DEPARTAMENTO DE CIÊNCIAS DA TERRA

MAHIMA PRAVEEN PAI

Licenciada em Geologia

Quantitative analysis of foraminifera and sedimentology of the marine Pliocene of Vale Farpado (Pombal, West Portugal) and its palaeoenvironmental interpretation

MESTRADO EM PALEONTOLOGIA

Universidade NOVA de Lisboa

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DEDICATION

To my Father Praveen Kumar and Mother Shobha K. V.

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Many wonderful people supported and guided me throughout my Master studies thus helping me complete this thesis in time. Firstly, I would like to thank my advisors, Prof. Paulo Legoinha and Prof. Pedro Callapez for their guidance and encouragement. Especially Prof. Paulo Legoinha for his complete support and patience to help me through each obstacle during my work and Prof. Pedro Callapez for his unmatched energy and contagious enthusiasm. I would also like to thank Prof. Pedro Dinis from the University of Coimbra for his guidance and support during sedimentological analysis and also in helping me perfect my literature in sedimentology. I also want to thank Prof José Almeida for his guidance with operating the Leica software. Finally, thank you to all my colleagues and friends; mainly Catarina, Rita and my twin sister Meghana for their support and assistance.

ABSTRACT

Foraminifera occupy a large geological range from the Cambrian to the present day. They are excellent proxies to environmental changes due to their high abundance, well-preserved shells and short response time to changing environmental conditions. Planktonic foraminifera are also excellent markers of geological age as some species have a very specific age range. Sedimentology is the study of sediments such as clay, slit and sand and sedimentary rocks in general. Sedimentology aims to derive information on the depositional conditions of sediments.

The outcrop sampled is located in Vale Farpado, near Carnide village, in the municipality of Pombal of West Portugal, and belongs to the Carnide Formation. The deposit is mainly Pliocene in age and its basal contact with the Amor Formation is a disconformity representing a stratigraphic lacuna from the middle Miocene to the lower Pliocene. Nine layers of the outcrop namely, 2bottom, 2a, 2b, 2c, 3, 4a, 4b, 5a & 5b were sampled and only seven (2bottom-4b) of them yielded fossils. Sedimentological analysis was carried out for all the samples except for 2bottom and 2a since these samples had too much organic matter and could not be processed in time. It showed that the sediments are poorly sorted and extremely asymmetrical. There is an upward increase of smectite which reaches a maximum at layer 4b. Fifty- eight species of benthic foraminifera and 11 species of planktonic foraminifera were identified. The dominance of *Cibicides, Lobatula, Elphidium* and the presence of mostly smooth and striate forms of *Quinqueloculina* concludes the environment to be high energy, cool temperate carbonate shelf sea. The occurrence of *Globigerinella obesa* in all the layers and the presence of *Globigerinella pseudobesa* (4.37-5.20Ma) in some indicates that early Pliocene (Zanclean age) could not be excluded. However further research in this regard is required. *Globigerinoides diminutus* remobilized by the erosion of the Miocene deposits can be found in layers 2bottom and 4a. It indicates the age of the Miocene sediments could be within N7-N9 zone (14.24-17.54Ma), late Burdigalian-Langhian age, in accordance with previous dating of this unit based on vertebrates MN5 (17-15Ma).

KEYWORDS: Foraminifera, Pliocene, Vale Farpado (Pombal), Palaeoenvironment.

