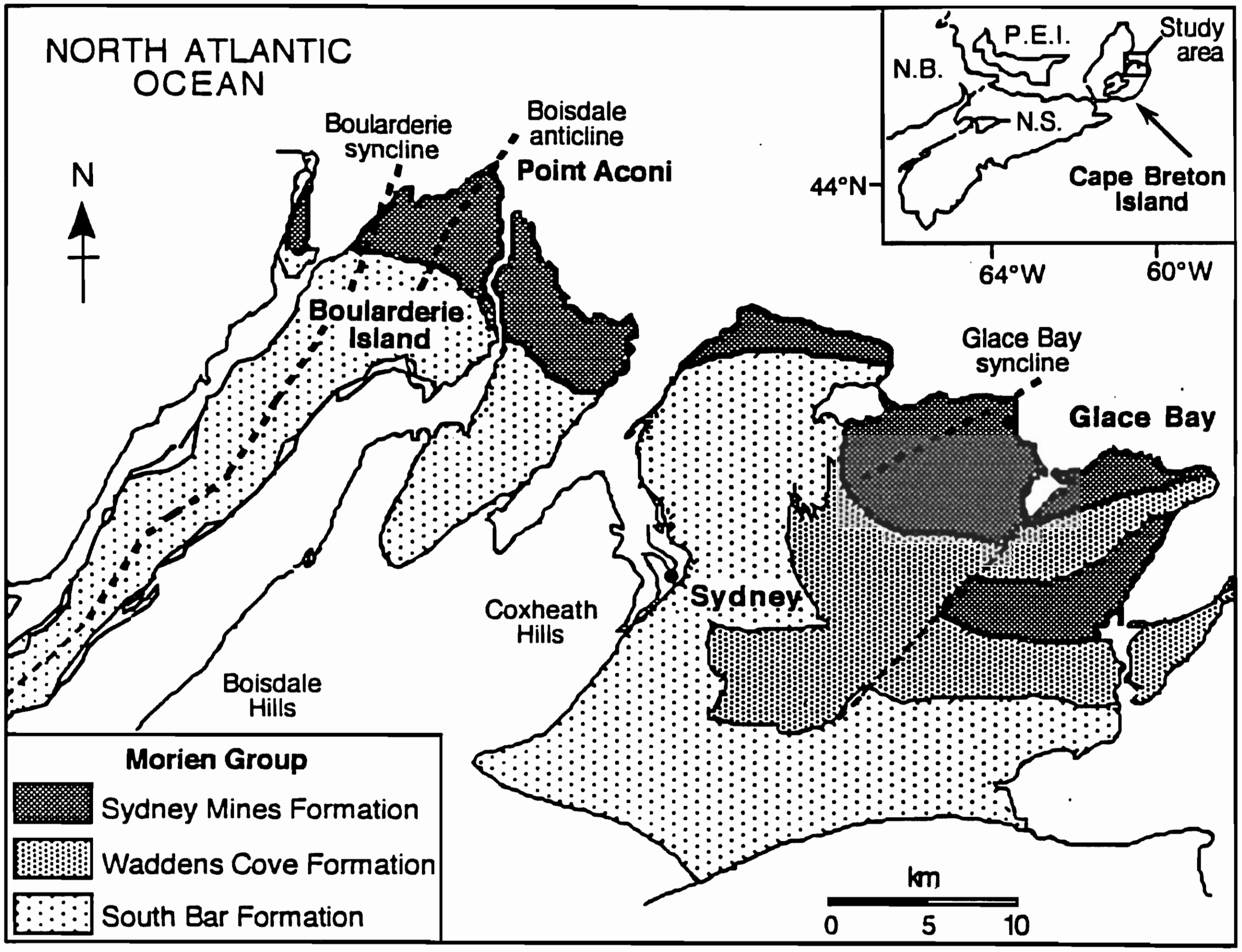

Kilometres
0
200
400
0
100
200
Miles
Sverdrup Basin
Study Area
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
80°
75°
70°
QUEEN
ELIZABETH
ISLANDS
Alert
Nansen Sound
AXEL
HEIBERG
ISLAND
Eureka
ELLESMERE
ISLAND
Kennedy Channel
Kane Basin
GREENLAND (DENMARK)
Alexandra Fiord
Meighen I
SVERDRUP
ISLANDS
Ellef Ringnes Island
Isachsen
Amund Ringnes I
Hassel Sound
Borden I
Prince Gustaf Adolf Sea
MacKenzie King Island
King Christian Island
Lougheed Island
Cornwall
Lnckens Island
Norwegian
Graham I
Bay
Prince Patrick Island
Mould Bay
Emerald Isle
PARRY
ISLANDS
Sabine Pen
Grinnell Pen
Grise Fiord
Jones Sound
BAFFIN
BAY
M'Clure Strait
Melville
Island
Bathurst Island
Byam Martin I
Cornwallis Island
Resolute
Devon Island
Lancaster Sound
VISCOUNT MELVILLE SOUND
BARROW STRAIT
Banks Island
Sachs Harbour
Victoria Island
Stefansson Island
Prince of Wales Island
Somerset Island
Prince Regent Inlet
Arctic Bay
Bylot Island
Pond Inlet
BAFFIN ISLAND
GSC

Figure 1.4 Map of the Sydney Basin, Nova Scotia, Canada (Wightman et al. 1994)


NORTH ATLANTIC OCEAN
N
Boularderie syncline
Boisdale anticline
Point Aconi
Boularderie Island
Glace Bay syncline
Glace Bay
Sydney
Coxheath Hills
Boisdale Hills
P.E.I.
N.B.
N.S.
Study area
Cape Breton Island
44°N
64°W
60°W
km
0
5
10
Morien Group
▩ Sydney Mines Formation
▦ Waddens Cove Formation
⁚ South Bar Formation

assemblages as follows: i) When the test of *Ammobaculites* and *Ammotium* agglutinate small xenosomes (silt-size), they indicate lower-salinity, upper estuarine conditions; when the size of the xenosomes is larger (fine sand size) they signify higher-salinity, lower estuarine conditions; ii) The mixed assemblage of *Trochammina-Ammobaculites-Ammotium* is interpreted as indicative of lower marshes growing in still water and affected by nearby tidal estuaries; iii) the *Trochammina*-dominated assemblages, containing reworked thecamoebians, are indicative of high marsh; this latter assemblage grades into: (iv) the thecamoebians-only assemblage, which is indicative of supra-tidal fresh-water.

A final comment of Wightman et al. (1994, p.200-201), of great relevance in this context, is the following: "*The assemblages are remarkably similar to those occurring in modern coastal wetlands*....[this]... *suggests that marginal marine agglutinated foraminiferal faunas have evolved little, if at all, during the past 300m.y* ....*The relationship between foraminiferal test morphology, life habitat and feeding strategy appear to have changed little* [since the Carboniferous]."

## 1.6 Organization

The second chapter of this thesis describes the geological and physical setting the study area in detail. The chapter describes the sequence stratigraphy of the area and a description of the principal rock units under study. The third chapter discusses sample preparation methodology. Each rock type obtained was processed differently for extraction of Foraminifera and, because some of the techniques may prove to be new, they are documented here. The fourth chapter contains the foraminiferal and thecamoebian results obtained in this investigation. Comparison with similar fossil assemblages assisted in the interpretation of this present study. Chapter 5 addresses these other known microfossil assemblages. In particular, the study of Cretaceous Foraminifera from the Sverdrup Basin (Wall, 1983) is compared to this additional discovery of marginal margin foraminiferal fauna. A review of the Carboniferous Sydney Coal Basin, of Nova Scotia, (Wightman, 1993) is also included in light of this new discovery of fossil marsh foraminifera. This chapter also presents the conclusions reached in this study, in the context of the sequence stratigraphy of the area and with respect to the reconstruction of the paleoenvironment. The final chapter summarizes the general conclusions drawn from this study. Appendix A contains the systematic taxonomy of the microfossils in this investigation. Appendix B contains micrographs of the microfossil assemblage documented in this investigation.

# CHAPTER 2 REGIONAL GEOLOGY

## 2.1 Introduction

This chapter contains a description of the geological history of the study area, including a brief overview of the structural and deformational geology. A detailed summary of the sedimentology and genesis of the major stratigraphic units follows.

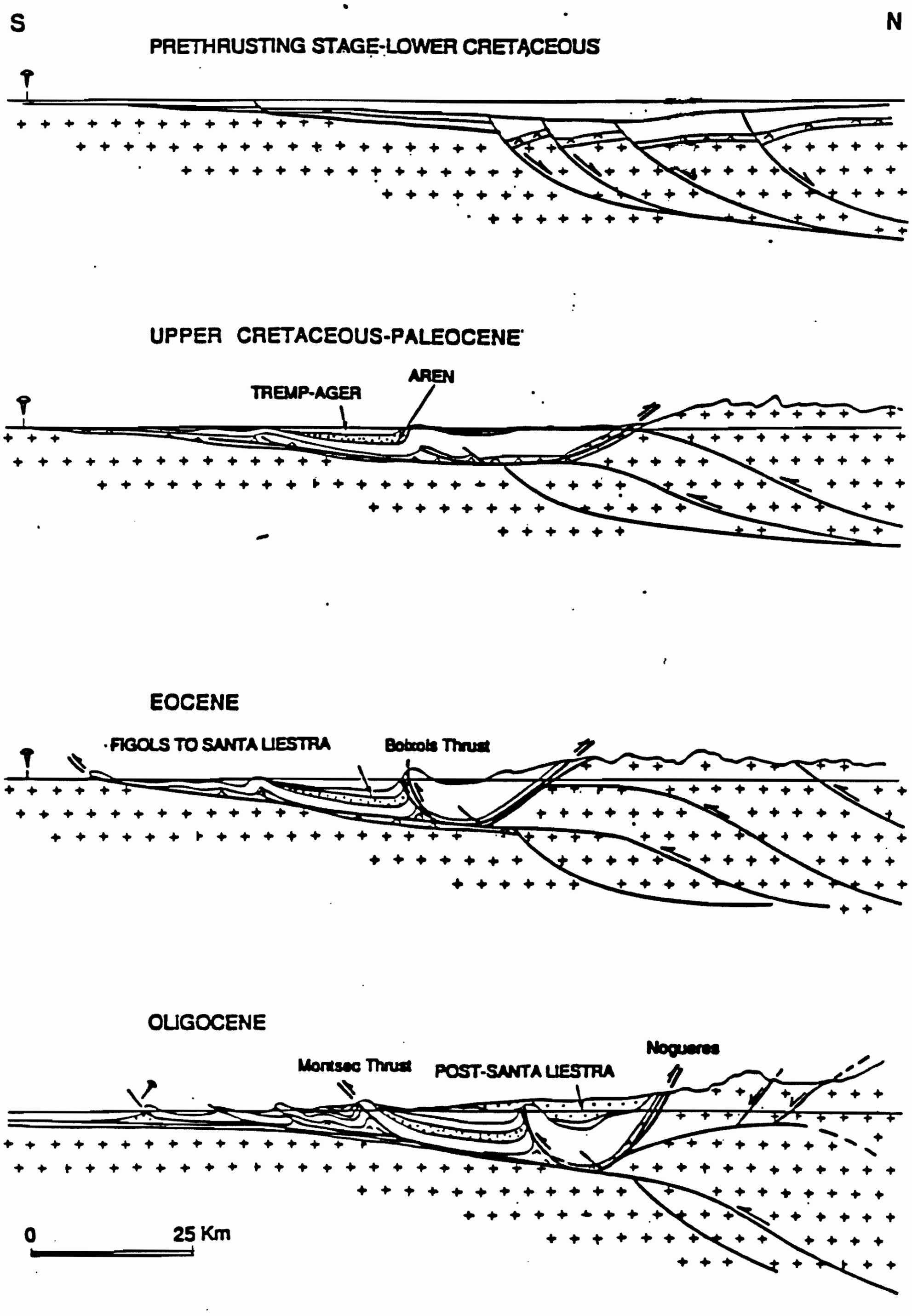
## 2.2 Structural And Deformational Geology

The general area of this study is the thrust fold belt of the south-central Pyrenees of northern Spain. The folded Upper Cretaceous and lower Tertiary strata that outcrop in this area were deposited in an overall ESE-trending foreland basin that opened toward the Atlantic. Formerly this basin was bounded to the north by the rising Axial Zone and to the south by the unfolded Ebro Basin (Mutti et al. 1994).

During the Late Cretaceous, thrusting began in the eastern part of the south-central Pyrenees. Inversion of a former extensional setting probably caused the growth of thrust-related anticlines (Figure 2.1) (Mutti et al. 1994). Thrust propagation progressively extended southward and westward during the Paleocene, the Early Eocene, and the early Mid Eocene. Tectonism peaked in late Mid Eocene, at which time the formation of the present-day important structural features was essentially complete (Mutti et al. 1994). Figure 2.1 shows that thrust propagation occurred until Oligocene and probably Miocene times.

The climax of the thrust propagation occurred during the late Mid Eocene and was related to the growth of an antiformal stack in the axis of the south-central Pyrenees. This thrusting process led to a major paleogeographic change of the southern Pyrenean foreland basin. The result was the southward shift of the main

Figure 2.1 Tectonic stages of the folded foreland of the south-central Pyrenees from the lower Cretaceous to the Oligocene (from Mutti et al. 1994).


S
N
PRETHRUSTING STAGE-LOWER CRETACEOUS
UPPER CRETACEOUS-PALEOCENE
TREMP-AGER
AREN
EOCENE
FIGOLS TO SANTA LIESTRA
Boixols Thrust
OLIGOCENE
Montsec Thrust
POST-SANTA LIESTRA
Nogueres
0
25 Km

depocenters, and the incorporation of much of the fill of the former foreland basin into the frontal thrust zone (Mutti et al. 1994). Associated with the climax of the thrust propagation are large volumes of reworked sediment.

The south-central Pyrenean foreland has been subdivided (Mutti et al. 1988, 1994) into two main basins: (1) an Inner Basin, predating the climax of the late Mid Eocene phase of deformation; and (2) an Outer Basin that originated from the new tectonic setting (Mutti et al. 1985a,b).

The stratigraphy and depositional setting of the lower Eocene strata of the Inner Basin are well documented, whereas the geological history of the Paleocene and Upper Cretaceous strata remains more obscure. The Eocene basin fill consists of three sectors, each of which records a progressively deeper and more distal environment in a westward direction (Mutti et al. 1994). In the eastern sector, sedimentation is predominantly characterized by alluvial, nearshore and shelf deposits; the central sector is characterized by slope mudstones (thin-bedded turbidite wedges) and basin-proximal turbidites (channel-fills and proximal lobes). The western sector is characterized by basin-distal turbidites (distal lobes and basin-plain deposits) (Mutti et al. 1994). Most of the samples in this study fall into either: (i) the Inner Basin alluvial, nearshore, and shelf deposits; or (ii) the basin-proximal turbidites.

## 2.3 Sequence Stratigraphy

All the sedimentary groups that characterize the sequence stratigraphy of this area formed in an essentially stable paleogeographic setting characterized by a specific and distinctive depositional pattern within the same depositional system. Tectonically-induced unconformities of local significance affected each group, thus, each group records a successive stage in the paleogeographic evolution of the Inner Basin (Mutti et al. 1994). From base to top, the major units are: (1) the Aren

Group, (2) the Tremp-Ager Group, (3) the Figols Group, and (4) the Castigaleu Group (Figure 2.2).

### 2.3.1 Aren Group

The Aren Group begins with breccias and slumps of the Pumanyons olistostrome and grades upward into the non-marine or brackish lignite-bearing strata that cap the nearshore sandstones of the Aren Formation (Figure 2.3) (Mutti et al. 1994).

### 2.3.2 Tremp-Ager Group

The Tremp-Ager Group refers to a number of lithostratigraphic units in which the vertical and lateral sequence-stratigraphic relationships remain poorly understood. Included in this group are a number of lithostratigraphic units that are essentially extensive accumulations of continental red beds grading upward into transgressive shallow-marine carbonates (Mutti et al. 1994). In this study, this unit is here taken to include both the Tremp Group and the lower part of the Ager Group of Puigdefabregas et al. (1989).

The lower stratigraphic units of Tremp-Ager Group consist of continental red beds representing the continental highstand strata of the Aren depositional sequence. Marine sediments overlie these lower units and are well developed further westward in the Isabena and Esera Valleys (Mutti et al. 1994). The biostratigraphers correlate the strata in these valleys with the uppermost part of the Aren Group, and an angular unconformity separates them from younger Tremp-Ager strata (Mutti et al. 1994). Although, from a genetic standpoint, these beds should be part of the Aren Group, lithostratigraphic criteria have generally prevailed in subsequent literature and the basal portions of the Tremp-Ager strata are traditionally included within the Tremp Formation of Mey et al. (1968). This text follows the same approach to facilitate comparison with other work (Figure 2.3).

Figure 2.2 Comparison between allostratigraphic subdivisions suggested in this thesis and the main lithostratigraphic units used in previous literature (from Mutti et al. 1994).

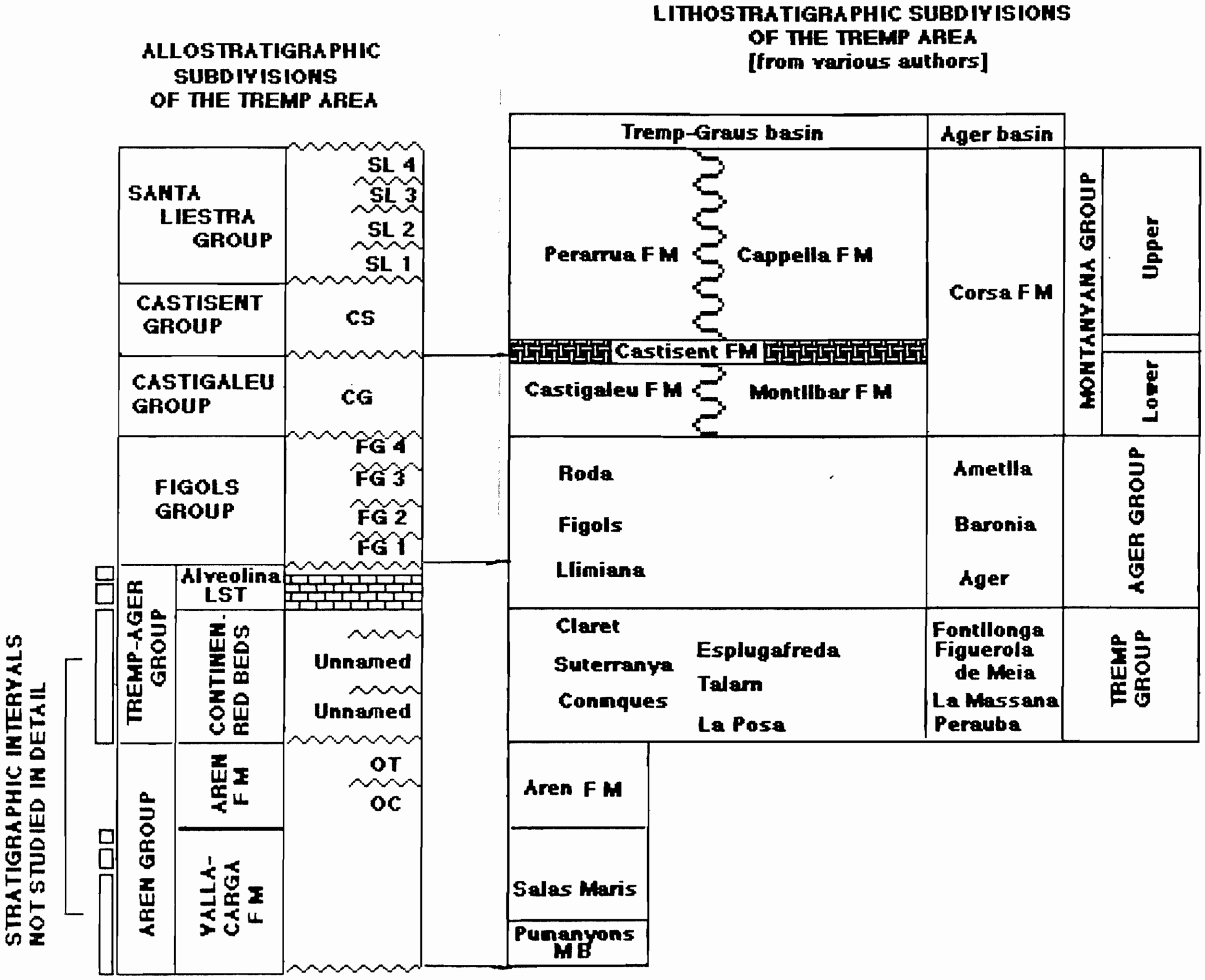
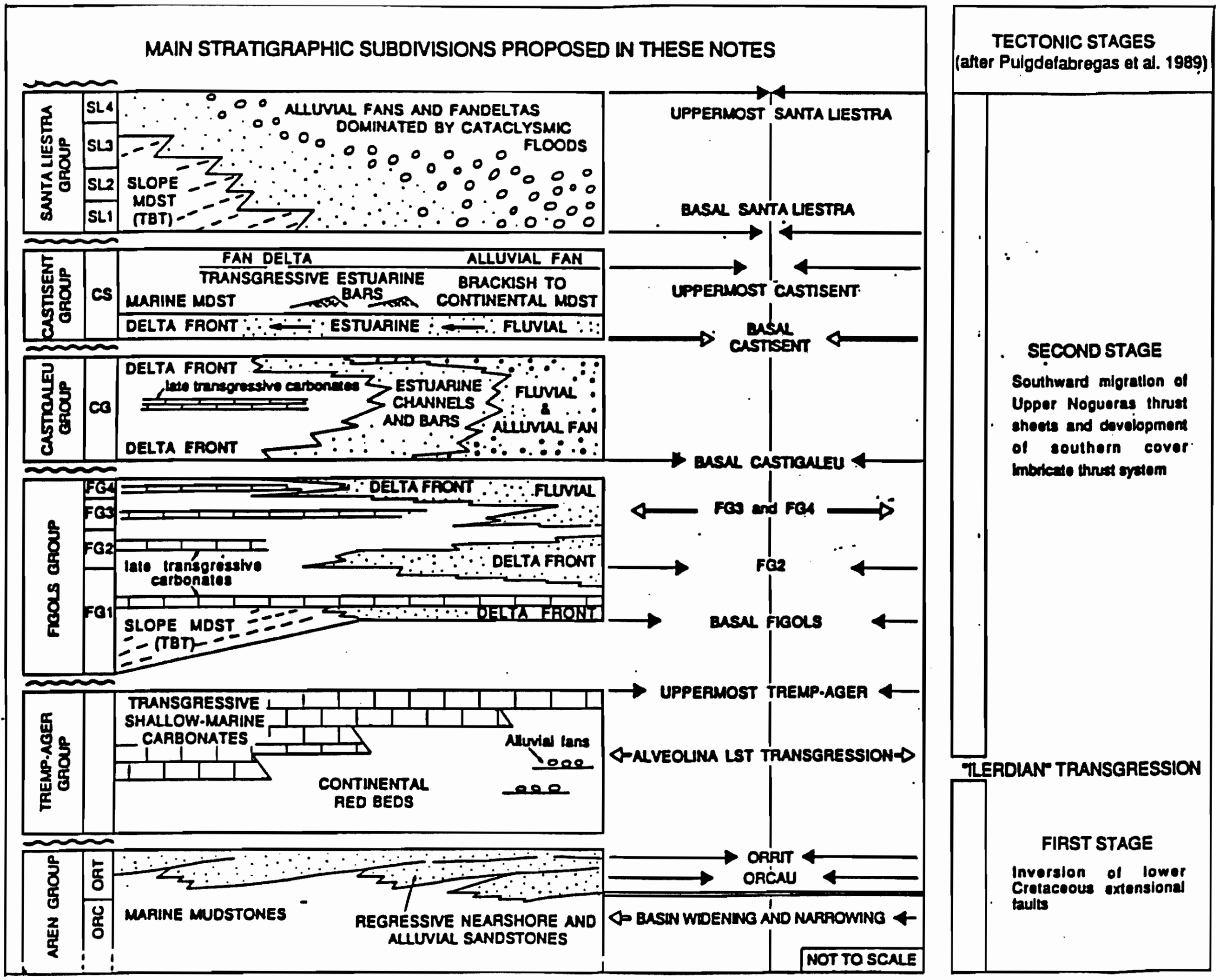

ALLOSTRATIGRAPHIC SUBDIVISIONS OF THE TREMP AREA
LITHOSTRATIGRAPHIC SUBDIVISIONS OF THE TREMP AREA [from various authors]
SANTA LIESTRA GROUP
SL 4
SL 3
SL 2
SL 1
CASTISENT GROUP
CS
CASTIGALEU GROUP
CG
FIGOLS GROUP
FG 4
FG 3
FG 2
FG 1
TREMP-AGER GROUP
Alveolina LST
CONTINEN. RED BEDS
Unnamed
Unnamed
AREN GROUP
AREN F M
OT
OC
VALLA-CARGA F M
STRATIGRAPHIC INTERVALS NOT STUDIED IN DETAIL
Tremp-Graus basin
Ager basin
Perarrua F M
Cappella F M
Corsa F M
Castisent FM
Castigaleu F M
Montllbar F M
MONTANYANA GROUP
Upper
Lower
Roda
Figols
Llimiana
Ametlla
Baronia
Ager
AGER GROUP
Claret
Suterranya
Conmques
Esplugafreda
Talarn
La Posa
Fontllonga
Figuerola de Meia
La Massana
Perauba
TREMP GROUP
Aren F M
Salas Maris
Pumanyons MB

Figure 2.3 The main stratigraphic subdivisions (allogroups) of the Upper Cretaceous, Paleocene, and Eocene strata of the study area and their comparison with the main tectonic stages in basin evolution (from Mutti et al. 1994)


MAIN STRATIGRAPHIC SUBDIVISIONS PROPOSED IN THESE NOTES
SANTA LIESTRA GROUP
SL4
SL3
SL2
SL1
ALLUVIAL FANS AND FANDELTAS DOMINATED BY CATACLYSMIC FLOODS
SLOPE MDST (TBT)
UPPERMOST SANTA LIESTRA
BASAL SANTA LIESTRA
CASTISENT GROUP
CS
FAN DELTA
ALLUVIAL FAN
TRANSGRESSIVE ESTUARINE BARS
MARINE MDST
BRACKISH TO CONTINENTAL MDST
DELTA FRONT
ESTUARINE
FLUVIAL
UPPERMOST CASTISENT
BASAL CASTISENT
CASTIGALEU GROUP
CG
DELTA FRONT
late transgressive carbonates
ESTUARINE CHANNELS AND BARS
FLUVIAL & ALLUVIAL FAN
DELTA FRONT
BASAL CASTIGALEU
FIGOLS GROUP
FG4
FG3
FG2
FG1
DELTA FRONT
FLUVIAL
late transgressive carbonates
DELTA FRONT
SLOPE MDST (TBT)
DELTA FRONT
FG3 and FG4
FG2
BASAL FIGOLS
TREMP-AGER GROUP
TRANSGRESSIVE SHALLOW-MARINE CARBONATES
Alluvial fans
CONTINENTAL RED BEDS
UPPERMOST TREMP-AGER
ALVEOLINA LST TRANSGRESSION
AREN GROUP
ORT
ORC
MARINE MUDSTONES
REGRESSIVE NEARSHORE AND ALLUVIAL SANDSTONES
ORRIT
ORCAU
BASIN WIDENING AND NARROWING
NOT TO SCALE
TECTONIC STAGES (after Puigdefabregas et al. 1989)
SECOND STAGE
Southward migration of Upper Nogueras thrust sheets and development of southern cover imbricate thrust system
"ILERDIAN" TRANSGRESSION
FIRST STAGE
Inversion of lower Cretaceous extensional faults

Unconformably overlying the Tremp-Ager Group are continental red beds that represent coarse-grained, lenticular alluvial-fan and lacustrine-fan delta systems (Mutti et al. 1994). The uppermost part of the Tremp-Ager Group consists of transgressive, shallow-marine carbonates belonging to the *Alveolina* Limestone Formation (Mey et al. 1968). In the basal section, these carbonates include lowstand or transgressive strata consisting of red beds and coarse-grained alluvial facies lithostratigraphically belonging to the underlying Tremp Group (Mutti et al. 1994). The deposition of the Tremp-Ager Group ended with a marked phase of structural deformation (Figure 2.1) (Mutti et al. 1985, 1988; Eichenseer & Luterbacher, 1992).

### 2.3.3 Figols Group

The Figols Group records the first widespread occurrence of siliciclastic sediments in the Eocene succession of the study area. The Figols Group strata occur as southward and westward prograding fluvio-deltaic depositional systems that pass seaward into thick sections of shelf mudstones (Mutti et al. 1994). Carbonate facies occur as shelf mudstones, and as shallow-water, high-energy deposits that mark periods of terrigenous sediment starvation and, as such, are associated with transgressive events (Mutti et al. 1994). The samples of this study come mainly from these strata. The Figols has been subdivided (Mutti et al. 1988, 1994) into four large-scale composite depositional sequences which, in ascending stratigraphic order, are termed Figols 1, 2, 3 and 4 (Mutti et al. 1988, 1994). Figures 2.2 and 2.3 show that these strata include a large number of both formal and informal lithostratigraphic units.

### 2.3.4 Castigaleu Group

The Castigaleu Group is a large-scale, composite depositional sequence recording a long-lived fluvial-deltaic system. The system grades both laterally and vertically into an alluvial-fan, with coarse-grained facies to the north and northeast.

It also records an important sediment source from rivers entering the Tremp-Graus basin from the south (Mutti et al. 1994). Represented in these sediments is an initial westward forestepping of fluvial and estuarine facies, followed by a backstepping of these same sediments accompanied by a limited development of carbonate facies in the west (Mutti et al. 1994). Renewed basinward shifting of fluvial and estuarine facies occurred during the highstand period (Figure 2.3).

### 2.3.5 Castisent and Santa Liestra groups

The detailed depositional setting of the Castisent Group remains poorly understood. The highstand deposits of the unit are mostly represented by sharp basal unconformities and by shallow marine, conglomerate lithofacies. These highstand deposits represent tectonically-forced regressive events (Figure 2.3) (Mutti et al. 1988, 1994).

The Santa Liestra Group records the final events of the Eocene Inner Basin (Figure 2.2). These sediments consist of a thick succession of alluvial sandstones and conglomerates with subordinate amounts of flood-plain mudstones, which pass seaward into similarly thick successions of shallow-marine and shelf conglomerates, sandstones, and mudstones (Crumeyrolle & Mutti, 1986).

These two uppermost groups complete an overall picture of the local sequence stratigraphy, but they are beyond the scope of this thesis. For this reason, samples were not collected from these stratigraphic units.

## 2.4 Summary

The geological setting of the South-Central Pyrenees is that of a tectonically deformed and uplifted continental shelf. The continental shelf prograded and retrograded cyclically in response to both tectonic and eustatic changes in sea level. Large-scale regressive and transgressive cycles are well-documented, based on sedimentary evidence, but small-scale, high-order cycles have not been positively identified in these strata. High precision sea-level points are needed to trace the high-order cycles through geological time (as recorded in the rocks of this area).

# CHAPTER 3 METHODS

## 3.1 Introduction

Smaller Foraminifera and thecamoebians described in this thesis have never before been reported from the study area. Because, in a study of this kind, adequate sample preparation may determine success or failure, documentation of the degree of success of each extraction method is necessary. Despite long experience, micropaleontologists have not yet produced a standard set of protocols applicable to the extraction of microfossils from all rock types. A variety of more or less complicated methods to process and extract microfossils exists in the literature. Ultimately, however, the final choice of the method to be used with specific samples remains a very time-consuming, trial-and-error type of operation. The differences in results are mainly caused by the minor differences in general porosity and solubility of the matrix of each sample, properties which can only be evaluated *a posteriori*.

The widely accepted routine requires samples to be of standard volumes, the volumes of the enriched residue examined vary from sample to sample depending on: i) the yield of the particular extraction method; ii) the fossil content of the rock; and iii) the original amount of sample collected in the field.

## 3.2 Sample Collection

Bulk rock samples were collected in March 1992 from various outcrops of Eocene age in the south-central Pyrennes, Spain. Because sampling of the lignite layers (forming the tops of allostratigraphic cycles) was the main goal of the field work, samples were collected above, below, and within the lignite. Multiple stops were made at exposure sites of each sequence stratigraphic type-location (each stop representing a specific well-exposed part of the stratigraphic section) and multiple samples were collected at each stop (samples were always collected around lignite layers from the bottom upward, i.e., up section).

## 3.3 Foraminifera And Thecamoebian Extraction

### 3.3.1 Drying

The samples were archived and dried indoors for two years before processing. As a result, no moisture remained in the pore space of the rocks. Owing to the porous nature of the rocks, the thorough drying greatly assisted in the breakdown of the material during subsequent processing.

### 3.3.2 Boiling

Initially, approximately 80 ml of rock were placed in a beaker of boiling water to cause disaggregation of the matrix. The matrix is significantly weakened by the removal of all the water in its structure. The introduction of boiling water results in the buildup of high osmotic pressure in the pore space of the rock causing the weakening of the matrix and eventually allowing sediment to break apart. This common and inexpensive method produced positive results (i.e., the matrix dissolved, facilitating extraction of the siliciclastics and Foraminifera) in most samples from Isobena Valley and in some samples from Ager and La Pasarela. Most samples from other localities, however, responded very poorly to this method of extraction. Even after many hours of daily boiling over a period of six months many samples were wholly unchanged.

### 3.3.3 Detergent

Immersion in detergent broke down and removed mud- and silt-size particles. Ordinary glass cleaner, Sparkleen®, produced excellent results, as did generic dish detergent. Disintegrated material was placed on a 63mm sieve and detergent was poured on top. The detergent was then rinsed off with a gentle spray of warm tap water. This process was repeated until no more material washed through the sieve. Semi-processed material, remaining on the sieve, was also disaggregated by means of detergent.

### 3.3.4 Oven drying and soaking

The most successful method for microfossil extraction was repeated drying and soaking of the rock in lukewarm tap water. The samples were gently broken in smaller pieces after each soaking. The pieces were then dried at night in a low temperature oven (~40°C) . When samples were completely dry, they were washed over a 63 µm sieve with detergent and dried again. Particles larger than 1000µm were reprocessed until the samples were completely disaggregated or until a sufficient number of microfossils were extracted to no longer warrant the processing of the remaining material.

### 3.3.5 Formic acid treatment

Certain carbonate samples were processed using a formic acid treatment. Loose rock particles were placed in a 15% formic acid solution and a vigorous reaction followed. After 15 minutes in the solution, the material was washed over a 63 µm sieve and the remaining large pieces were again placed in a 15% formic acid solution for 15 minutes. Samples were all washed with detergent to remove excess acid and then dried in a low temperature oven (~40°C). This method worked successfully only with extremely fossiliferous material. The cement between the microfossils readily dissolved before the acid could damage or completely dissolve the tests. This process worked especially well in Alveoline-rich samples, whereas in less fossiliferous material it dissolved calcareous tests as well as the cement within agglutinated Foraminifera, if left in the solution for more than a few hours. Calcareous sand and silt grains became pitted and broken.

## 3.4 Foraminifera and Thecamoebian Microscope Examination

### 3.4.1 Preparation

Once all the samples were washed and dried, they were passed through a series of sieves (500 μm, 250 μm, 125 μm and 63μm) to sort the residue into size fractions and to facilitate microscope analysis. Any material smaller than 63 μm was lost due to processing. Samples were either picked clean or, when excessively large and/or fossiliferous, passed through a dry splitter and then one or more fractions were picked clean of microfossils. All picked specimens were mounted on a multiple slide and glued into position with Gum Tragacanth. Specimens selected for Scanning Electron Microscope (SEM) examination were later removed and mounted onto double-sided tape attached to the surface of an aluminum stub.

### 3.4.2 Scanning electron microscope examination

The SEM examination was based essentially on the study of photomicrographs, and only occasionally by direct observation on this microscope. The SEM used for this work is a Bausch and Lomb Nanolab 2000 machine belonging to the Department of Biology at Dalhousie University. SEM stubs were vacuum dried and sputter coated with a gold/palladium (60/40) alloy in a Tousimis Samsputter 2a (Automatic Sputter-coating apparatus). The sputter was set at 1.5 Angstrom/second for approximately 55 seconds. Prepared samples were placed in the vacuum chamber of the SEM. The SEM was set at 15kV and magnifications were kept, as much as possible, between 100 and 200X so that the photomicrographs would roughly retain their relative sizes in side-by-side comparison. Pictures were taken on 35mm Plus X Kodak film and were printed, in black and white, on a variety of papers.

### 3.4.3 Examination under light microscope

Samples were examined dry, under a Student model Zeiss binocular stereo-microscope using reflected light, a standard procedure in routine micropaleontological work. Specimens were examined at 20X, 40X, and 80X magnifications.

# CHAPTER 4 RESULTS

## 4.1 Introduction

Foraminiferal assemblages identified in each sample area define an ecological environment. The definition of a niche relies upon both the presence and/or absence of particular genera and on the nature of the foraminiferal tests. The presence of freshwater, estuarine, and marginal marine assemblages indicate the beginning or end of significant trends (i.e. transgressions and regressions).

Modern marginal marine settings, in which the identification of the fauna at the species level is possible, supply a detailed model for the interpretation of fossil material of similar origin (Scott & Medioli, 1980). When dealing with fossil material, however, taphonomic process complicate the identification of the remains. Recrystallization and deformation of the test can make identification impossible at the species level; consequently, the identifications in this thesis are at the generic level. Some loss of accuracy in the determination of paleo-environment is inevitable, although the regressive and transgressive cycles can still be identified with an accuracy previously not possible.

All identification was done on the basis of photomicrographs, chiefly relying on the external morphology of the test. In numerous cases, the identification is tentative because the internal structures are either not visible or they have been destroyed by recrystallization during fossilization. Tentative identifications are indicated by a **(?)** following the genus (or species) name.

Seven representative samples were chosen to illustrate the marginal marine environments encountered in these samples.

## 4.2 Ager

Figure 4.1 shows the location of the Ager study area. Samples were collected in stratigraphic order through parts of the sections, such that sample one

Figure 4.1 Detailed map of northern Spain. Sample locations were in the vicinity of the towns with the same names (from National Geographic Society 1990).


FRANCE
LANGUEDOC
PYRÉNÉES
ARAGON
CATALUÑA
ANDORRA
ROUSSILLON
Corbières
GOLFE DU L
Costa Brava
Toulouse
Montpellier
Nîmes
Béziers
Narbonne
Perpignan
Carcassonne
Castres
Albi
Mazamet
Sète
Agde
Tarbes
Pau
Lourdes
Oloron
Auch
Dax
Mont-de-Marsan
Bagnères-de-Bigorre
Pamiers
Foix
Andorra
Puigcerdà
Figueras
Gerona
Olot
Vich
Manresa
Tarrasa
Sabadell
BARCELONA
Badalona
Hospitalet
Granollers
Mataró
Tarragona
Reus
Valls
Lérida
Huesca
Jaca
Zaragoza
Monzón
Barbastro
Fraga
Balaguer
Berga
Ripoll
Palafrugell
Palamós
Rosas
Cadaqués
Cabo de Creus
Golfo de Rosas
Étang de Leucate
Étang de Bages et de Sigean
Bassin de Thau
Camargue
Pic d'Aneto
Monte Perdido
PARQ. NAC. DE ORDESA
Sierra de Guara
Sierra del Cadí
Sierra de Alcubierre
Sierra de la Peña
Montes Alberes
Embalse de Mequinenza
Ebro
14
15
16
17
18
19
20
21
22
2°
3°
4°
0°

is always the lowest in the sequence. Table 4.1 shows the stratigraphic unit and lithology of all samples taken in the Ager area, as well as fossiliferous and barren suites. These samples have only been tentatively examined and only a few pieces of information are discussed further in this thesis. Foraminifera and thecamoebians, however, have been found within various samples.