RESUMO

Os Foraminíferos têm uma vasta repartição estratigráfica desde o Câmbrico até os dias atuais. São excelentes indicadores para as mudanças ambientais devido à sua alta abundância, preservação das conchas e curto tempo de resposta a variações nas condições de ambiente. Os foraminíferos planctónicos também são bons marcadores de idade geológica, pois algumas espécies ocorrem num intervalo de tempo curto. Sedimentologia é o estudo de rochas sedimentares e também inclui processos fundamentais definidos pelo termo sedimentação. A sedimentologia visa obter informações sobre as condições de deposição dos sedimentos. O afloramento estudado está localizado em Vale Farpado, próximo da vila de Carnide, no município de Pombal, Oeste de Portugal, e pertence à Formação de Carnide. O depósito é principalmente de idade Pliocénica e seu contato basal com a Formação de Amor é uma desconformidade que representa uma lacuna estratigráfica do Mioceno médio ao Plioceno inferior. Nove camadas do afloramento, a saber, 2bottom, 2a, 2b, 2c, 3, 4a, 4b, 5a e 5b foram amostradas e apenas sete (2bottom-4b) delas forneceram fósseis. A análise sedimentológica foi realizada para todas as amostras, excepto 2bottom e 2a devido à quantidade de matéria orgânica. Revelou que os grãos são mal selecionados e com distribuição extremamente assimétrica. Há um aumento crescente de esmectite que atinge um máximo na camada 4b. Foram identificadas 58 espécies de foraminíferos bentónicos e 11 espécies de foraminíferos planctónicos. A dominância de *Cibicidas, Lobatula, Elphidium* e a presença de formas principalmente lisas e estriadas de *Quinqueloculina* concluem o ambiente como sendo de alta energia, mar da plataforma carbonatada, temperada fria. A ocorrência de *Globigerinella obesa* em todas as camadas e a presença de *Globigerinella pseudobesa* (4,37-5,20Ma) em algumas indica que o Pliocénico inferior (idade Zancleana) não pode ser excluído. No entanto, são necessárias mais pesquisas a este respeito. *Globigerinoides diminutus,* remobilizados pela erosão dos depósitos do Miocénico, ocorrem nas camadas 2bottom e 4a. Indicam que a idade dos sedimentos do Miocénico seria do intervalo N7-N9, burdigaliana tardia a langhiana (17,54-14,24 Ma), corroborando a datação anterior desta unidade baseada em vertebrados MN5 (17-15Ma).

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ABBREVIATIONS

CF- Cumulative frequency

D- Dominance

H- Shannon-Weaver index

Ma- Million years

PAST- PAlaeontological STatistics data analysis package

S.D- Standard Deviation

XRD – X-ray diffraction

1 INTRODUCTION

Foraminifera are unicellular protists whose existence can be traced back to the early Cambrian (Culver, 1991). They are very abundant and are easily preserved because of their hard shells and thus are the most widely used microorganisms for biostratigraphy, correlation of sediments, and age-dating purposes (Murray, 2006). Foraminifera also act as indices that provide information on palaeogeographic information such as palaeotemperatures, extend of glaciation, etc. and because their test composition, abundance, and distributional patterns are largely dependent on environmental circumstances, some benthic foraminifera species are also excellent markers of ecological conditions. Foraminifera make ideal indicators of environmental change due to their high abundance, well-preserved shells and short response time to changing conditions (Alve *et al*., 2016; A. R. L. Loeblich & Tappan, 1988). Sedimentology is a branch of geology that studies the physical and chemical characteristics of sedimentary rocks as well as the processes that lead to their formation, such as sediment transport, deposition, and lithification. The understanding of ancient environmental conditions in sediment source areas and depositional sites is the goal of much sedimentological study. By investigating the components, textures, structures, and fossil content of deposits formed in various geological settings, the difference between continental, littoral, and marine deposits in the geologic record can be established.

1.1 OBJECTIVES

This work focuses on the fossil site of Vale Farpado, one of the classical outcrops known from the marine Pliocene units of the Carnide area, in the Pombal range of the northern onshore sector of the West Portuguese Margin. This work aims to:

- increase the list of Pliocene foraminifera known from the Carnide Formation and the Pliocene of Portugal;
- draft a palaeoenvironment scenery of the successive layers using benthic foraminifera and sedimentological analysis;
- precise aspects of the stratigraphic age of the Carnide Formation using the planktonic foraminifera.

1.2 STRUCTURE OF WORK

This dissertation is organized into eight chapters.

- Chapter 1 is a brief introduction to foraminifera and sedimentology and the objectives for this dissertation.
- Chapter 2 discusses the research methods used for sedimentological analysis such as grain size distribution, bulk and clay mineralogy and foraminifera picking and identification. The various techniques used to obtain data from foraminifera such as tri plot diagram of wall structures, diversity indexes and the formula used to obtain the palaeodepth using planktonic forams and the formula proposed by Van der Zwaan *et al*. (1990) are focused. Finally, it also discusses the technique used for digital imaging of foraminifera specimens.
- Chapter 3 deals with previous works about the study area and the foraminifera previously found in the Pliocene of Portugal.
- Chapter 4 is about the geology of Vale Farpado, containing a basic introduction to sedimentology and the results of sedimentological analysis of the studied outcrop.
- Chapter 5 is a basic introduction to foraminifera, its classification, ecology and its use in paleoenvironmental analysis
- Chapter 6 deals with the systematics and classification of foraminifera along with a complete list of all the foraminifera identified.
- Chapter 7 presents the results obtained from the foraminifera identified such as information from the wall structure, the number of individual species, the age of the sediments inferred from the planktonic species, the calculation of diversity indexes and the depth using planktonic foraminifera.
- Chapter 8 concerns the conclusion, including brief and precise points about the various conclusions obtained throughout the work.

At the end, the bulk text is completed with the references used in completing this dissertation.

2 METHODS

After a phase of detailed bibliographic and mapping research about Foraminifera taxonomy, biostratigraphy and ecology, the Neogene stratigraphy of Portugal, and the geology of the Carnide area, our study was followed by extensive fieldwork in the Pliocene units of Carnide area, focusing on the Vale Farpado fossil site recently rediscovered by the researchers Ricardo Pimentel and Pedro Callapez (University of Coimbra). A local stratigraphic log was made and several bulk samples of the various beds were collected for fossil counting in the laboratory of micropalaeontology of the Departamento de Ciências da Terra da Universidade Nova de Lisboa. At the same time, an accurate sampling was completed for sedimentological purposes in the Laboratory of sedimentology of the Departamento de Ciências da Terra da Universidade de Coimbra. Both the outcrop and all fossil samples were fully photographed in situ and registered with labels, as described in the next sections.

2.1 EQUIPMENT USED

The following equipment was used to carry out this dissertation:

1. 125µm,150µm, and 500µm sieves
2. Coulter LS230
3. Geological hammer
4. Heraeus Megafuge 16 Centrifuge
5. Laboratory oven
6. Leica M165C optical microscope
7. Micro slide
8. Plastic bags
9. Plummer cell slide

2.2 SEDIMENTOLOGICAL ANALYSIS

2.2.1 GRAIN SIZE DISTRIBUTION

The laser diffraction Coulter method with a Coulter LS230 was used to determine the particle size distribution of our sample. The sample was passed through a sieve of 2mm, as the coulter cannot detect particles larger than 2mm. Sample material (1-2g) is dissolved in a water container placed in the apparatus. A laser beam is sent through an upstream flow and depending on the size of the particles, it will break at different angles.

The basic principle is that the angle of diffraction is inversely proportional to the particle size. Laser diffraction uses two theories to calculate the particle size:

a) the Mei theory of light scattering
b) the Fraunhofer approximation

The Fraunhofer model was used in this work. Grain size is then represented in volume. Each sample was measured twice and the average result was used to determine the grain-size characterization. A graph was plotted with size against volume in an excel spreadsheet.

2.2.2 BULK AND CLAY MINERALOGY

X-ray diffraction (XRD) was used to evaluate the mineral composition using an Aeris apparatus (Malvern PanAlytical) with a Cu tube at 15 kV, 40 mA. Measurements were made with 0.02173° step-size at a velocity of 3.3°/min and XRD data was analyzed using the HighScore software. For bulk mineralogy, the samples were crushed using a mortar and pestle and later analyzed using diffractograms obtained on randomly oriented grains in the range 2–60° 2θ. To determine the clay mineralogy, samples underwent centrifugation to separate the clay fractions (<2μm) according to Stokes law and the clay dispersions were pipetted on glass slides and air-dried. XRD was performed on the slides (2–30° 2θ) and after solvation with ethylene glycol and heating at 550 °C (2–15° 2θ).

Semi-quantitative estimations of mineral proportions were based on the areas of characteristic reflections (Dinis *et al*., 2020). The characteristic reflections at 4.26 Å, 3.23 Å and summed reflections of ~7.1 Å, 10 Å and 15 Å was used to estimate the proportions of quartz, feldspar and phyllosilicates respectively. For clay fractions, reflections at 14‑15 Å, that after ethylene-glycol treatment swelled to 16‑17 Å were used to estimate the abundance of smectite, 10 Å for illite, and reflections at 7 Å was used to estimate kaolinite and chlorite. By dividing the acquired areas by the following correction factors, the obtained areas were normalized to illite: 1.5 for kaolinite and chlorite and 4 for smectite. The findings obtained for both bulk and clay mineralogy are approximate estimations due to the limitations of semi-quantitative XRD assessments (Moore & Reynolds, 1997) but are enough to sort the samples in terms of proportion of the main mineral components (Dinis *et al.*, 2020).