## 4.3 Boltaña

The Boltaña study area is shown on Figure 4.1. Table 4.2 lists the stratigraphic units sampled at Boltaña. This region has yielded two extremely fossiliferous sample locations (Boltaña 4A and Boltaña 4B). Both of these samples were taken in the same location. Sample Boltaña 4A stratigraphically overlies sample Boltaña 4B.

### 4.3.1 Boltaña 4A

Table 4.3 shows a complete list of genera present in this sample. The presence of genera from entirely different biofacies clearly indicates sediment reworking. I underline the presence of a large number of *Heterohelix* and a few representatives of *Hedbergella* and *Praeglobotruncana* , typically Cretaceous planktonic forms living in open ocean conditions, together with the genera *Elphidium,* and *Ammobaculites*, both marginal marine is interpreted as being the result of reworking of older sediment that were eroded upslope.

### 4.3.2 Boltaña 4B

Table 4.4 contains a complete list of genera identified from this sample. This sample contains the genera *Trochammina*, and *Ammobaculites*, both marginal marine agglutinated forms, together with a variety of reworked calcareous forms: *Globotruncana* (a planktonic form); and *Globulina*, *Gavelinella, and Epistomina* (benthic open water forms). As in Boltaña 4A, this mixture of faunas indicates that

## AGER

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 3-1 | Aren Sandstone | Sandstone | Reworked Calcareous Foraminifera | no |
| 3-2 | Aren Sandstone | Biosparitic grainstone | Evidence of agglutinated Foraminifera | no |
| 4-5 | Figols 3 sandstone | Biosparitic grainstone | Evidence of agglutinated Foraminifera | no |
| 4-8 | Figols 3 sandstone | Biosparitic grainstone | Evidence of agglutinated Foraminifera | no |

Table 4.1 Stratigraphic unit, lithology, and microfossil content of samples from the Ager area.

## BOLTAÑA

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 3-1 | Figols Group | Micritic mudstone | Evidence of Foraminifera | no |
| 3-2 | Figols Group | Micritic mudstone | High concentration of Foraminifera | no |
| 3-3 | Figols Group | Micritic mudstone | Evidence of agglutinated Foraminifera | no |
| 4A | Figols Group | Biosparitic grainstone | Estuarine and Marginal Marine Foraminifera | yes |
| 4B | Figols Group | Micritic mudstone | Marginal Marine Foraminifera | yes |

Table 4.2 Stratigraphic unit, lithology and microfossil content of samples taken in the Boltaña area.

## Boltaña 4A

| Test Type | Organism | Genus and species |
|---|---|---|
| Agglutinated | Foraminifera | *Ammobaculites* sp. |
| Agglutinated | Foraminifera | *Glomospira* sp. |
| Agglutinated | Foraminifera | *Heterohelix* sp. |
| Agglutinated | Foraminifera | *Reophax* sp. |
| Agglutinated | Foraminifera | *Verneuilinoides* sp. |
| Calcareous | Foraminifera | *Cuvillierina* sp. (?) |
| Calcareous | Foraminifera | *Elphidium* sp. |
| Calcareous | Foraminifera | *Eoguttulina* sp. |
| Calcareous | Foraminifera | *Epistomina* sp. (?) |
| Calcareous | Foraminifera | *Gavellinella* sp. (?) |
| Calcareous | Foraminifera | *Hedbergella* sp. (?) |
| Calcareous | Foraminifera | *Praeglobotruncana* sp. (?) |
| Calcareous | Foraminifera | *Quinqueloculina* sp. |
| Calcareous | Foraminifera | *Rectobulimina* sp. |

Table 4.3 List of fossil assemblage present in sample Boltaña 4A.

## Boltaña 4B

| Test type | Organism | Genus and species |
|---|---|---|
| Agglutinated | Foraminifera | *Ammobaculites* sp. |
| Agglutinated | Foraminifera | *Ammodiscus* sp. |
| Agglutinated | Foraminifera | *Saccammina* sp. |
| Agglutinated | Foraminifera | *Trochammina* sp. (?) |
| Calcareous | Foraminifera | *Epistomina* sp. (?) |
| Calcareous | Foraminifera | *Gavellinella* sp. (?) |
| Calcareous | Foraminifera | *Globotruncana* sp. (?) |
| Calcareous | Foraminifera | *Globulina* sp. (?) |

Table 4.4 List of fossil assemblage present in sample Boltaña 4B.

the calcareous forms are derived from older, uplifted and eroded marine sediments.

## 4.4 Guara

Table 4.5 contains a description of the samples from the Guara study area, as well as the stratigraphic and lithological units in which each sample has been collected. A number of samples were given a preliminary examination and large number of agglutinated Foraminifera were recorded. The delicate tests are composed of agglutinated, coarse sand grains, and are badly broken by processing. For this reason I did no further work on these samples..

## 4.5 Isabena Valley

Table 4.6 shows a complete list of samples taken in the Isabena Valley. The samples occur in stratigraphic order from bottom (sample 4-9) to top (sample 4-19).

I must underline, for later discussion, that this sequence shows continental shelf, grading into the marginal marine, and finally estuarine or freshwater assemblages, as indicated by the presence of fragments of thecamoebian fragments near the top of the cycles.

I have examined only two representative samples in the SEM and, consequently, a complete list of genera and species for the for the area has not been generated. Both the samples were examined in detail because they marginal marine conditions.

### 4.5.1 Isabena Valley 4-12

Table 4.7 shows a complete list of genera identified in sample 4-12. A totally agglutinated fauna, consisting of *Spiroplectammina, Ammobaculites, Haplophragmoides, Pseudothurammina, and Trochammina* together with the

**Guara**

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 1-1 | Figols Group | Turbidite layer (of carbonate composition) | Evidence of calcareous Foraminifera | no |
| 1-2 | Figols Group | Muddy turbidite (of carbonate composition) | Evidence of agglutinated Foraminifera | no |
| 1-3 | Figols Group | Sandy turbidite (of carbonate composition) | Marginal Marine Foraminifera | no |
| 1-4 | Figols Group | Muddy turbidite (of carbonate composition) | Evidence of agglutinated Foraminifera | no |
| 2-1 | Castigaleu Group | Biomicritic wackestone | Evidence of agglutinated Foraminifera | no |
| 2-2 | Castigaleu Group | Biomicritic wackestone | Evidence of agglutinated Foraminifera | no |

Table 4.5 Stratigraphic unit, lithology and microfossil content of samples taken in the Guara area.

**Isabena Valley**

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 4-6 | Castigaleu Group | Limestone | Foraminifera | no |
| 4-7 | Castigaleu Group | Limestone | Foraminifera | no |
| 4-8 | Castigaleu Group | Micritic mudstone | Foraminifera | no |
| 4-9 | Castigaleu Group | Black peat unit | Foraminifera | no |
| 4-10 | Castigaleu Group | Siliceous sandstone with brown peat | Foraminifera | no |
| 4-11 | Castigaleu Group | Shelly layer (Coquina) | Foraminifera | no |
| 4-12 | Castigaleu Group | Gray mudstone | Foraminifera | yes |
| 4-13 | Castigaleu Group | Poorly lithified, coarse sandstone | Foraminifera | no |
| 4-14 | Castigaleu Group | Poorly lithified, coarse sandstone | Foraminifera | no |
| 4-15 | Castigaleu Group | Blue clay | Foraminifera | no |
| 4-16 | Castigaleu Group | Light brown clay | Foraminifera | no |
| 4-17 | Castigaleu Group | Poorly lithified, coarse sandstone | Foraminifera | no |
| 4-18 | Castigaleu Group | Siliceous | Foraminifera | no |
| 4-19 | Castigaleu Group | Carbonate | Foraminifera | yes |

Table 4.6 Stratigraphic unit, lithology and microfossil content of samples taken in the Isabena Valley area.

## Isabena Valley 4-12

| Test type | Organism | Genus and species |
|---|---|---|
| Agglutinated | Foraminifera | *Ammobaculites* sp. |
| Agglutinated | Foraminifera | *Haplophragmoides* sp. |
| Agglutinated | Foraminifera | *Spiroplectammina* sp. (?) |
| Agglutinated | Foraminifera | *Pseudothurammina* sp. (?) |
| Agglutinated | Foraminifera | *Trochammina* sp. |
| Calcareous | Foraminifera | *Globotruncana* sp. |

Table 4.7 List of fossil assemblage present in sample Isabena Valley 4 - 12.

planktonic *Globotruncana*, indicates a marginal marine association with some reworked Cretaceous material.

### 4.5.2 Isabena Valley 4-19

Table 4.8 is a detailed list of the foraminiferal genera present in this sample. The abundance of well-preserved *Trochammina* , *Haplophragmoides,* and *Glomospira* together with *Globotruncana* (?), *Guttulina* and abraded calcareous forms suggest a marginal marine association with some reworked Cretaceous material.

### 4.5.3 Isabena Valley--Selected specimens from a range of samples

The list in Table 4.9 shows some specimens initially selected from the entire range of the Isabena Valley collection. They are listed and illustrated because these are some of the best specimens retrieved from this section.

## 4.6 Isona

None of these samples have been examined in detail because of the difficulties encountered in processing the rock material. Further study is needed to determine if Foraminifera or thecamoebians are present.

## 4.7 La Pasarela

Table 4.10 lists samples taken in the La Pasarela region.

### 4.7.1 La Pasarela 2A-5

Table 4.11 contains a complete list of genera identified in this sample. In this sample location a number of agglutinated forms are mixed with numerous different genera of thecamoebians. The presence of thecamoebians indicates two possible environments:

i) upper marginal marine, into which thecamoebians from the freshwater environment were reworked and transported by surface runoff; and

## Isabena Valley 4-19

| **Test type** | **Organism** | **Genus and species** |
|---|---|---|
| Agglutinated | Foraminifera | *Globotruncana* sp. (?) |
| Agglutinated | Foraminifera | *Glomospira* sp. |
| Agglutinated | Foraminifera | *Haplophragmoides* sp. |
| Agglutinated | Foraminifera | *Trochammina* sp. |
| Calcareous | Foraminifera | *Guttulina* sp. |

Table 4.8 List of fossil assemblage present in sample Isabena Valley 4 - 19.

## Isabena Valley (miscellaneous sample locations)

| Test type | Organism | Genus and Species |
|---|---|---|
| Agglutinated | Foraminifera | *Haplophragmoides* sp. |
| Agglutinated | Foraminifera | *Trochammina* sp. |

Table 4.9 List of fossil assemblage present in miscellaneous samples Isabena Valley.

**La Pasarela**

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 2-3 | Tremp-Ager Group | Fossiliferous Biosparitic grainstone | Marginal Marine Foraminifera | no |
| 2A-4 | Tremp-Ager Group | Biosparitic grainstone | Marginal Marine Foraminifera | no |
| 2A-5 | Tremp-Ager Group | Biosparitic grainstone | Marginal Marine Foraminifera | yes |

Table 4.10 Stratigraphic unit, lithology and microfossil content of samples taken in the La Pasarela area.

## La Pasarela 2A-5

| **Test type** | **Organism** | **Genus and species** |
|---|---|---|
| Agglutinated | Foraminifera | *Ammotium* sp. |
| Agglutinated | Foraminifera | *Polysaccammina* sp. |
| Agglutinated | Thecamoebian | Difflugiid-like (?) |
| Agglutinated | Thecamoebian | Heleopora-like (?) |

Table 4.11 List of fossil assemblage present in sample La Pasarela 2 A - 5.

ii) presence of *Ammotium* suggests the environment could have been estuarine, in which case, thecamoebians and Foraminifera would have lived so close to each other that euryhaline forms could intermittently invade each others habitats.

## 4.8 Tremp

Table 4.12 shows a complete list of stratigraphic units for this sample area.

### 4.8.1 Tremp 2

Table 4.13 shows a list of genera present in this sample. This sample contains a mixture of: i) open water forms such as *Cassidulina, Cuvillierina, and Marginulina* ; ii) forms believed to live in suspension in the nepheloid layer (e.g., *Polymorphina, Globobulimina* ); iii) attached bottom dwellers such as *Pseudothurammina*, and *Cibicides*; and iv) freshwater thecamoebians. This unequivocally indicates reworking from pre-consolidated sediments into marginal marine and/or freshwater environment.

### 4.8.2 Tremp 4-3

Table 4.14 shows a list of genera present in this sample. The lack of typical marsh dwellers suggests this sample represents a somewhat more distal environment in which older planktonic forms, such as Cretaceous *Praeglobotruncana*, have been reworked. The presence of shallow water forms such as Miliolids, *Elphidium, Haynesina,* and *Cibicides* indicates that the distance from shore was minimal. The presence of abundant reworked Alveolines, in this sequence, indicates that an Alveoline-reef had developed offshore during one of the intermittent transgressive cycles. This indicates a very shallow sea in which the Alveoline-reefs could grow. This would confirm the hypothesis that throughout the sequences in this thesis a shallow shelf bordered the coastline. The Alveolines are

## Tremp

| Stop Number | Stratigraphic Unit | Lithology | Microfossil Fauna | Discussed in thesis |
|---|---|---|---|---|
| 1-1 | Tremp-Ager Group | Siliceous shale | Evidence of marginal marine, agglutinate Foraminifera | no |
| 1-2 | Tremp-Ager Group | Siliceous shale | Barren | no |
| 1-3 | Tremp-Ager Group | Fossiliferous limestone | Alveoline-rich fauna | no |
| 1-4 | Tremp-Ager Group | Siliceous claystone | Evidence of marginal marine, agglutinated Foraminifera | no |
| 2 | Figols 1 | Siliceous shale | Evidence of Foraminifera | yes |
| 3-1 | Tremp/Castigaleu Groups | Micritic mudstone | Marginal marine Foraminifera & reworked calcareous Foraminifera present | no |
| 4-1 | Figols Group | Micritid mudstone | Small number of agglutinated Foraminifera present | no |
| 4-3 | Figols Group | Black fossiliferous micritic mudstone | Marginal marine Foraminifera & reworked calcareous Foraminifera present | yes |
| 4-5 | Figols Group | Dark gray micritic mudstone | Evidence of marginal marine Foraminifera | no |

Table 4.12 Stratigraphic unit, lithology and microfossil content of samples taken in the Tremp area.

**Tremp 2**

| Test type | Organism | Genus and species |
|---|---|---|
| Agglutinated | Foraminifera | *Ammodiscus* sp. |
| Agglutinated | Foraminifera | *Tholosina* sp. |
| Agglutinated | Thecamoebian | Centropyxis-like |
| Agglutinated | Thecamoebian | Difflugiid-like |
| Calcareous | Foraminifera | *Cassidulina* sp. (?) |
| Calcareous | Foraminifera | *Cibicides* sp. |
| Calcareous | Foraminifera | *Cuvillierina* sp. (?) |
| Calcareous | Foraminifera | *Globobulimina* sp. |
| Calcareous | Foraminifera | *Marginulina* sp. (?) |
| Calcareous | Foraminifera | *Pararotalia* sp. (?) |
| Calcareous | Foraminifera | *Polymorphina* sp. (?) |

Table 4.13 List of fossil assemblage present in sample Tremp 2.

## Tremp 4-3

| Test type | Organism | Genus and species |
|---|---|---|
| Agglutinated | Foraminifera | *Ammobaculites sp.* |
| Agglutinated | Foraminifera | *Heterohelix sp.* |
| Calcareous | Foraminifera | *Cibicides* sp. |
| Calcareous | Foraminifera | *Elphidium* sp. |
| Calcareous | Foraminifera | *Haynesina* sp. (?) |
| Calcareous | Foraminifera | Miliolid |
| Calcareous | Foraminifera | *Praeglobotruncana* sp. (?) |
| Calcareous | Foraminifera | *Rectobulimina* sp. |

Table 4.14 List of fossil assemblage present in sample Tremp 4 -3 .

not discussed in this thesis because they are not directly relevant to the marginal marine phenomena under study.

### 4.9 Summary

Seven representative micropaleontological samples in order to produce sufficient evidence to establish the environment of deposition of the lignite layers and related sediments outcropping in the south central Pyrenees. Marginal-marine Foraminifera, calcareous Foraminifera, and Thecamoebians present in the samples supply useful information that will be discussed in the following chapter.

# CHAPTER 5 DISCUSSION

## 5.1 Introduction

The Pyrenean area is a classic one for the study of sequence stratigraphy (Mutti 1994). Sequence stratigraphy is based on the concept of cyclicity of transgressive and regressive events and on the signature that such events leave in the sedimentary record. Whereas the sedimentary evidence may suggest the presence of such cycles, sediments alone cannot establish their existence with any degree of certainty. In an attempt to document sequence stratigraphy specialists have drawn information from a wide range of sources. Geophysical evidence, for example, does not conflict with the idea of cyclicity (Carminatti 1994), but does not support it convincingly. Dr. Emiliano Mutti (University of Parma) believed that further evidence from micropaleontology was needed.

With the exception of two other study locations, no previous work exists in the area of marginal marine micropaleontology of older deposits. This chapter discusses and compares the assemblages described by Wall (1976, 1983), Wightman et al. (1994) and Thibaudeau (1993) with the material of this study.

Reconstruction of paleoenvironments uses many different approaches. Sedimentology can supply information on the depositional environment, but seldom can supply accurate details about the physical/chemical conditions of the water. On the other hand, in recent years, micropaleontology has provided a wealth of information on the ecological conditions within which many microorganisms live. Applying the Uniformitarian Principle to this information is not always feasible because: i) organisms evolve and may change their ecological preferences; ii) fossilized foraminiferal and thecamoebian material can be identified to the species level only under unusual conditions; and

iii) many groups have become extinct, and their ecological preferences are only known because of their association with better known and/or better studied organisms. Figure 5.1 indicates its relative location with respect to the rest of the ocean basin. This area is very poorly studied.

Foraminifera, in recent as well as in ancient marginal marine environments, occupy a narrow vertical zone the extent of which is controlled by the tidal regime. This distribution enables the specialist to discriminate the distinct faunal divisions between the assemblages of freshwater and marshes, upper and marine environment object of this thesis. (see Figure 5.1--Not in scale).

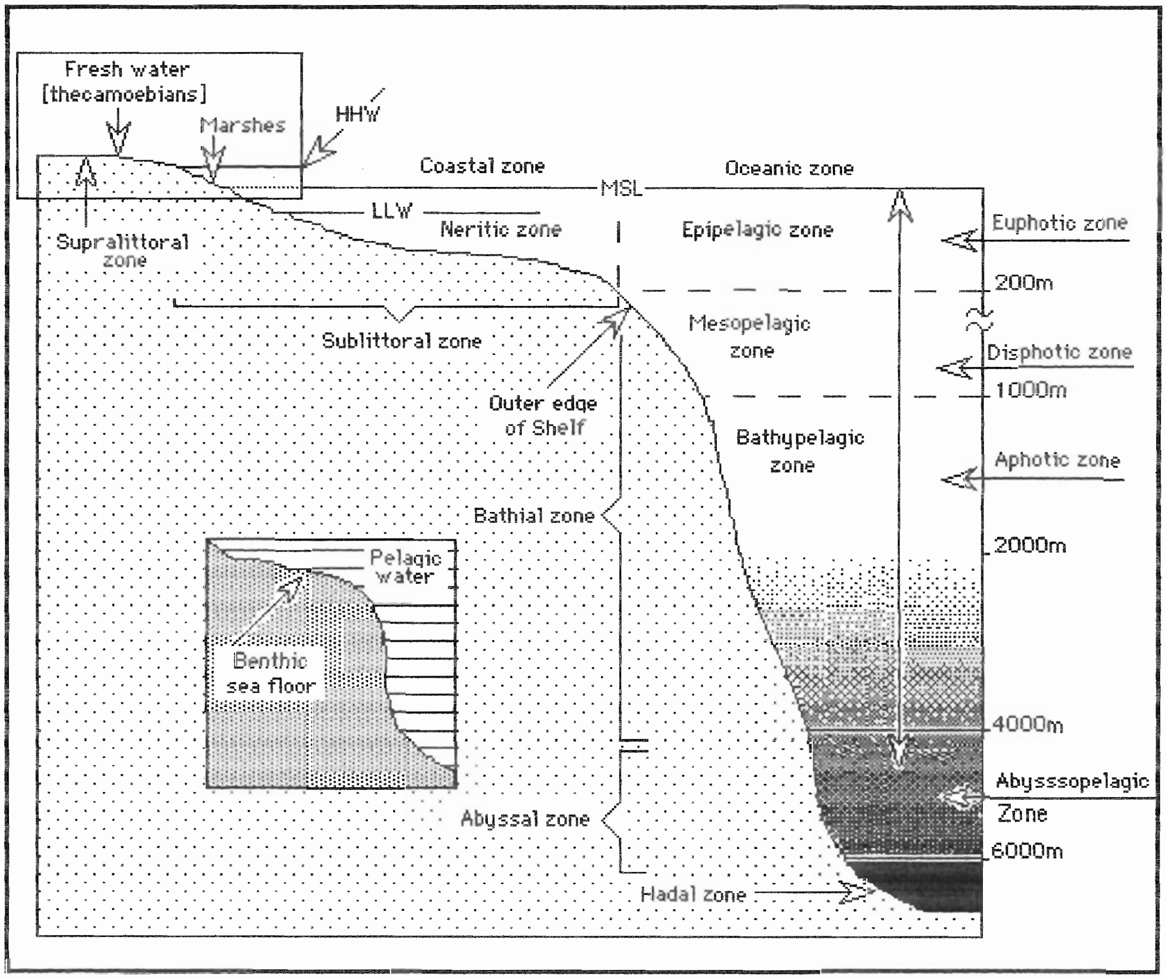
## 5.2 Known ecological significance of faunal assemblages.

The marginal marine environment is located on the terrestrial edge of the continental shelf. Figure 5.1 indicates its relative location with respect to the rest of the ocean basin. This is an area that is very poorly studied.

Fortunately, the organisms occurring in the extremely harsh marginal marine environment require highly specialized adaptations, and seem to have remained almost unchanged since Paleozoic time. A well-known example of this is the brachiopod *Lingula* . This genus lives buried in the swash area, free of competitors, and has remained practically unchanged since the Cambrian.

Traditionally, palynologists alone studied freshwater deposits on the assumption that only spore and pollen had fossilized within this material. Unfortunately, this assumption becomes a reality because palynologists boil their samples in hydrofluoric acid, thus destroying everything except the pollen. Medioli and Scott (1983) showed that thecamoebians could fossilize and be successfully used for paleo-ecological reconstructions in the Holocene. Since then a number of studies have confirmed that thecamoebians are reliable

Figure 5.1 Generalized profile of an ocean bottom. The boxed area at the top left represents the marginal marine environment as defined in this thesis.


Fresh water
[thecamoebians]
Marshes
HHW
Coastal zone
Oceanic zone
MSL
LLW
Neritic zone
Epipelagic zone
Euphotic zone
Supralittoral zone
200m
Mesopelagic zone
Sublittoral zone
Disphotic zone
1000m
Outer edge of Shelf
Bathypelagic zone
Aphotic zone
Bathial zone
2000m
Pelagic water
Benthic sea floor
4000m
Abysssopelagic Zone
Abyssal zone
6000m
Hadal zone

paleo-environmental indicators for deposits ranging from Carboniferous to Quaternary in age (Medioli et al.1990; Wightman et al.; 1993, Thibaudeau 1994; Asioli and Medioli 1994).

Foraminifera, in recent as well as ancient marginal marine environments, occupy a narrow vertical zone, the extent of which is controlled by the tidal regime. This distribution enables the specialist to discriminate the distinct faunal divisions between the assemblages of freshwater and marshes; upper and lower marshes, and estuaries and open marine conditions (Scott and Medioli 1978, 1980, 1986; Scott et al. 1990, 1991). With very few exceptions, salt marshes occupy the vertical interval between HHW and MSL (Wells and Hirvonen 1988). Although many factors may vary considerably within a marsh, the faunal successions are well established and do not change significantly with the latitude, except for the addition of few local forms (Scott and Medioli 1980). Diversity, as a rule, decreases from estuarine to upper marsh environments. "*Trochammina* oligotypic assemblages" (i.e., assemblages characterized by one or two very abundant species) normally dominate the upper marsh environment (Scott et al. 1990).

*Ammobaculites* and *Ammotium* , common forms in the Pyrenean samples, are typical forms of modern estuaries and marshes (Ellison 1972; Scott et al. 1983, 1990). *Ammobaculites* can live within the sediment and tolerates reduced oxygen concentration (Buzas 1974).

## 5.3 Significance of this Study for Sequence Stratigraphy

Although supporting the general stratigraphic concept of cyclicity, traditional micropaleontology has been unable to firmly document complete cycles because open water Foraminifera cannot define marginal marine and terrestrial settings with respect to sea-level (Gaboardi et al. 1994). The missing evidence comes from marginal marine and freshwater fossil assemblages. This inability to define the uppermost limits of transgressive cycles is partly complicated by the marginal marine and freshwater deposits which are situated, within the sequences, in association with, and within, lignite layers (originating from marsh and bog peat deposits). Traditionally, it has been assumed that these lignite deposits are freshwater and devoid of microfossils. This belief stems from inappropriate sample preparation which results in the breakage or destruction of the delicate agglutinated tests from marsh deposits. Consequently, these deposits were either ignored or made barren by improper preparation. In addition, even if the appropriate sample preparation involved had been used, most micropaleontologists would have studied only the >150 mm residue, thus discarding the most important and relevant fraction (63-150 mm) (Schröder et al. 1987). This smaller fraction contains almost all the marginal marine and freshwater microfossils, and is rich in reworked calcareous forms, the material essential for the establishment of paleo-sea-levels. Unless the investigator is familiar with recent marsh forms, they cannot be recognized in the fossil state.

Figure 5.2 (a and c) shows the marginal marine environment during transgressive and regressive events. Sediment is typically deposited landward as the sea transgresses. The marginal marine deposits range in composition from silts and sands to lignites. When a regressive event begins, the marginal marine deposits are the first to be exposed and eroded. The erosional surface left behind usually leaves little or no evidence of the former marsh deposits. Rare preservation of *in situ* peats can yield marginal marine microfossils, as is the case in this study.

## 5.4 Comparison

A small number of foraminiferal genera were identified. The majority of Foraminifera in this study are agglutinated, although significant numbers of reworked, calcareous forms are also present.

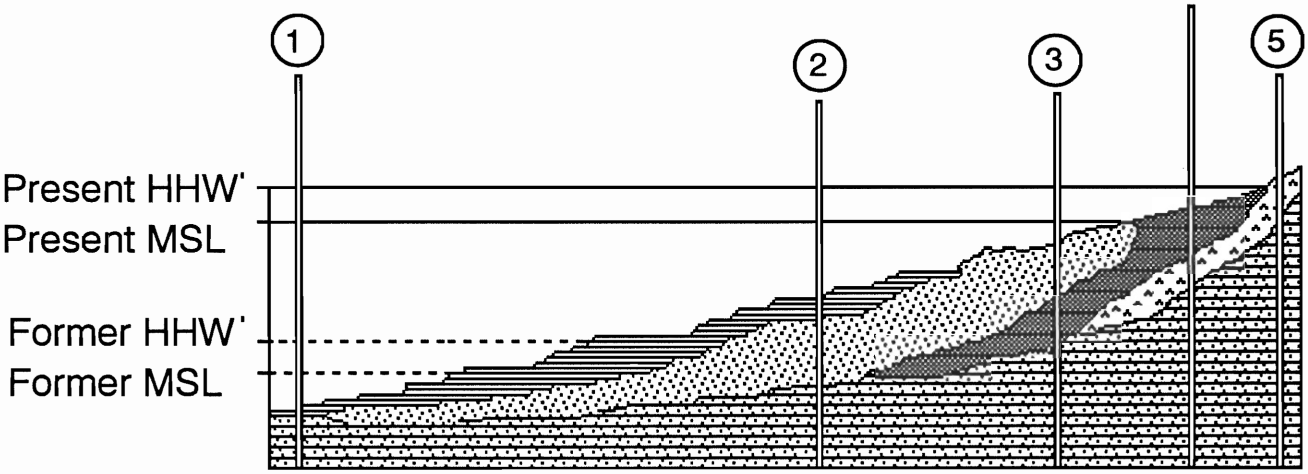
The most common agglutinated forms are the following genera: *Ammobaculites , Trochammina* , and *Haplophragmoides* . Less numerous, but still widespread, are: *Ammotium* , *Ammodiscus* , *Glomospira* ,*Spiroplectammina* ,and *Saccammina* . These same genera, arranged in three different associations, were reported by Wightman et. al. (1994) from the cyclothems in the coal deposits of the Sydney Basin and indicate of various marsh zones. In addition, the modern brackish-water *Polysaccammina* strongly supports the occurrence of marsh deposits among the study samples.

Thecamoebians, which I did not identify except as belonging to this informal group, are common in the samples of La Pasarella, and Ager (I do not discuss the latter as a separate section because of the poor fossil content. Occasionally, however, I will refer to some relevant observations made during a cursory study). As is often the case with fossilized thecamoebians, the associations show a taphonomic bias in favor of agglutinated Arcellaceans (Medioli et al. 1990a). All the forms present in the samples are either difflugiids or centropyxids, the former, usually strongly constructed and the latter having a thin but low-pH-resistant test are commonly coated with a rigid layer of xenosomes. Wall (1983) illustrated similar thecamoebians identifying them as foraminifers and later Medioli et al. (1990b) transferred Wall's forms to thecamoebians. In the Sydney Basin material of Wightman et. al. (1994), the taphonomic bias does not seem to be as strong as in the Pyrenean material or in the Sverdrup Basin material. Wightman et al. (1994) report, in addition to all the forms that Wall and I found, fossilized delicate forms such as *Nebela* and

Figure 5.2

Figure 5.2a Generalized example of a hypothetical coastal area undergoing transgression and accumulating sediments in several different environments. Minimal erosion is occurring inland. Refer to Figure 5.2 b for legend.

# Generalized Sequence of Proximal Deposits In a Coastal Area Undergoing Transgression



← Relatively undisturbed shelf deposits in which, during this cycle, the distribution of foraminiferal assemblages is controlled by water masses.

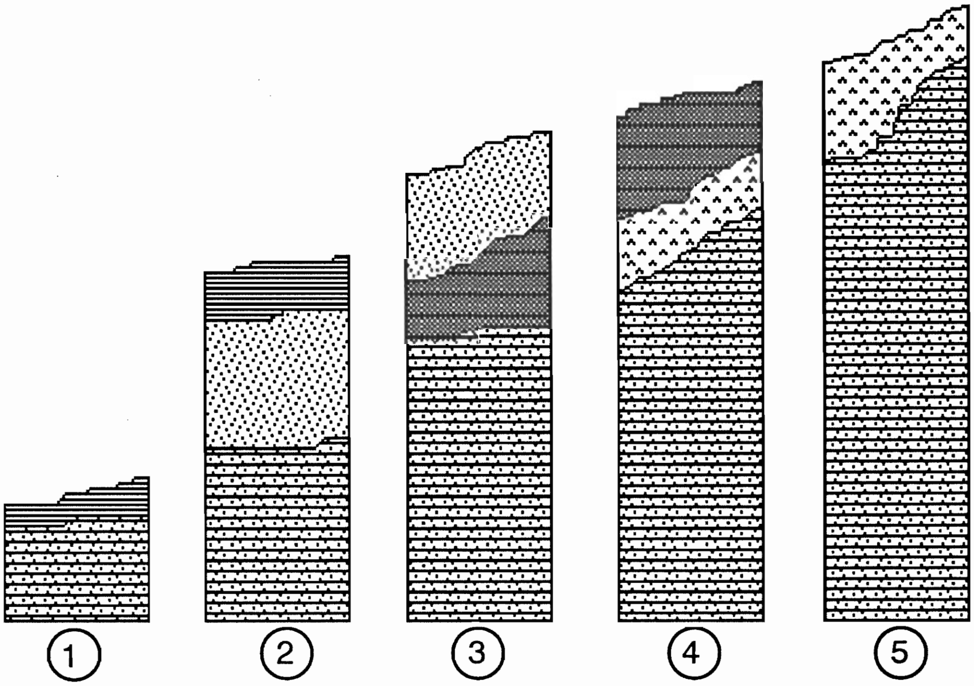


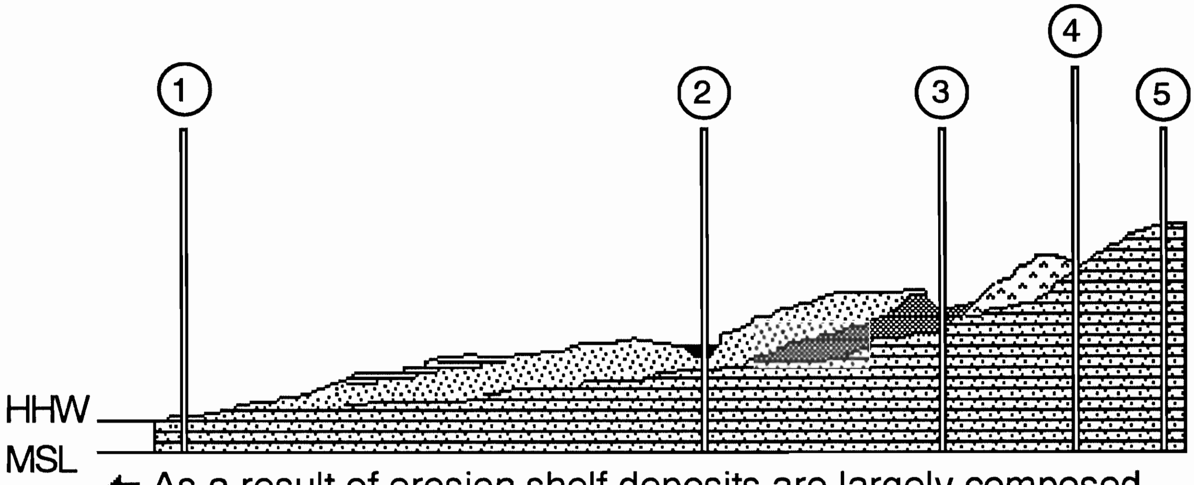
Figure 5.2b Legend explaining symbols used in Figure 5.2a.

LEGEND: The various symbols refer to the fossil content. Lithologies vary from place to place. All deposits are horizontally synchronous and vertically diachronous, becoming younger as they become more proximal.

| | |
|---|---|
| ▨ | Subaerial and freshwater, often containing thecamoebians. |
| ▓ | Marsh and upper tidal deposits, usually dominated by *Trochammina* and *Miliammina.* |
| ░ | Proximal shallow marine deposits dominated by benthic foraminifera, usually devoid of autochthonous planktonic forms. |
| ▤ | Distal shallow marine deposits dominated by benthic foraminifera, occassionally autochthonous planktonics present. |
| ▦ | Undifferentiated sediments deposited and/or eroded during the previous cycles. |

Figure 5.2c Generalized example of a hypothetical coastal area undergoing regression. Erosion inland is at its peak and most of the sediment deposited during the previous transgressive cycle (Figure 5.2a) is reworked and dispersed offshore. Only a few isolated lenses of *in situ* marginal marine material remain.

# Generalized Sequence of Proximal Deposits In a Coastal Area Undergoing Regression



⬅ As a result of erosion shelf deposits are largely composed of reworked materials deposited during the previous transgressive cycle. Foraminiferal assemblages are a mixture of forms actually living in situ and reworked subfossils transported by turbidity currents.

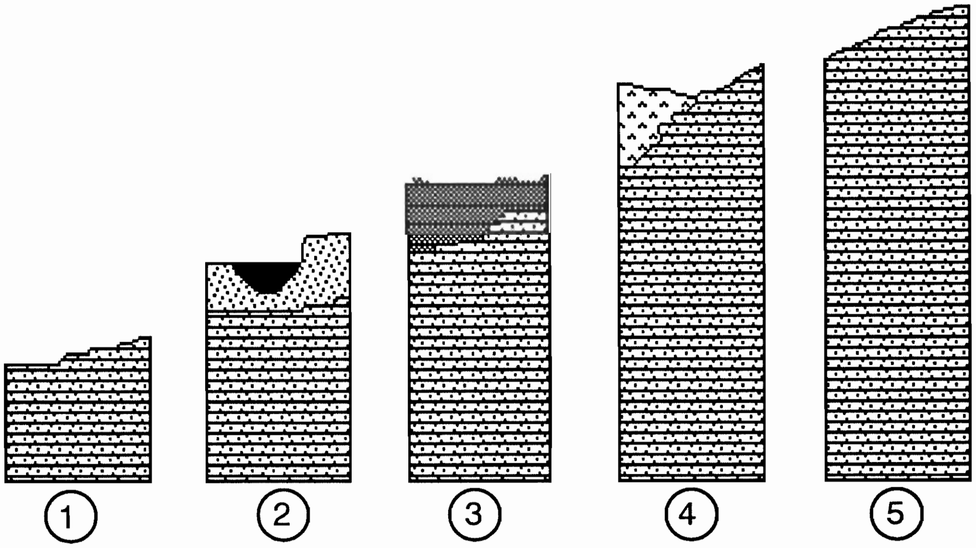


Figure 5.2d Legend explaining symbols used in Figure 5.2c.

# LEGEND: The various symbols refer to fossil content. Lithology may vary from place to place.

| | |
|---|---|
| ▦ | Subaerial and freshwater deposits, often containing thecamoebians. |
| ▒ | Marsh and upper tidal deposits, usually dominated by *Trochammina* and *Miliammina*. |
| ░ | Proximal shallow marine deposits dominated by benthic foraminifera, usually devoid of autochthonous planktonic forms. |
| ▤ | Distal shallow marine deposits dominated by benthic foraminfera, occassionally autochthonous planktonics present. |
| ▥ | Undifferentiated sediments deposited and/or eroded during the previous cycles. |
| ■ | Reworked marsh and/or freshwater bog peat containing a mixture of marsh foraminifera and/or thecamoebians. |

organic (i.e.: non agglutinated) centropyxids so delicately preserved that their specimens nº 6 and 9 (Plate II) clearly show even the animal encystment structure. The lack of taphonomic bias and the extremely delicate processes of fossilization strongly suggest that a very low-energy environment was prevalent during the sedimentation for the Sydney Basin material.

Little exists in common between the reworked component in the Pyrenean material and the other studies because the composition of the reworked material depends on local geology, and not on environmental or physical factors. Little similarities exist between the reworked fractions in the Pyrenees and the Sverdrup Basin with the reworked material in the Sydney Basin. Most of the reworked calcareous fractions in the former basins, of course, is represented by forms that evolved after the Carboniferous.

Calcareous forms from the Pyrenean section are usually in a rather poor state of preservation and, with very few exceptions, they all show evidence of abrasion. Many of the individuals are broken and are difficult or impossible to identify. Practically all of them were deposited outside their natural environments. The presence of Cretaceous planktonic forms such as: *Hedbergella*, *Globotruncana*, *Heterohelix* , *Praeglobotruncana* strongly suggest that Cretaceous material deposited under open-water or oceanic conditions has been reworked into shallow water, mainly intertidal deposits.

Other calcareous forms such as: 1) *Globobulimina* , *Globulina* and *Polymorphina* (which prefer to inhabit the nepheloid layer); *Marginulina, Globobulimina* , *Epistomina* , *Cuvillierina* , *Pararotalia* , *Gavelinella* , *Eoguttulina* (the last two of which became extinct in Upper Cretaceous), also support the idea of extensive reworking of older, deeper water deposits (Loeblich and Tappan 1964, 1988).

The scarcity of previous work restricts my comparisons to the studies of ancient material by Wall (1983), Thibaudeau (1993), and Wightman et al. (1994), and a number of studies on recent material (Scott and Medioli 1978a, 1980b, 1986; Scott et al. 1990, 1991). The similarity between the lower Tertiary marginal marine assemblages of this study in the Pyrenees, the Cretaceous ones studied by Wall (1983) in western Canada and in the Sverdrup Basin, the Carboniferous Sydney Basin ones studied by Wightman et al. (1994) and Thibaudeau (1993) and the recent ones studied by Scott and Medioli (1978, 1980, 1986) and Scott et al. (1990, 1991) are remarkable. Despite minor faunal differences which appear to be of local nature, all these studies, spanning more than 300 million years of marginal marine sedimentation, suggest that *Ammobaculites* , *Ammotium* , *Trochammina* and arcellaceans are the most significant elements of the associations.

Equally remarkable and significant are the differences between the various studies. The recent material represent the most accurate and detailed information available, to the point that it has become the standard for a number of ongoing studies on marginal marine phenomena. My material supplies signals that are substantially more confused. Surprisingly, however, the Carboniferous material of Sydney Basin as well as that of the Sverdrup Basin, despite the age and the taphonomic problems, is more directly comparable to the modern material than the material of the area discussed here. The reasons for this apparently contradictory situation probably can be found in the geologic history of the areas. In the Sydney and Sverdrup Basins the sedimentation appears to be essentially uninterrupted with a continuous pulsating subsidence which creates small basins in which sediment accumulates until the area emerges and deposition of fresh water material begins. The weight of the accumulated deposit causes gradual subsidence and the cycle is repeated.

Well-known and thoroughly studied examples of this mechanism still in action are those of the Mississippi delta (USA) and the Po delta (Northern Italy) where gradual subsidence is the dominant factor affecting relative sea level.

The nature of the transgression-regression cycles in the Pyrenees is of an entirely different nature. The isostatic sea-level changes brought about sudden changes from transgression to regression, thus sharply interrupting the cycles and causing reworking of older sediments during regressive events. As illustrated in Figure 5.2c, the marginal-marine material deposited during transgressions is almost entirely destroyed during regressions. A few, discontinuous lignite lenses have survived the erosion of regressions and represent all that is left of the marginal marine deposits. Mountain-building was occurring to the north of the area, and while isostatic transgressions and regressions were occurring, the Pyrenees were uplifted. Consequently the net movement of the entire area is regressive, although the coastal region, the object of this study, underwent small-scale transgressions and regressions probably due to totally independent eustatic sea-level changes.

The constant supply of reworked Cretaceous material in my samples can be explained by this complex interaction between uplifting and eustatic sea-level changes. Some of the lower deeper water Tertiary material might also be reworked as well, but probably from nearby deposits originating from an earlier isostatic cycle.

## 5.6 Summary

The discovery of microfossil assemblages in peat lenses will enable sequence stratigraphers working in the northeastern Pyrenees to establish a number of fixed paleo-sea level points upon which they can build a hierarchy of sedimentary cycles. It also allows much better paleoenvironmental resolution of various deposits that had previously been either ignored or incorrectly classified.

# CHAPTER 6 CONCLUSIONS

Contrary to most of the literature, the foraminiferal assemblages in the Upper Cretaceous to Eocene strata of the south-central Pyrenees indicate that HHW can indeed be firmly established even in cyclic transgressive and regressive deposits. In conjunction with elevation data, this paleontological information can determine sea-level points specifically throughout the Pyrenees, and ultimately in sedimentary deposits worldwide. Micropaleontological studies of this kind will help establish whether high orders of cyclicity exist within the classic and well-documented sequence stratigraphy of the study area.

In addition to solving the paleo sea-level problems, the discovery of fossil marginal-marine and freshwater assemblages has profound biostratigraphic as well as taxonomic implications extending well beyond the Pyrenees.

Marginal marine and estuarine foraminifera, as well as fresh water thecamoebians, have not been previously reported in fossil lignite deposits. Consequently, their stratigraphic distribution is very poorly documented, and for some of the genera discussed in this thesis, such distribution must be extended back several tens of million of years. Many of the lignite layers, once thought to be freshwater, are now firmly established to be marine because they contain foraminifera. Furthermore, accurate former sea levels are determinable and can calibrate the sequence stratigraphic models of this region. Because this region is one of the most famous localities in modern sequence stratigraphy, the use of micropaleontological study such the present on is a significant contribution to the existing database.

The presence of reworked calcareous foraminifera can also provide evidence of the tectonic, eustatic, and related surface processes at work in the region during the uplifting of the Pyrenees.

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# APPENDIX A

# SYSTEMATIC TAXONOMY AND BIBLIOGRAPHY

# SYSTEMATIC PALEONTOLOGY

My systematic arrangement of genera follows the classification of Loeblich and Tappan (1964) which has been the micropaleontological standard for the last thirty years.

Recently the same authors have changed their classification in a monograph (Loeblich & Tappan, 1988) which has not received wide acceptance by the scientific community. The result is the that high rank systematic of foraminifera, which had been so uncharacteristically stable for over 20 years, has become controversial and very much a matter of choice. Consequently, I have decided to adopt the 1964 classification up to the level of superfamily, ignoring everything above it.

Bibliographic references are difficult to verify accurately because of the antiquity and rarity of some of the fundamental publications. Some of the most important papers were published between 1772 and the 1860s. In those days the International Code of Zoological Nomenclature was not in effect and the publishers were not consistent with respect to the date of publication and pagination of a document. Also authors often published the same paper, or a slightly different version of it, more than once in different journals. In some cases, when checking or retrieving a piece of information was impossible, I put a **(?)** after or instead of it.

Stratigraphic as well as geographic distributions are those recorded in the previous literature. Fossil marginal marine deposits are poorly known and it is to be expected that this study will modify some of them.

To avoid endless repetition, I divided this appendix into two parts representing the major natural foraminiferal taxa:

1) Part I: agglutinated forms.
2) Part II: calcareous forms.

Unless otherwise stated, all forms are free-living (i.e., not attached to the substratum).

| | |
|---|---|
| **OD** | **ORIGINAL DESIGNATION** |
| **SD** | **SUBSEQUENT DESIGNATION** |
| **NOMEN CORRECTUM** | **= IMPROVED NAME: i.e., derived by valid emendation of pre-existing taxon.** |
| **NOMEN TRANSLATUM** | **= TRANSFERRED NAMES: i.e., necessary or arbitrary emendations not covered by ICZN regulations.** |

Table A1. List of abbreviations used throughout this appendix.

# PART I - Agglutinated forms

## Superfamily AMMODISCACEA Reuss, 1862, p. (?)

["nomen correctum" by Loeblich & Tappan, 1961, p.275, from Ammodiscoidea Chapman, Park & Collins, 1934, p.556]

Test composed of xenosomes held together by variable cement.
**Stratigraphic distribution**: Cambrian - Recent.

## Family SACCAMMINIIDAE Brady, 1884, p.64

["nomen correctum" by Eimer & Flckert, 1899, p. 671 from family Saccamminina Lankester, 1885, p. 846; "nomen translatum" by Loeblich & Tappan, 1964, p.c194 from subfamily Saccammininae Brady, 1884, p. 64]

Test sack-like; aperture single or multiple, often on a small collar.
**Stratigraphic distribution**: Ordovician - Recent.

## Subfamily SACCAMMININAE Brady, 1884, p. 64

[Saccammininae Brady, 1884, p. 64]

Test with a definite aperture.
**Stratigraphic distribution**: Ordovician - Recent.

## Genus Saccammina SARS in: Carpenter, 1869, p.61

[Type species: *Saccammina sphaerica* Brady, 1871, p. 183; SD by Cushman, 1928, p.72]

Test unilocular, globular; wal coarsely and firmly cemented; aperture rounded, at times on a blunt neck.
**Stratigraphic distribution**: Silurian - Recent.
**Geographic distribution**: Cosmopolitan.

## Subfamily THURAMMININAE Mikluko-Maklay, 1963, p. 153

[Thuramminiinae Mikluko-Maklay, 1963, p. 153]

Test large, globular, rarely attached, and at times with cylindrical projections on the surface; apertures numerous either on surface or on projections.
**Stratigraphic distribution**: Holocene.

## Genus Pseudothurammina SCOTT, MEDIOLI & WILLIAMSON, 1981, p. 126

[Type species: *Thurammina limnetis* , Scott & Medioli, 1980, p. 43]

Test large, globular, rarely attached, with up to five irregularprojections; wall flexible due to much organic cement; aperture at open end of projections.
**Stratigraphic distribution**: Holocene.
**Geographic distribution**: Americas.

### Subfamily POLYSACCAMMININAE Loeblich & Tappan, 1984, p.5

[Polysaccamminidae Loeblich & Tappan, 1984, p.5]

Test consisting of a linear series of irregular, round chambers; organic inner layer; aperture terminal at times slightly elevated. Lives nearshore in brackish water.

**Stratigraphic distribution**: Holocene.

### Genus Polysaccammina SCOTT, 1976, p.316

[Type species: *Polysaccammina ipohalina* Scott, 1976, p.316; OD]

Test with irregular globular chambers increasing in size with growth and arranged in a roughly uniserial/biserial or irregular series; wall agglutinating fine sand and with an inner organic layer; aperture terminal, round and slightly projected.

**Stratigraphic distribution**: Holocene.
**Geographic distribution**: Americas.

### Family AMMODISCIDAE Reuss, 1862, p.365.

["nomen correctum" by Rhumbler, 1895, p. 83 from Ammodiscinea Reuss 1862, p.365]

Test free or attached, proloculus followed by nonseptate enrolled tubular second chamber, aperture formed by open end of tube.
**Stratigraphic distribution**: Silurian - Recent.

### Subfamily AMMODISCINAE Reuss, 1862, p.365

["nomen translatum"by Rhumbler, 1904, p. 275
from Ammodiscinea Reuss, l862, p.365)]

Test planispiral, or irregularly coiled.
**Stratigraphic distribution**: Silurian - Recent.

### Genus *Ammodiscus* REUSS, 1862, p. 365

[Type species: *Ammodiscus infimus* BORNEMANN, 1874, p. 725;
SD by Loeblich & Tappan, 1954, p. 306]

Test discoidal, proloculus followed by a planispirally or transversally enrolled tubular chamber with no internal partitions; aperture at open end of tube.
**Stratigraphic distribution**: Silurian - Recent.
**Geographic distribution**: cosmopolitan.

### Genus *Glomospira* RZEHAK 1885, p. 126

[Type species: Trochammina *squamata* Jones & Parker, var.
*gordialis* Jones & Parker, 1860, p. 304; OD]

Test similar to *Ammodiscus,* but coiling streptospiral or irregular; aperture at end of tube.
**Stratigraphic distribution**: Silurian - Recent.
**Geographic distribution**: cosmopolitan.

### Subfamily TOLYPAMMININAE Cushman 1928, p.103

[Tolypammininae Cushman 1928, p.103 ]

Test attached, proloculus followed by an irregular second chamber.

**Stratigraphic distribution**: Silurian - Recent.

### Genus Lituotuba RHUMBLER, 1895, p.83

[Type species: *Serpula filum* Schmid, 1867, p. 583; SD by Schellwien, 1898, p.265]

Test free or attafched, early stage irregularly coiled unchambered tube, later uncoiling; aperture at end of tube.

**Stratigraphic distribution**: Silurian - Recent.

**Geographic distribution**: cosmopolitan.

### Superfamily LITUOLACEA de Blainville, 1825, p. (?)

["nomen correctum" by Loeblich & Tappan, 1961, p. 277 from Lituolidea Glaessner 1945, p. 93]

Multilocular, coiled spirally or uncoiled or straight, chambers may be arranged biserially or triserially. Wall siliceous or, more often, agglutinating a variety of xenosomes. Aperture single or multiple.

**Stratigraphic distribution**: Mississippian - Recent.

### Family LITUOLIDAE de Blainville, 1825, p. 380

["nomen correctum" by Schulze, 1875, p.28, from family
Lituacea and Lituacés de Blainville, 1825, p. 380]

Test free or attached, early stage coiled, later stages uncoiled, irregular or annular; wall with calcareous cement or microgranular calcite; aperture single or multiple.

**Stratigraphic distribution**: Carboniferous - Recent.

### Family HORMOSINIDAE Haeckel, 1894, p. 185

["nomen correctum" by Loeblich & Tappan, 1964, p. c185 from Hormosinida Haeckel, 1894, p.185]

Chambers arranged in straight or curved series; aperture terminal.

**Stratigraphic distribution**: Mississippian - Recent.

### Subfamily HORMOSININAE Haeckel 1894, p. 185

["nomen translatum" by Loeblich & Tappan, 1964, p. c185 from family Hormosinida Haeckel, 1894, p.185]

Chambers in rectilinear series; aperture single or multiple.

**Stratigraphic distribution**: Mississippian - Recent.

### Genus *Reophax* de MONTFORT, 1808, p.331

[Type species: *Reophax scorpiurus* , de Montfort, 1808, p.331; OD]

Test elongate, often arcuate; chambers increasing in size as added; sutures nearly horizontal; aperture on a terminal neck.

**Stratigraphic distribution**: Mississippian - Recent.

**Geographic distribution**: cosmopolitan.

## Subfamily HAPLOPHRAGMOIDINAE Maync, 1952. p.43

[Haplophragmoidinae Maync, 1952, p.43]

Test coiled, interior simple, labyrinthic, no alveolar hypodermis.
**Stratigraphic distribution**: Carboniferous - Recent.

### Genus *Haplophragmoides* CUSHMAN, 1910, p. 99

[Type species: *Nonionina canariensis* d'Orbigny 1839, p. 128; OD]

Test planispirally coiled, involute; aperture simple, at the base of the last chamber.
**Stratigraphic distribution**: Carboniferous - Recent.
**Geographic distribution**: cosmopolitan.

## Subfamily LITUOLINAE de Blainville, 1825, p. 381

["nomen translatum" by Brady, 1884, p. 65 from
family Lituacea de Blainville, 1825, p. 381]

Test a coiled spire uncoiling in adult, interior of chambers simple.
**Stratigraphic distribution**: Carboniferous - Recent.

### Genus *Ammobaculites* CUSHMAN, 1910, p. 114

[Type species: *Spirolina agglutinans* d'Orbigny, 1846, p. 137; OD].

Test with early portion coiled, later rectilinear, rounded in section; aperture terminal, rounded. [*Ammobaculites* differs from *Lituola* in having a single round aperture].
**Stratigraphic distribution**: Carboniferous - Recent.
**Geographic distribution**: cosmopolitan.

### Genus *Ammotium* LOEBLICH & TAPPAN, 1953, p.33

[Type Species: *Lituola cassis* Parker <u>in</u>: Dawson 1870, p.177; OD]

Test medium-sized, auriculate, strongly compressed. Early portion planispiral, evolute, with 10 to 12 chambers; later three to four chambers uncoiled and rapidly increasing in size; sutures indistinct; wall relatively thin, with much cement, surface smooth. Aperture terminal, elliptical, elevated in some specimens.
**Stratigraphic distribution**: Upper Cretaceous - Recent.
**Geographic distribution**: Atlantic, Pacific, Western Canada.

## Family TEXTULARIIDAE Ehrenberg, 1838, p. 200

["nomen correctum" by Chapman, 1900, p. 9, from family Textularina, Ehrenberg, 1838, p. 200]

Test free or attached, may start coiled then become biserial or uniserial; aperture single or multiple, basal or teminal.
**Stratigraphic distribution**: Carboniferous - Recent.

### Subfamily SPIROPLECTAMMININAE Cushman, 1927, p. 21

[Spiroplectammininae Cushman, 1927, p. 21]

Early stage planispiral, later biserial.

**Stratigraphic distribution**: Carboniferous - Recent.

### Genus *Spiroplectammina* CUSHMAN, 1927, p. 23

[Type species: *Textularia agglutinans* d'Orbigny var. *biformis*, Parker & Jones, 1865, p. 370; OD]

Test elongate, early stage planispiralli coiled, later biserial; aperture a low arch at inner margin of last chamber.

**Stratigraphic distribution**: Carboniferous - Recent.

**Geographic distribution**: cosmopolitan.

### Genus *Vulvulina* d'ORBIGNY 1826, p.264

[Type species: *Vulvulina capreolus* d'Orbigny 1826, p.264; SD by Cushman, 1928, p. 118]

Test flaring or elongate lozange-shaped, lateral margin acute; chambers increasing rapidly in size, early stage may be coiled, later biserial; aperture a narrow terminal slit.

**Stratigraphic distribution**: Upper Cretaceous - Recent.

**Geographic distribution**: cosmopolitan.

### Family TROCHAMMINIDAE Schwager, 1877, p. 21

["nomen correctum" by Lister in: Lankester, 1903, p.142 from family Trochamminidea Schwager 1877, p. 21]

Test free or attached, trochospiral; aperture single or multiple.

**Stratigraphic distribution**: Carboniferous - Recent.

### Subfamily TROCHAMMININAE Schwager, 1877, p. 21

["nomen correctum" by Brady 1884, p. 66 from family Trochamminidea Schwager 1877, p. 21]

Test free or attached, trochospiral; interior simple.

**Stratigraphic distribution**: Carboniferous - Recent.

### Genus *Trochammina* PARKER & JONES, 1859, p. 374

[Type species: *Nautilus inflatus* Montague, 1808, p.81; OD]

Test trochospiral; wall with organic cement; chambers globular to ovate; aperture forming an arched slit at the inner margin of the ventral side of the last chamber.

**Stratigraphic distribution**: Carboniferous - Recent.

**Geographic distribution**: cosmopolitan.

### Family ATAXOPHRAGMIIDAE Schwager, 1877, p.22

["nomen correctum" by Galloway & Heminway 1941, p 320 from family Ataxophragmidea Schwager, 1877, p.22]

Test trochospiral, uncoiling or uniserial; aperture a basal slit in the early stage, later may become terminal, cribrate or toothed.
**Stratigraphic distribution**: Pennsylvanian - Recent.

### Subfamily VERNEUILININAE Cushman, 1911, p. 52

[Verneuilininae Cushman, 1911, P. 52]

Triserial in early stage, later biserial or uniserial in some forms; number of chambers to whorl tending to decrease with growth; aperture simple.
**Stratigraphic distribution**: Upper Triassic - Recent.

### Genus *Verneuilinoides* LOEBLICH & TAPPAN, 1949, p. 91

[Type species: *Verneuilina schizea* Cushman & Alexander, 1930, p. 9; OD].

Test elongate, triserial throughout, with rounded angles; chambers increasing in size toward apertural end; sutures depressed; aperture an arch at the inner margin of the last chamber.
**Stratigraphic distribution**: Jurassic - Cretaceous.
**Geographic distribution**: North America and Europe.

## PART II - Calcareous forms

### Superfamily MILIOLACEA Ehrenberg, 1839, p. (?)

["nomen correctum" by Loeblich & Tappan, 1961, p. 289, from superfamily Miliolidea Glaessner, 1945, P. 116]

Wall porcelanous, imperforate, may have adventitious material attached to the exterior; aperture terminal, single, cribrate or variously modified.
**Stratigraphic distribution**: Carboniferous - Recent..

### Family MILIOLIDAE Ehrenberg, 1839, p. 120

["nomen correctum" by d'Orbigny, 1839, p. xxxix, 160, from family Miliolina Ehrenberg, 1839, p. 120]

Test typically with 2 chambers per whorl, arranged in varying planes around a vertical axis, may become rectilinear or involute; aperture terminal, simple, cribrate or with a tooth.
**Stratigraphic distribution**: Jurassic - Recent.

### Subfamily QUINQUELOCULININAE Cushman, 1917, p. 41

[Quinqueloculininae Cushman, 1917, p. 41]

Aperture with various modifications of a bifid tooth.
**Stratigraphic distribution**: Jurassic - Recent.

### Genus *Quinqueloculina* d'ORBIGNY, 1826, p. 301

[Type species: *Serpula seminulum* Linné, 1758, p. 786; SD by Parker & Jones, 1857, p. 480]

Test coi;led, with chambersalternating in 5 planes 72º apart, so that 3 chambers are visible from one side and 4 from the other side; aperture terminal, rounded with simple or bifid tooth.

**Stratigraphic distribution**: Jurassic - Recent.

**Geographic distribution**: cosmopolitan.

### Superfamily NODOSARIACEA Ehrenberg, 1838, p. (?)

["nomen correctum" by Loeblich & Tappan, 1961, p. 295 from superfamily Nodosariidea Nørvang, 1957, p. 23, "nomen translatum" by family Nodosarina Ehrenberg, 1838]

Test wall finely perforate; chambers planispirally coiled or uncoiled, or straight, or coiled about longitudinal axis; aperture peripheral or terminal, typically radiate but may be slit-like or rounded.

**Stratigraphic distribution**: Permian - Recent.

### Family NODOSARIIDAE Ehrenberg, 1838, p. 200

["nomen correctum" by Lister in: Lankester 1903, p. 144 from family Nodosarina EHRENBERG 1838, p. 200]

Test with one or more chambers in planispiral, biserial, uncoiling, curved or straight series; aperture simple, slitlike or radiate, may have an apertural chamberlet or an elongate neck.

**Stratigraphic distribution**: Permian - Recent.

### Subfamily NODOSARIINAE Ehrenberg, 1838, 838

["nomen correctum": by Chapman, 1900, p. 30 from subfamily Nodosaridea REUSS, 1862 p. 334; "nomen translatum" by Chapman, 1900, p. 30 from family Nodosarina Ehrenberg, p. 838]

Test with one or more chambers arranged in straight, arcuate or enrolled series; aperture terminal, rounded or radiate.

**Stratigraphic distribution**: Permian - Recent.

### Genus *Marginulina* d'ORBIGNY 1826, p.258

[Type species: *Marginulina raphanus*, d'Orbigny 1826, p.258; SD by Deshayes, 1830, p. 416]

Early portion slightly coiled, later rectilinear; sutures oblique; aperture slightly protruding from dorsal angle.

**Stratigraphic distribution**: Triassic - Recent.

**Geographic distribution**: cosmopolitan.

### Family POLYMORPHINIDAE d'Orbigny, 1839, p. xxxix, 131

[Polymorphinidae d'Orbigny, in de la Sagra, 1839, p. xxxix, 131].

Test multilocular, biserial or uniserial, chambers in spiral or sigmoidal coil about longitudinal axis; apertures all terminal, radiate.

**Stratigraphic distribution**: Triassic - Recent.

## Subfamily POLYMORPHININAE d'Orbigny1839, p. (?)

["nomen translatum" by Brady, 1881, p. 44 from family Polymorphinidae d'Orbigny, 1839].

Test with chambers arranged in spiral, sigmoidal, biserial or asymmetrically alternating series; aperture terminal, radiate.
**Stratigraphic distribution**: Triassic - Recent.

### Genus *Polymorphina* d'ORBIGNY, 1826, p. 265

[Type species: *Polymorphina burdigalensis;* d'Orbigny, 1826, p. 265
SD by Galloway & Wissler, 1927 p. 53]

Test elongate, somewhat compressed, commonly twisted; chambers biserial, early ones may be somewhat sigmoid.
**Stratigraphic distribution**: Paleocene - Recent.
**Geographic distribution**: cosmopolitan.

### Genus *Eoguttulina* CUSHMAN & OZAWA 1930, p. 16

[Type species: *Eoguttulina anglica* , Cushman & Ozawa, 1930, p. 16, OD]

Test with chambers arranged in a long spiral series in planes less than 90º apart.
**Stratigraphic distribution**: Jurassic - Upper Cretaceous
**Geographic distribution**: cosmopolitan.

### Genus *Guttulina* d'ORBIGNY in: de la Sagra, 1839, p.132

[Type species: *Polymorphina* (Guttuline) *communis* d'Orbigny, 1826; SD by Galloway & Wissler, 1927, p.56].

Test ovate to elongate; inflated chambers added, in quinqueloculine style,144º apart, each successive chamber extending farther from base ; aperture radiate.
**Stratigraphic distribution**: Jurassic - Recent.
**Geographic distribution**: cosmopolitan.

### Genus Globulina d'ORBIGNY 1839, p. 134

[Type species: *Polymorphina (Globuline) gibba* , d'Orbigny, 1825, p. 266; SD by Cushman, 1927, p.189

Test subovate, chambers strongly overlapping 144º apart; sutures flush; aperture radiatem but commonly obscured by fistolous growth.
**Stratigraphic distribution**: Upper Jurassic - Recent.
**Geographic distribution**: cosmopolitan.

## Superfamily BULIMINACEA Jones 1875, p. (?)

["nomen correctum": by Loeblich & Tappan 1961, p. 299 from superfamily Buliminidea Glaessner 1945, p. 134]

Test usually an elongate spiral but can become biserial or uniserial; wall perforate often highly ornamented; aperture loop-shaped but in some forms can develop a neck or become cribrate.
**Stratigraphic distribution**: Upper Triassic - Recent.

### Family TURRILINIDAE Cushman 1927, p. 65

["nomen translatum" by Loeblich & Tappan, 1961a, p. 300, from subfamily Turrilininae, Cushman, 1927, p. 65]

Test high trochospiral with mopre than 3 chambers per whorl, or biserial; aperture may be grooved.
**Stratigraphic distribution**: Middle Jurassic - Recent.

### Subfamily TURRILININAE Cushman 1927, p. 65

[Subfamily Turrilininae Cushman 1927, p. 65]

Test high trochospiral with mopre than 3 chambers per whorl; aperture loop-shaped, in face of last formed chamber.
**Stratigraphic distribution**: Middle Jurassic - Recent.

### Genus Rectobulimina MARIE 1956, p. b249

[Type species: *Rectobulimina carpentierae* Marie 1956, p. b249; OD]

Test triserial evolving to biserial and uniserial; aperture terminal, rounded to oval, flush with surface.
**Stratigraphic distribution**: Upper Cretaceous - Recent.
**Geographic distribution**: cosmopolitan.

### Family BULIMINIDAE Jones 1875, p. 320

["nomen correctum" Eimer & Fickert, 1899, p. 680, from family Buliminida, Jones 1875, p. 320]

Test high trochospiral with not more than 3 chambers per whorl, may be reduced to biserial; aperture a loop on apertural face or indistinct.
**Stratigraphic distribution**: Paleocene - Recent.

### Genus Globobulimina CUSHMAN 1927, p.67

[Type species: *Globobulimina pacifica* , Cushman 1927, p.67; OD]

Test globular to ovate, chambers triserial and strongly overlapping; aperture terminal, loop-shaped with often with a fan-like lip.
**Stratigraphic distribution**: Paleocene - Recent.
**Geographic distribution**: cosmopolitan.

### Superfamily ROTALIACEA Ehrenberg, 1839, p. (?)

["nomen correctum" by Loeblich & Tappan, 1961 p. 303 from superfamily Rotalidea Glaessner, 1945 p. 143]

Test free; without primary aperture or large pores, or with pores on apertural face or elsewhere, and may have ventral intercameral foramina.
**Stratigraphic distribution**: Upper Cretaceous - Recent.

## Family ROTALIIDAE Ehrenberg, 1839, p. 201

["nomen correctum" by. Chapman, 1900 p. 10 from family Rotalina
Ehrenberg 1839 table opposite p. 201]

Test trochospiral throughout; with radial canals or fissures and intraseptal and subsutural canals.
**Stratigraphic distribution**: Upper Cretaceous - Recent.

### Subfamily ROTALIINAE Ehrenberg, 1839, p. (?)

["nomen correctum" by. Chapman, 1900, p. 11 from subfamily
Rotalida Schultze, 1854 p. 52]

Test trochospiral, all external openings, except perforations, on umbilical side; with radial canals or fissures or umbilical cavities.
**Stratigraphic distribution**: Upper Cretaceous - Recent.

### Genus *Pararotalia* Y. LE CALVEZ, 1949, p 32

[Type species: *Rotalia inermis* Terquem, 1882, p.68; OD]

Test rotalliid in structure, smooth or variously ornamented with large solid spines or fine scattered spines or nodes; aperture comma-shaped or slit-like parallel to the base of the last chamber.
**Stratigraphic distribution**: Upper Cretaceous - Recent.
**Geographic distribution**: cosmopolitan.

### Subfamily CUVILLIERININAE Loeblich & Tappan 1964, p.c614

[Cuvilliericninae Loeblich & Tappan 1964, p.c614]

Test trochospiral to nearly planispiral; both sides with similar ornamentation.
**Stratigraphic distribution**: Upper Cretaceous - Miocene

### Genus Cuvillierina DEBOURLE 1955, p. 55

[Type species: *Cuvillierina eocenica* , Debourle 1955, p. 55, OD]

Test planispiral, slighty asymmetrical, surface strongly ornamented; aperture at nase of last chamber.
**Stratigraphic distribution**: Eocene.
**Geographic distribution**: cosmopolitan.

## Family ELPHIDIIDAE Galloway, 1933, p.265

["nomen translatum" by Sigal <u>in</u>: Piveteau, 1952, p. 240
from subfamily Elphidiinae Galloway, 1933, p. 265]

Test planispiral, trochospiral, or uncoiling; sutural canal system opening into single or double row of sutural pores; wall perforate, radial in structure; aperture ventral, single or multiple, or areal.
**Stratigraphic distribution**: Paleocene - Recent.

## Subfamily ELPHIDIINAE Galloway, 1933, p. 265

[Elphidiinae. Galloway, 1933, p. 265]

Test planispiral and symmetrical, at least in adult, may uncoil in later stages, with sutural pores and retral processes projecting across sutures; aperture consisting of ventral or areal pores or both.
**Stratigraphic distribution**: Paleocene - Recent.

## Genus *Elphidium* DE MONTFORT, 1808, p. 14

[Type species: *Nautilus macellus* Fichtel & Moll var. b
Fichtel & Moll1798, p. 66; OD]

Test planispiral, bilaterally symmetrical, involute; chambers numerous; sutures distinct with numerous retral processes; apertures one or more at the base of the last chamber.
[Habitat shallow water or tide pools on sandy or shelly bottoms, with algae, radiating pseudopodia binding together a mass of sand to prevent dislodging during moderate turbulence.]
**Stratigraphic distribution**: Lower Eocene - Recent.
**Geographic distribution**: cosmopolitan.

## Family CIBICIDIDAE Cushman, 1927a, p.93

["nomen translatum" by Chapman, Parr & Collins, 1934,
p. 556 from subfamily Cibicidinae Cushman, 1927a, p.93]

Test free or attached, trochospiral to nearly planispiral, or spreading laterally, irregular or cyclical; wall coarsely perforate; aperture ventral often extending onto spiral side; and peripheral supplementary apertures may occur.
**Stratigraphic distribution**: Cretaceous - Recent.

## Subfamily CIBICIDINAE Cushman, 1927a, p.93

[Cibicidinae Cushman 1927a, p. 93]

Test attached by spiral side; primary aperture equatorial, may extend onto spiral side, advanced forms may have multiple aperture. **Stratigraphic distribution**: Cretaceous - Recent.

## Genus *Cibicides* DE MONTFORT, 1808, p. 122

[Type species: *Cibicides refulgens* de Montfort, 1808, p. 122; OD]

Test attached; planoconvex, trochospiral, periphery angular, with nonporous keel; wall coarsely perforate on spiral side, finely perforate on umbilical side, apertural face nonporous; aperture a low ventral opening with narrow lip, may extend along spiral suture on spiral side.
**Stratigraphic distribution**: Cretaceous - Recent.
**Geographic distribution**: cosmopolitan.

### Superfamily CASSIDULINACEA d'Orbigny, 1839, p. (?)

[nomen translatum by Loeblich & Tappan, 1961, p. 313 from family Cassidulinidea d'Orbigny, 1839]

Test enrolled planispirally or trochospirally; wall perforate; aperture slit-like or multiple.
**Stratigraphic distribution**: Upper Triassic - Recent.

### Superfamily GLOBIGERINACEA Carpenter, Parker & Jones 1862 p. (?)

["nomen correctum" by Loeblich & Tappan, 1961, p. 307, from superfamily Globigerinidea, Morozova, 1957, p. 1110]

Test planispiral or trochospiral or modified from either; chambers globular, may be compressed or otherwise modified; wall distinctly perforate, apertures in a variety of positions, rarely multiple.
Habit planktonic.
**Stratigraphic distribution**: Middle Jurassic - Recent.

### Family HETEROHELICIDAE Cushman 1927a p.59

[Heterohelicidae Cushman 1927a p.59]

Early stage trochospiral, planispiral, biserial or triserial; aperture ventral or may be terminal in biseriual and triserial forms.
**Stratigraphic distribution**: Middle Jurassic - Oligocene.

### Subfamily HETEROHELICINAE Cushman 1927a p. 59

["nomen translatum" by Cushman, 1927, p.59, from Spiroplectinae Cushman, 1911, p.4]

Early stage planispiral or biserial, later stage may become disorganized; aperture simple, ventral or terminal in biserial and triserial forms.
**Stratigraphic distribution**: Lower Cretaceous - Oligocene.

### Genus *Heterohelix* EHRENBERG 1843 P. 429

[Type species: *Spiroplecta americana* Ehremberg, 1844, p. 75; SD by Ehremberg, 1844, p. 75]
Test small, biserial, may be planispiral in early stage; aperture at the base of the last chamber.
**Stratigraphic distribution**: Lower to Upper Cretaceous.
**Geographic distribution**: cosmopolitan.

### Family ROTALIPORIDAE Sigal 1958, p. 264

[Rotaliporidae Sigal 1958, p. 264]

### Genus Hedbergella BRÖNNIMANN & BROWN 1958, p. 16

[Type species: *Anomalina lorneiana*, d'Orbigny var. *trochoidea* Gandolfi, 1942, p. 98; OD]

Test trochospiral, biconvex, umbilicate, periphery rounded; aperture a.ventral arch bordered by a narrow lip.
**Stratigraphic distribution**: Lower - upper Cretaceous.
**Geographic distribution**: cosmopolitan.

### Genus Praeglobotruncana BERMUDEZ 1952, p. 52

[Type species: *Globorotalia delrioensis*, Plummer, 1931, p.199; OD]

Test trochospiral, biconvex to spiroconvex, umbilicate, periphery from rounded to subangular with more or less pronounced keel; chambers from subglobular to subangular; sutures depressed or elevated; aperture bordered by apertural lip.

**Stratigraphic distribution**: Lower - upper Cretaceous.
**Geographic distribution**: cosmopolitan.

### Family GLOBOTRUNCANIDAE Brotzen 1942, p. 28

["nomen translatum" by Morozova, 1957, p. 1111, from subfamily Globotruncaninae, Brotzen 1942, p. 28]

Test trochospiral, usually truncate or keeled; chambers spherical to angular; primary aperture umbilical.

**Stratigraphic distribution**: Upper Cretaceous.

### Genus Globotruncana CUSHMAN 1927, p. 91

[Type species: *Pulvinulina arca*, Cushman, 1926, p. 23; OD]

Test trochospiral, biconvex or planoconvex, broadly umbilicate, periphery single or double-keeled; sutures depressed or elevated; aperture umbilical.

**Stratigraphic distribution**: Upper Cretaceous.
**Geographic distribution**: cosmopolitan.

### Family ANOMALINIDAE Cushman 1927, p. 92

[Family Anomalinidae Cushman, 1927, p. 92]

Test trochospiral to nearly planispiral; wall coarsely perforate; aperture ventral extending to dorsal side.

**Stratigraphic distribution**: Upper Trias - Recent

### Subfamily ANOMALININAE Cushman 1927, p. 92

[Subfamily Anomalininae Cushman 1927, p. 92]

Test trochospiral; aperture peripheral extending to the umbilical side and bordered by an apertural flap.

**Stratigraphic distribution**: Upper Trias - Recent

### Genus *Gavellinella* BROTZEN 1942, p. 7

[Type species: *Discorbina pertusa* , Marsson, 1878, p. 166; OD]

Test trochospiral, biconvex, periphery rounded; all whorls visible on spiral side, umbilicus partly close by projections from chambers; aperture ventral slit extending to umbilicus bordered by narrow lip.

**Stratigraphic distribution**: Cretaceous - Miocene
**Geographic distribution**: cosmopolitan.

## Superfamily ROBERTINACEA Reuss 1850, p. 317

["nomen translatum" by Loeblich & Tappan, 1961, p. 317, from family Robertinidae Reuss 1850, p. 317]

Test trochospiral, aperture a low slit in chamber face and secondary ones in each septum above partitions.

**Stratigraphic distribution**: Jurassic - Recent.

## Family CERATOBULIMINIDAE Cushman 1927, p. (?)

["nomen translatum" by Glaessner, 1937, p. 27, from subfamily Ceratobumininae, Cushman, 1927, p.(?)]

Test trochospiral, aperture a low slit in chamber face and secondary ones in each septum, internal foramen

**Stratigraphic distribution**: Jurassic - Recent.

## Subfamily EPISTOMININAE Wedekind, 1937, p. (?)

["nomen translatum" by Loeblich & Tappan, 1961,p. 317, from family Epistominidae, Wedekind, 1937, p. (?)]

Coiling predominantly sinistral; primary aperture on peripheral margin of chambers with a lip.

**Stratigraphic distribution**: Jurassic - Recent.

## Genus *Epistomina* TERQUEM 1883, p. 37

[Type species: *Epistomina regularis* , Terquem 1883, p. 379, SD by Galloway & Wissler, 1927, p. 60]

Test lenticular, trochospiral, periphery sharply angular; umbilicus closed; aperture oval on umbilical side.

**Stratigraphic distribution**: Middle Jurassic - Lower Cretaceous

**Geographic distribution**: cosmopolitan.

## REFERENCES OF THE SYSTEMATIC PALEONTOLOGY

An accurate and complete list of references is an essential part of any research involving taxonomic problems. Being conscious of that, I have done my best to include as much accurate information as possible under each entry.

This effort was sometime frustrated, by limits of space but, above all, by the antiquity and rarity of some of the fundamental publications. Some of the most important ones were published between 1772 and the 1860s. Most of these publications were printed in small numbers and have become so rare that they are almost impossible to see in hardcopy, even in the form of photostatic copies through Interlibrary loans. I have been fortunate enough to be granted access to the private collections of the Faculty Members of the Centre for Marine Geology. These collections have been gradually enriched over the years and now contain, in one form or another, most of the older articles and monographs. On a few occasions, however, I failed to physically locate the publication I needed. In such cases I had to rely on what Loeblich & Tappan (1964) reported. As it is customary in these cases, in the list of references I clearly indicate that the paper was not directly consulted (i.e., with the annotation *"non vidi"* followed by *"fide"* followed by the source of my information).

In some of the oldest publications the all important date of issue is difficult or impossible to determine. In such cases I put the second best date in brackets to facilitate the use of the information.

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# APPENDIX B

# PLATES

## PLATE I : Boltaña 4 A

1 - *Quinqueloculina* sp.
2 - *Quinqueloculina* sp.
3 - *Quinqueloculina* sp.
4 - *Quinqueloculina* sp.
5 - *Rectobulimina* sp. (?), the aperture of this specimen is broken but it appears to be terminal and rounded. The early stage is impossible to resolve as it is often the case even in material in better conditions.
6 - *Heterohelix* sp.
7 - *Heterohelix* sp.
8 - *Verneulinoides* sp. (?) Numerous tests similar to this one are present in the sample. The course agglutination masks all structures and the attribution to *Verneulinoides* should be considered a simple suggestion.
9 - *Reophax* sp.
10 - *Eoguttulina* sp. (?), broken specimen. The attribution to Eoguttulina should be considered a simple suggestion.
11 - *Ammobaculites* sp.
12 - *Ammobaculites* sp.
13 - *Glomospira* sp.

1

2

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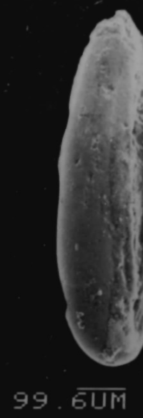

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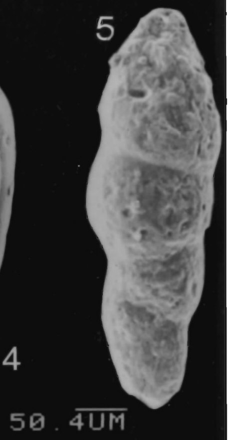

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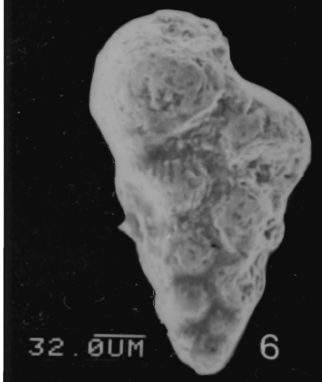

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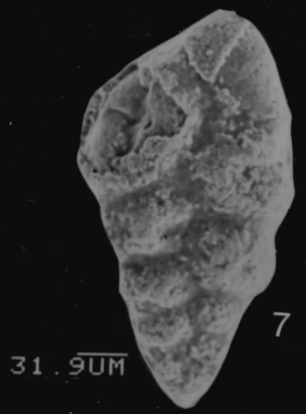

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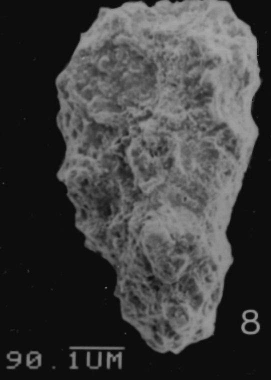

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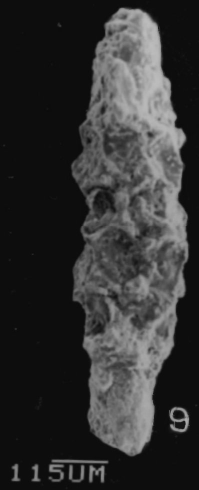

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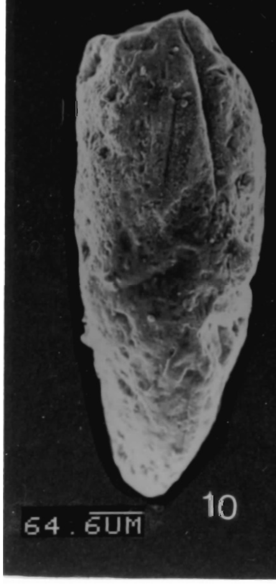

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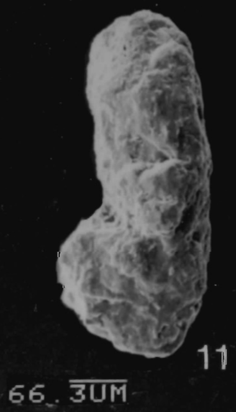

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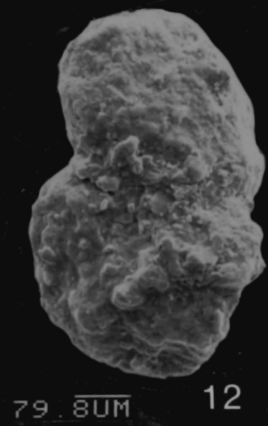

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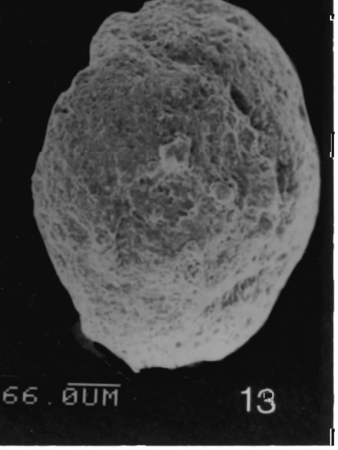

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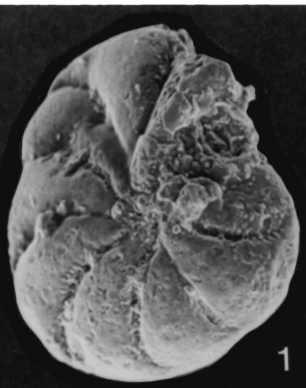
## PLATE II : Boltaña 4 A

1 - *Elphidium* sp.
2 - *Elphidium* sp.
3 - *Gavellinella* sp. (?) This calcareous perforate forms, and specimens 10 and 11, are clearly reworked as suggested by the state of preservation. Of all the genera compatible with their visible morphology the choice of *Gavellinella* seems to be more appropriate.
10 - *Gavellinella* sp. (?).
11 - *Gavellinella* sp. (?)
4 - *Cuvillierina* sp. (?)- *Epistomina* (?). Specimens 4, 5, and 6 clearly belong together, whether within *Cuvillierina* or *Epistomina* cannot be decided, although the specimens are common in the samples.
5 - *Cuvillierina* sp. (?)- *Epistomina* (?)
6 - *Cuvillierina* sp. (?)- *Epistomina* (?).
7 - *Hedbergella* sp. (?) - *Praeglobotruncana* sp. (?). Specimens 7, 8, and 9 are clearly primitive planktonic forms. The absence of keels suggests that they are not likely to belong to *Globotruncana* . The attribution to *Hedbergella* or *Praeglobotruncana* should be considered a simple suggestion.
8 - *Hedbergella* sp. (?) - *Praeglobotruncana* sp. (?)
9 - *Hedbergella* sp. (?) - *Praeglobotruncana* sp. (?)



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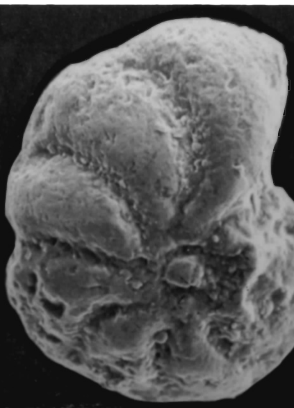

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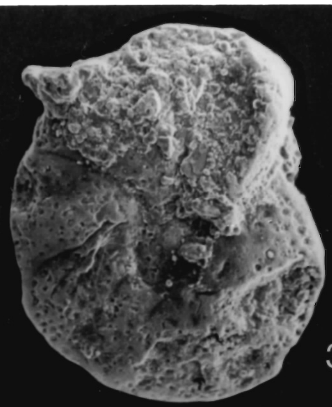

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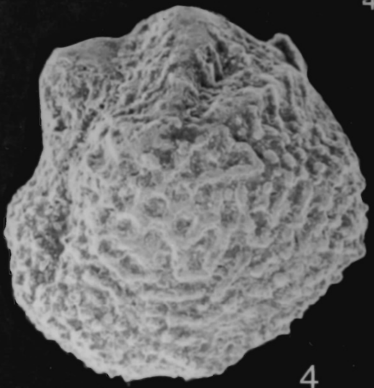

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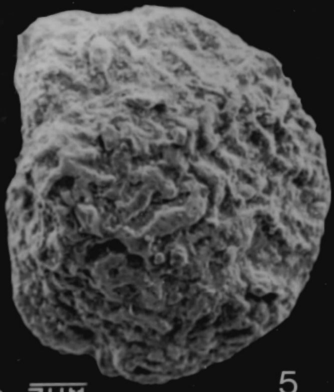

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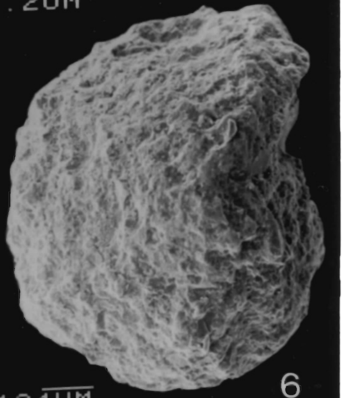

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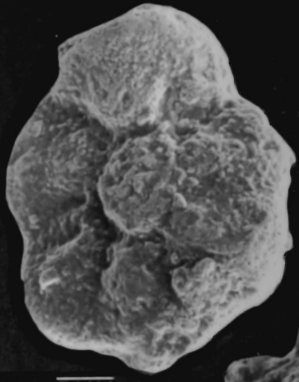

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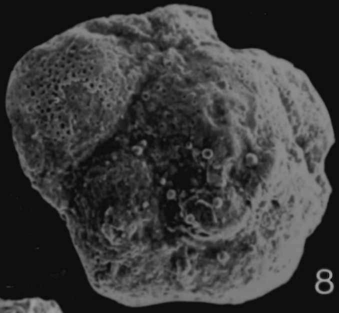

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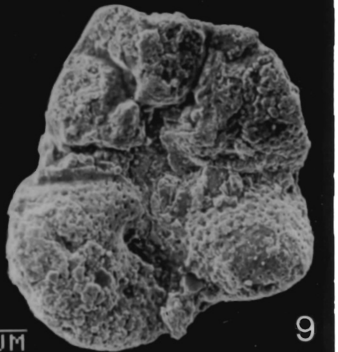

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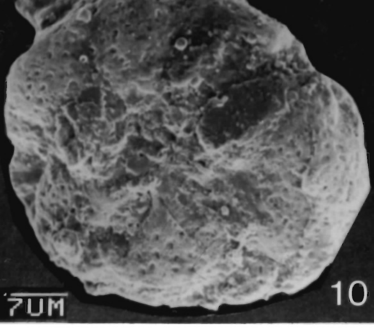

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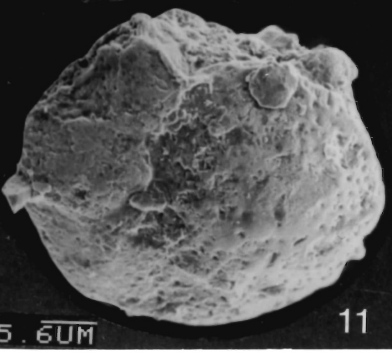

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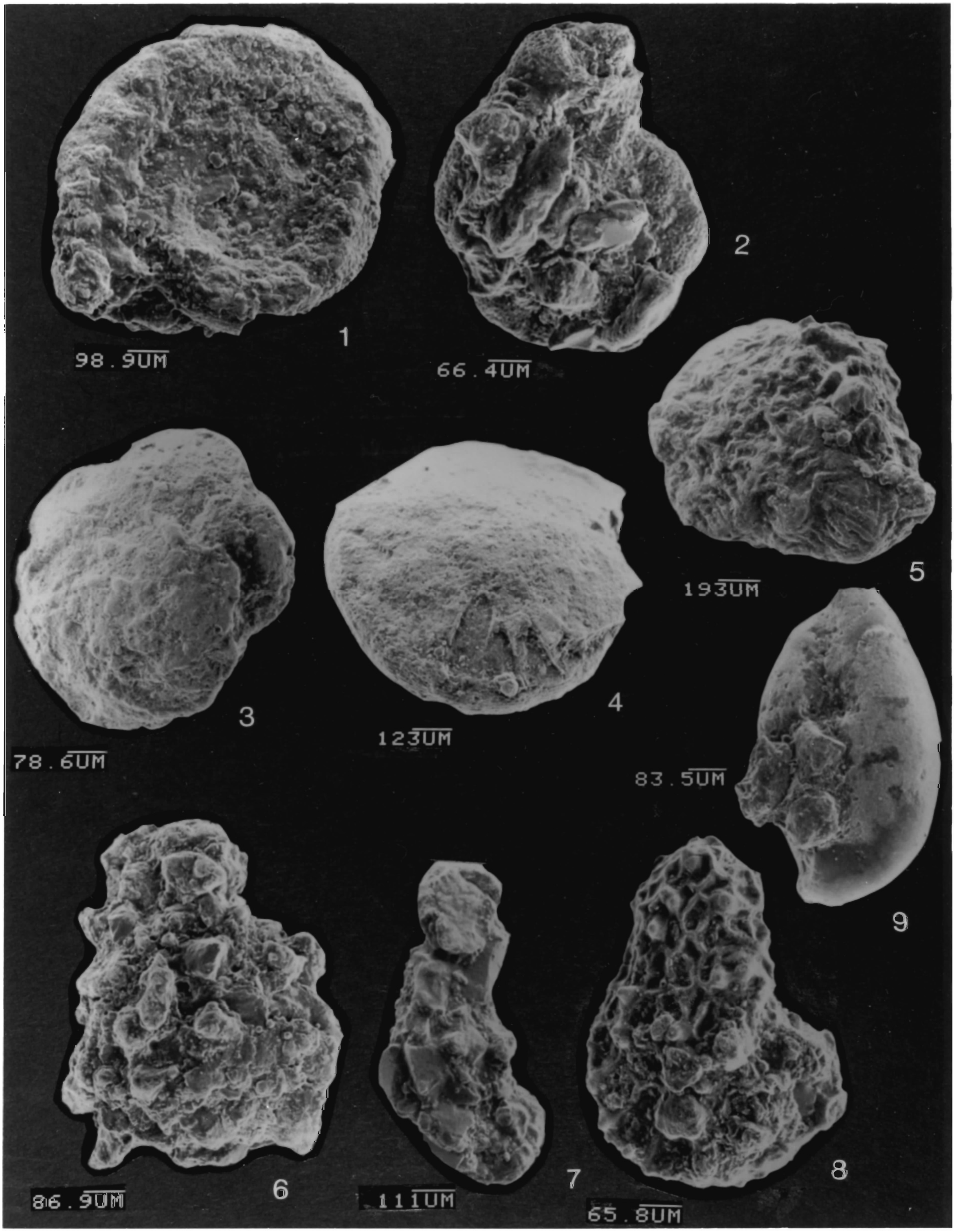
## PLATE III : Boltaña 4B

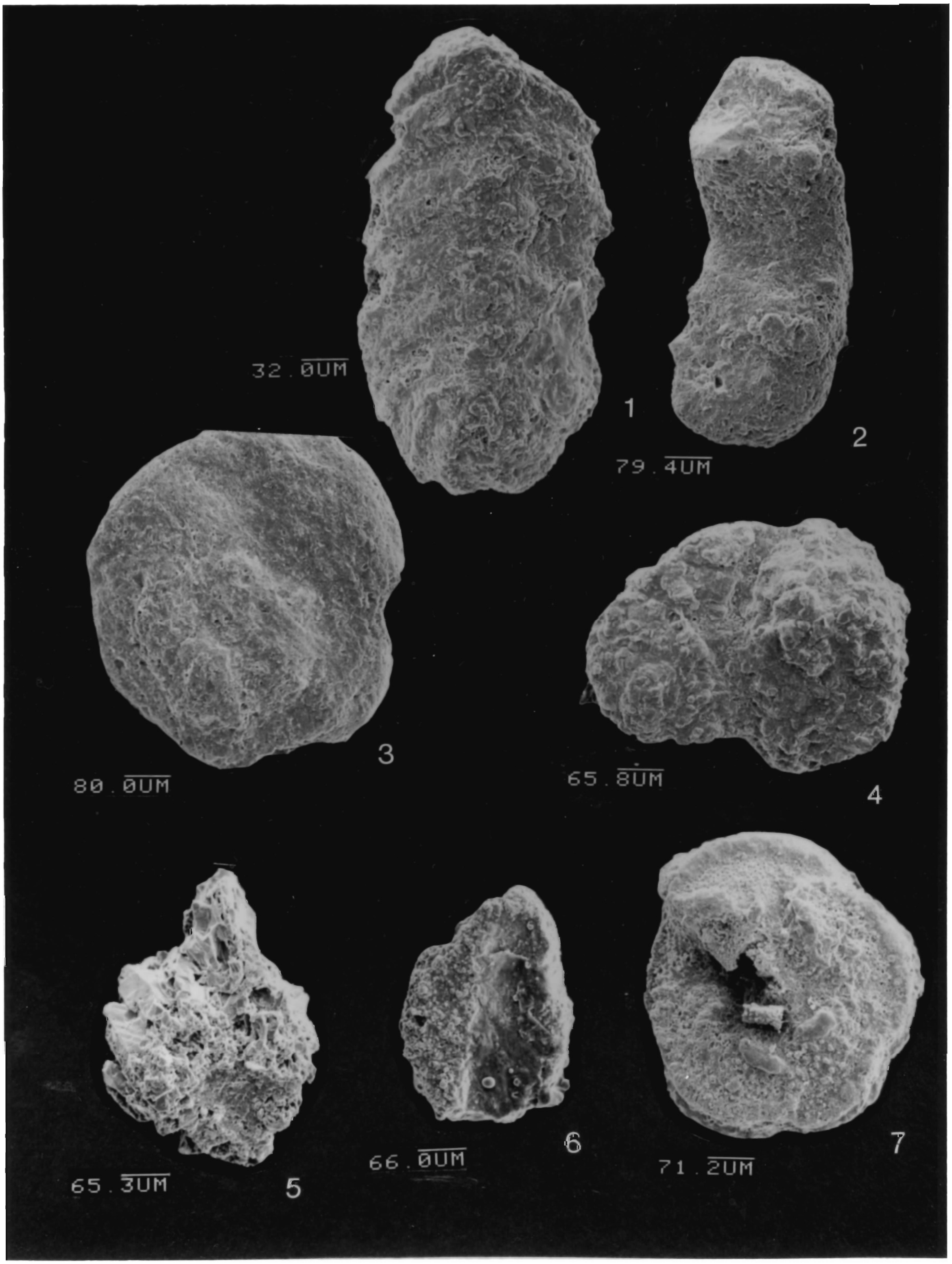
1 - *Ammodiscus* sp.
2 - *Gavellinella* sp. (?). At first glance this specimen appears to be coarsely agglutinated. A careful inspection, however, reveals a calcareous perforate test which is compatible with the tentative attribution to *Gavellinella* .
3 - *Trochammina* sp. (?)
4 - *Globotruncana* sp.(?) A faint peripheral keel suggests the attribution of this, and similar specimens, specimen to *Globotruncana* , a characteristic Cretaceous planktonic form reworked into my samples.
5 - *Epistomina* sp. (?) This and similar specimens are too badly damaged for a reasonably firm identification. The important point, however, is that they are calcareous and obviously reworked into my samples.
6 - *Saccammina* sp.
7 - *Ammobaculites* sp.
8 - *Ammobaculites* sp.
9 - *Globulina sp*. (?) - The specimen is broken no whole samples were present in the sample. The test is partly covered with sand grains obscuring part of its shape. Even recent *Globulina* specimens are very delicate and are often found in pieces



1
98.9UM
2
66.4UM
5
193UM
3
78.6UM
4
123UM
83.5UM
9
6
86.9UM
7
111UM
8
65.8UM

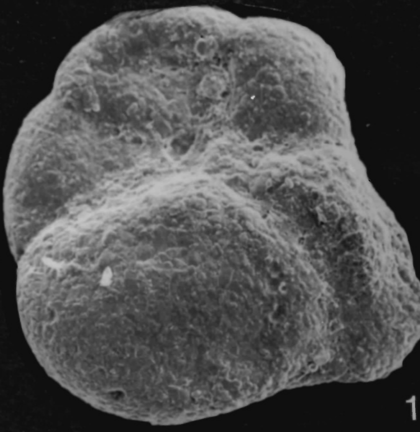
## PLATE IV : Isabena Valley 4 - 12

1 - *Spiroplectammina sp*. (?) - *Vulvulina* sp. (?) This form, although well preserved, is rare in my material, and I find it difficult to make a firm attribution to any one genus. I have compared the material with *Ammobaculites* and have decided that it does not belong in such genus.
2 - *Ammobaculites* sp.
3 - *Trochammina* sp.
4 - *Haplophragmoides* sp.
5 - *Polysaccammina* sp. I had problems identifying this genus which did not even appear to be a foraminifer. Close inspection of several specimens, however, has revealed the groove (specimens. 5, and 6) left by attachment to an elongate support (probably a blade of sea-grass).
6 - *Pseudothurammina* sp. (?)
7 - *Globotruncana* sp. The presence of a distinct keel points in the direction of *Globotruncana*. *Globorotalia* was a possibilty but the environment suggested by everything else indicates that this relatively delicate form must been fossilized and then reworked, obviously from older deposits, which makes *Globorotalia* a very unlikely candidate.


32.0UM
1
2
79.4UM
3
80.0UM
65.8UM
4
5
65.3UM
6
66.0UM
7
71.2UM

## PLATE V : Isabena Valley 4 - 19

1 - *Trochammina* sp.
2 - *Globotruncana* (?) This reworked calcareous form is rare and invariably badly broken. The attribution to *Globotruncana* should be considered a simple suggestion.
3 - *Guttulina* sp.
5 - *Guttulina* sp.
4 - *Haplophragmoides* sp.
6 - *Glomospira* sp.



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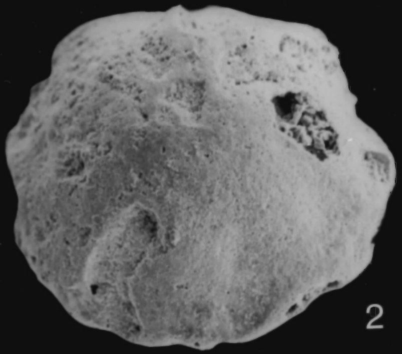

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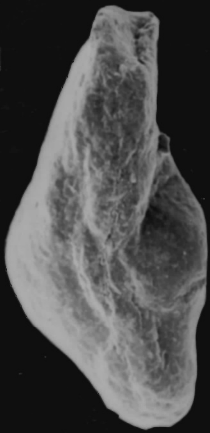

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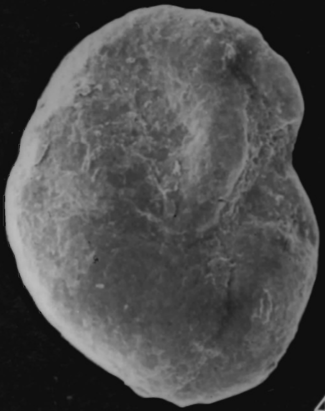

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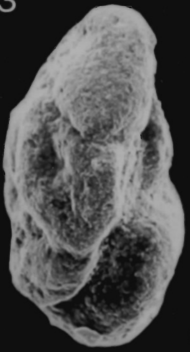

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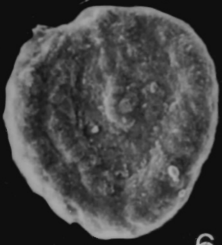

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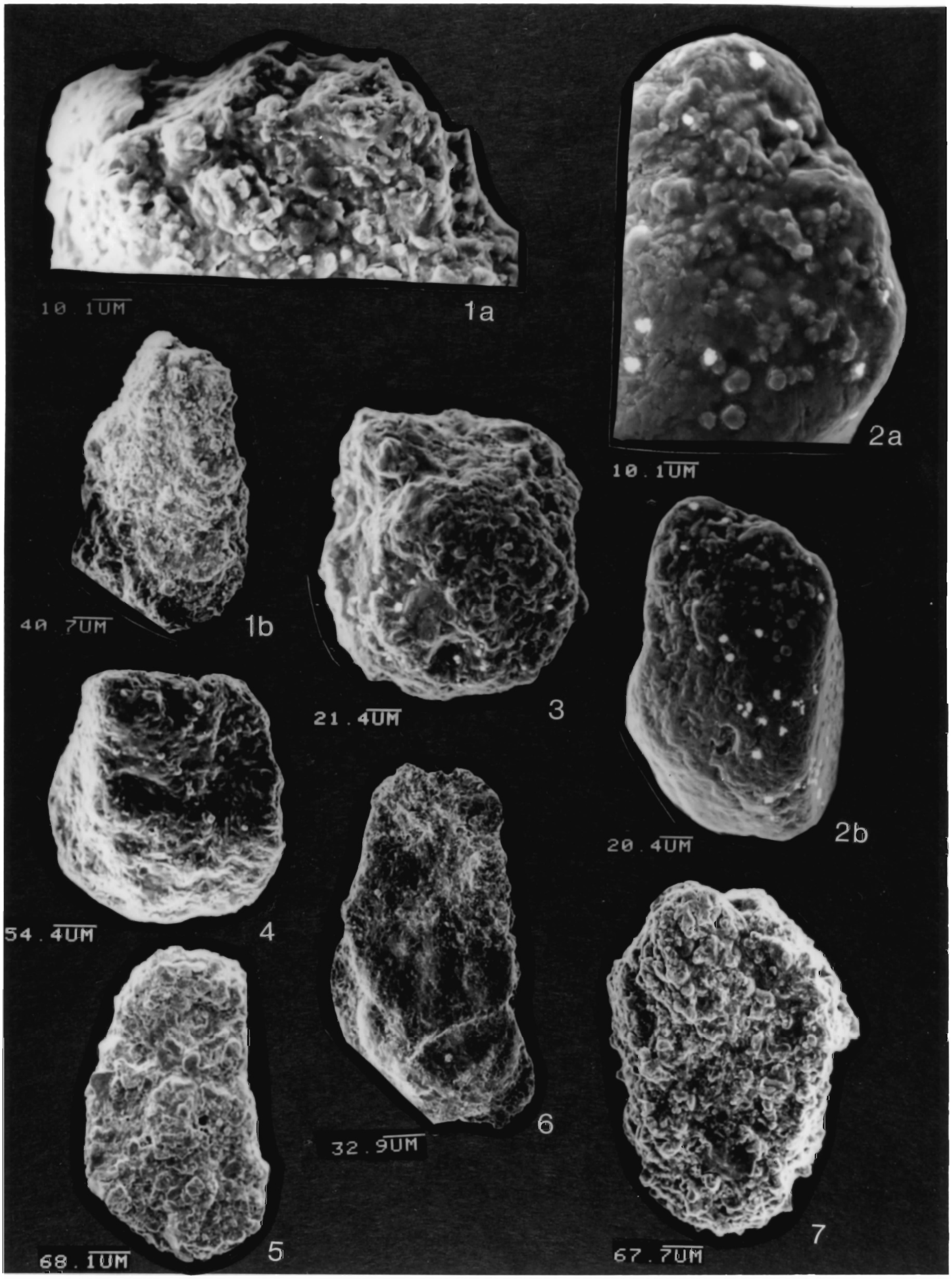
## PLATE VI : La Pasarela 2 A - 5

1a - Thecamoebian, enlargement of the aperture of specimen 1b.
1b - Thecamoebian, showing some affinity with the Difflugiid group.
2a - Thecamoebian, enlargement of the aperture of specimen 2b
2b - Thecamoebian (??)
3 - Thecamoebian, showing some affinity with the Difflugiid group.
4 - Thecamoebian, showing some affinity with the Difflugiid group.
5 - *Ammotium* sp. This and numerous other specimens of the same form are usually coarsely agglutinated and, in photographs, difficult to resolve. The material, however, clearly shows the characteristics of the genus.
6 - *Ammotium* sp. (?)
7 - Thecamoebian, showing some affinity with the Difflugiid group, or possibly the genus *Heleopera* group.

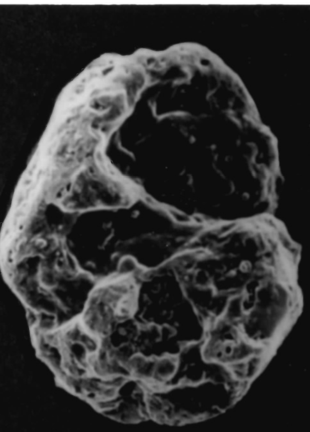

10.1UM
1a
10.1UM
2a
40.7UM
1b
21.4UM
3
20.4UM
2b
54.4UM
4
32.9UM
6
68.1UM
5
67.7UM
7

## PLATE VII : La Pasarela 2 A - 5

1 - Thecamoebian (?) The overall shape and the large aperture suggest a Difflugiid but, as for most thecamoebians in my samples, taphonomic problems make very problematic to narrow the field any further.

## Selected Specimens from a range of Isabena Valley Samples

2 - *Trochammina* sp.
3 - *Trochammina* sp.
5 - *Trochammina* sp.
4 - *Haplophragmoides* sp.
6 - *Haplophragmoides* sp.
7 - *Polysaccammina* sp. (?) has been reported only in recent sediments but this does not entirely rule out the possibility that *Polysaccammina* 's distribution must be substantially extended back to the Cenozoic or even further.
8 - *Polysaccammina* sp. (?)



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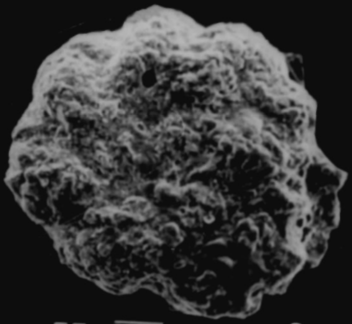

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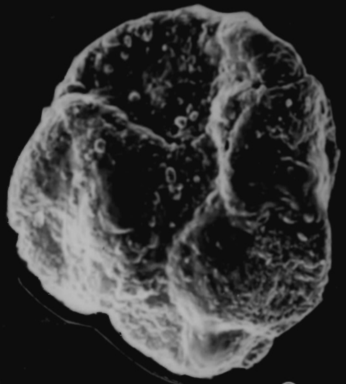

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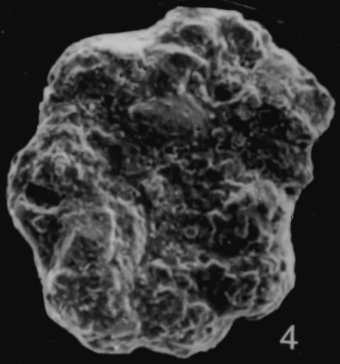

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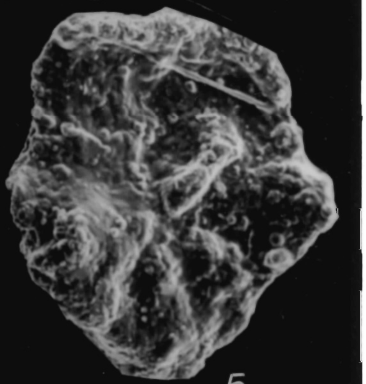

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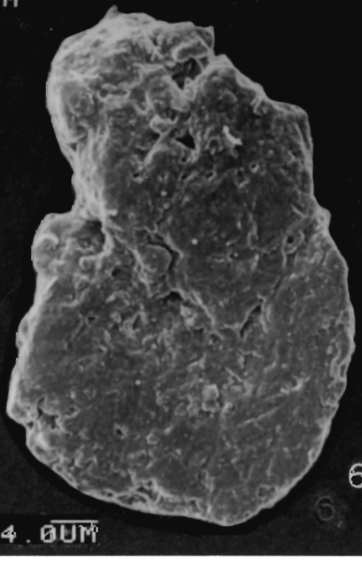

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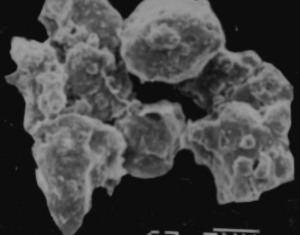

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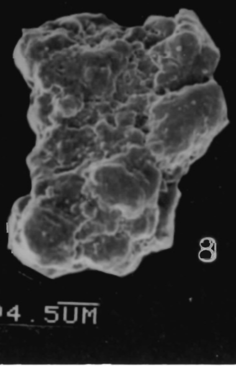

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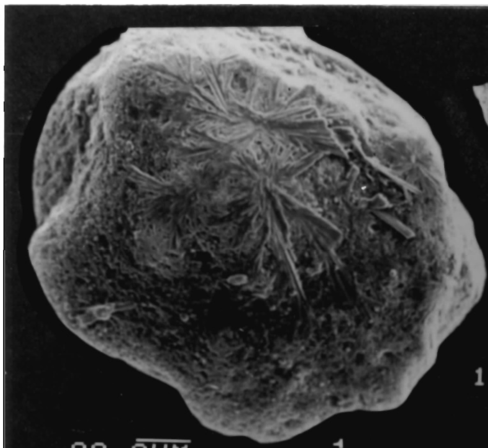
## PLATE VIII : Tremp 2

1 - *Pararotalia* sp. (?)
2 - *Marginulina* sp. (?) - This broken specimen is the best piece I found in my material of what must have been a common but very delicate form. The attribution to *Marginulina* should be considered a simple suggestion.
3 - *Cibicides* sp. This specimen and the one of specimen 4 show only some of the characteristics of *Cibicides* ; I have arrived at my identification through a compound mental picture of many specimens.
4 - *Cibicides* sp.
5 - *Cuvillierina* sp. (?)- *Epistomina* (?). Specimens 4, 5, and 6 clearly belong together, whether within *Cuvillierina* or *Epistomina* cannot be decided, although the specimens are common in the samples.
6 - *Polythurammina* sp. As in samples from Isabena Valley, I had problems identifying this genus. Upon closer inspection, a number of specimens have revealed the groove left by attachment to an elongate support (probably a blade of sea-grass).
7 - *Ammodiscus* sp.
8 - Thecamoebian (??), the specimen shows some morphological affinities with the Difflugiid group.
9 - *Polymorphina* sp. (?)
10 - Thecamoebian (?) the specimen shows some morphological affinities with the *Centropyxis* group.
11 - Cassidulinid (?)
12 - *Globobulimina* sp. This broken specimen shows the internal structure which agrees rather well with the structure of the genus. *Globobulimina* is a very delicate form and could not have survived reworking unless it was already fossilized at the time of deposition.



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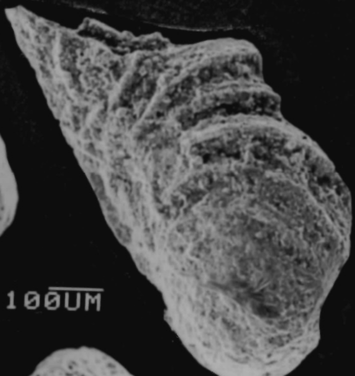

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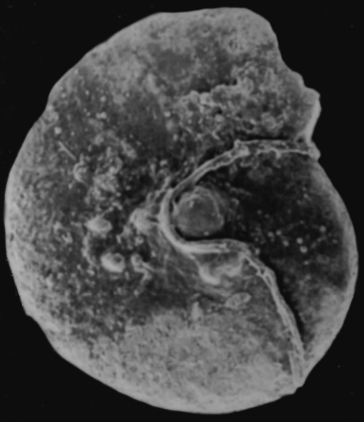

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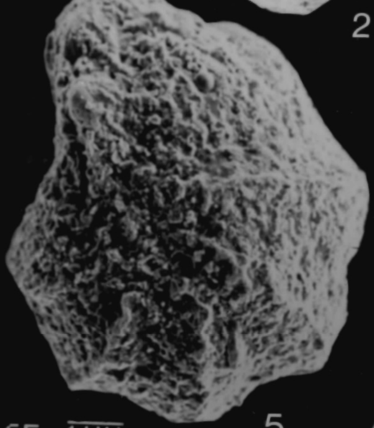

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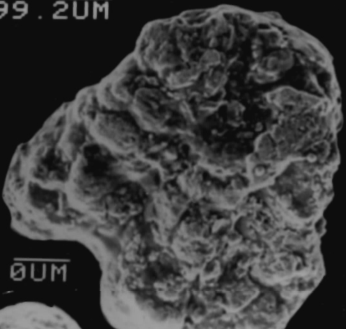

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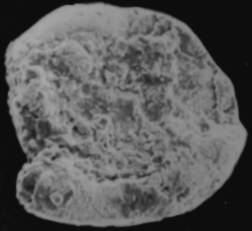

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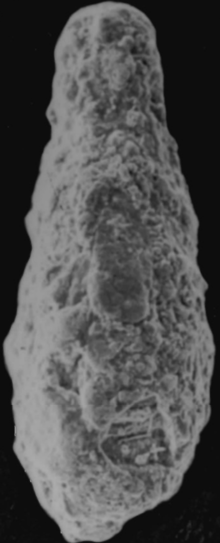

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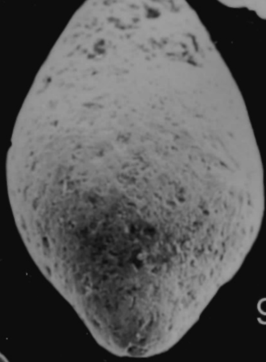

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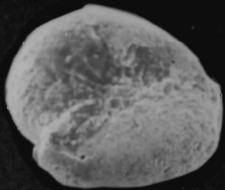

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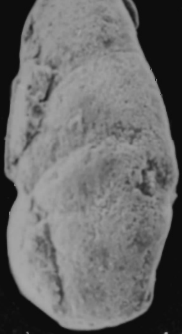

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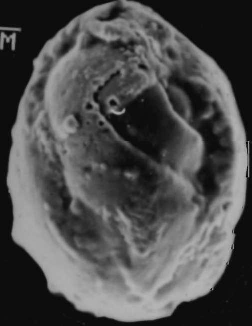

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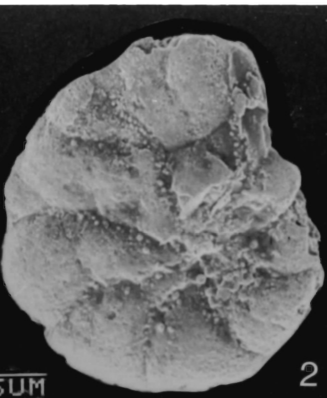
## PLATE IX : Tremp 4 - 3

1 - *Haynesina* sp. (?)
2 - *Haynesina* sp. (?)
3 - *Cibicides* sp.
4 - Reworked calcareous form (?); unidentifiable but common in samples.
5 - Reworked calcareous form (?); unidentifiable but common in samples.
6 - *Elphidium* sp.
7 - *Praeglobotruncana* sp.(?)
8 - Reworked calcareous form (?); unidentifiable but common in samples.
9 - Miliolid
10 - *Ammobaculites* sp.
11 - *Heterohelix* sp.
12 - *Rectobulimina* sp. This specimen was accidentally mounted upside-down.
13 - *Heterohelix* sp.
14 - *Ammobaculites* sp.


1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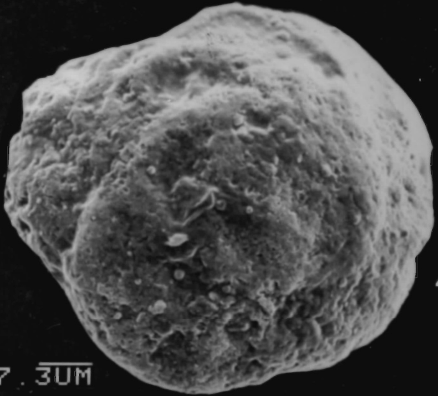
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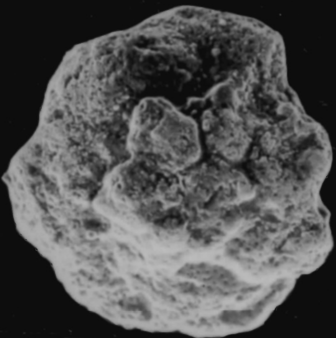
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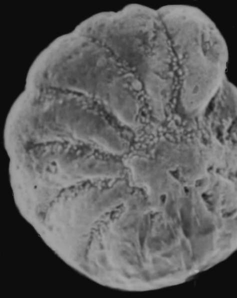
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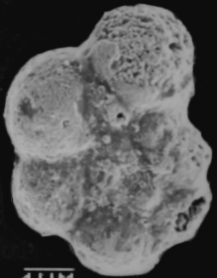
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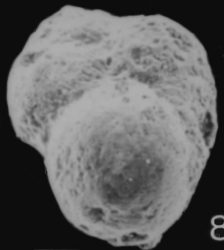
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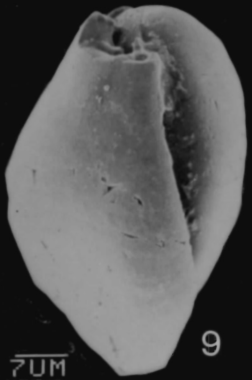
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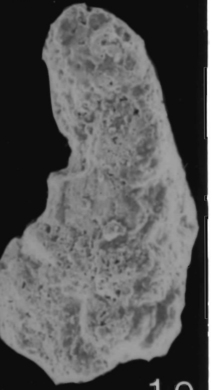
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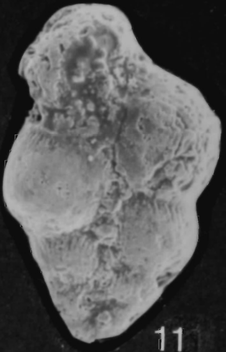
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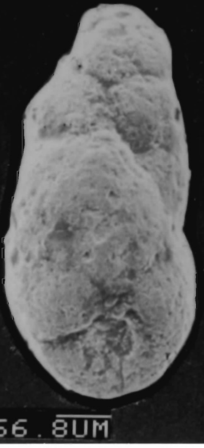
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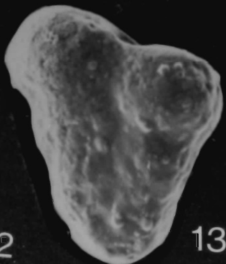
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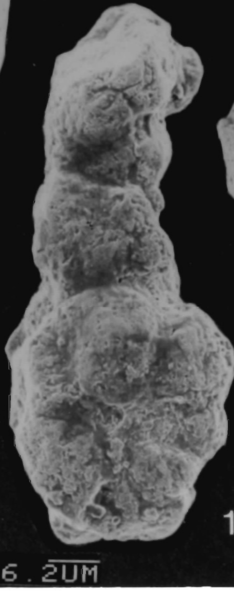
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