2.3 SAMPLING AND FORAMINIFERAL ANALYSIS

Eight bulk-sample bags of sample sediments were collected from the outcrop using a geological hammer. Some molluscan shells were collected from beds no.2 and 4. The samples were left to dry in an oven for two days. After drying, half of each sample was poured into a beaker and labeled accordingly and the other half was saved for backup. The beakers containing the samples were treated with a mixture of hydrogen peroxide (10%) and water and for samples containing organic matter, ethanol was also used and the matrix was left to dissolve in the solution for two days. The sediments were then washed through sieves of 125µm,150µm, and 500µm and put in respective containers and left to dry for four days in a muffle at 45ºC.

The shells collected from beds number two and four were cleaned and the matrix surrounding them was washed through a 63µm sieve to recover any foraminifera attached to them. The sediments, after drying were distributed on a black picking tray and the microfossils were picked under an optical microscope. In each sample, where possible, at least 250 to 700 specimens, including both benthic and planktonic foraminifera were counted and were generically identified. Beds 5a and 5b did not yield any fossils. The following table shows how many grams of sediment were needed to collect the total foraminifera in each sample.

Table 2.3.1: The weight of each sample from which the total foraminifera were collected from (TFC-Total Foraminifera Collected)

Sample	TFC	Weight (g)		
		125µm	**250µm**	**500µm**
2bottom	269	0.05	0.203	0.583
2a	698	0.202	1.91	1.108
2b	250	0.262	0.787	3.22
2c	350	0.076	0.308	1.962
3	271	0.05	0.069	2.85
4a	268	0.026	0.057	0.914
4b	308	0.023	0.104	0.506

As proposed in Murray (1973, 1991, 2006), the benthic foraminifera found from each sample were divided based on their test walls into agglutinated, hyaline and porcelaneous and their percentages were calculated and are summarized in Table 8.1.1. A ternary diagram was plotted (Figure 8.1) using the software, Tri-plot v1.4.2 (Graham & Midgley, 2000).

The number of individual species in each sample was counted and their percentage in the sample was calculated in Table 8.2.1 and Table 8.2.2 to facilitate an overview of the assemblage composition and to enable comparison among other samples. The assemblages were analyzed to identify the taxa with the highest percentage. The Planktonic to total foraminifera assemblage ratio was calculated as shown in Table 8.2.3, to determine the depth using the formula proposed by Van der Zwaan *et al*. (1990), which is Depth = $e^{(3.58718+\{0.03534*\%P\})}$. To better enable the results found, diversity indexes such as Fisher alpha index, Shannon- Weaver index (H) and Dominance (D) were calculated Table 8.4.1. These indexes were calculated using the PAlaeontological STatistics data analysis package - PAST

version 4 (Hammer *et al*., 2001). A graph was plotted with Shannon index against Fisher alpha index Table 8.1.1.
All the above tables and diagrams can be found in the results chapter.

2.4 DIGITAL IMAGING

In order to illustrate some species, foraminifera specimens with complete tests that were in good conditions were chosen. Specimens with broken tests or those yellowed were omitted. Digital images of species were acquired by using a camera coupled to the binocular microscope Leica M165C and the software application Leica Application Suite X 3.0.14.23224. In the toolbar of the application click on "Acquire" and follow the steps below.

1. Acquire > Acquisition > Z-stack.
2. In the Z-stack dialogue box, adjust the size and position of the specimen on the screen.
3. The Z-stack option makes a "stack" of multiple images from different layers and combines them into a single multifocal image.
4. Select the starting point of focus (usually the background or the bottom part of the specimen) using the focus tool on the microscope and select begin in the z-stack dialogue box. Then focus on the ending point of the stack (the tip of the specimen or the topmost region of the specimen) and click end in the z-stack dialogue box as shown in the figure below.

Figure 2.1: Z-stack dialogue box with the begin, end and number of steps options shown. (Selected options shown in red).

5. If using manual mode, add the number of steps in the z-stack dialogue box (the number of images taken to be stacked), for most of the specimens in this work about 50 steps were

used. Click on start and the software proceeds to click the images, stacks and combines them into a single image and lets the picture be saved in the desired folder.

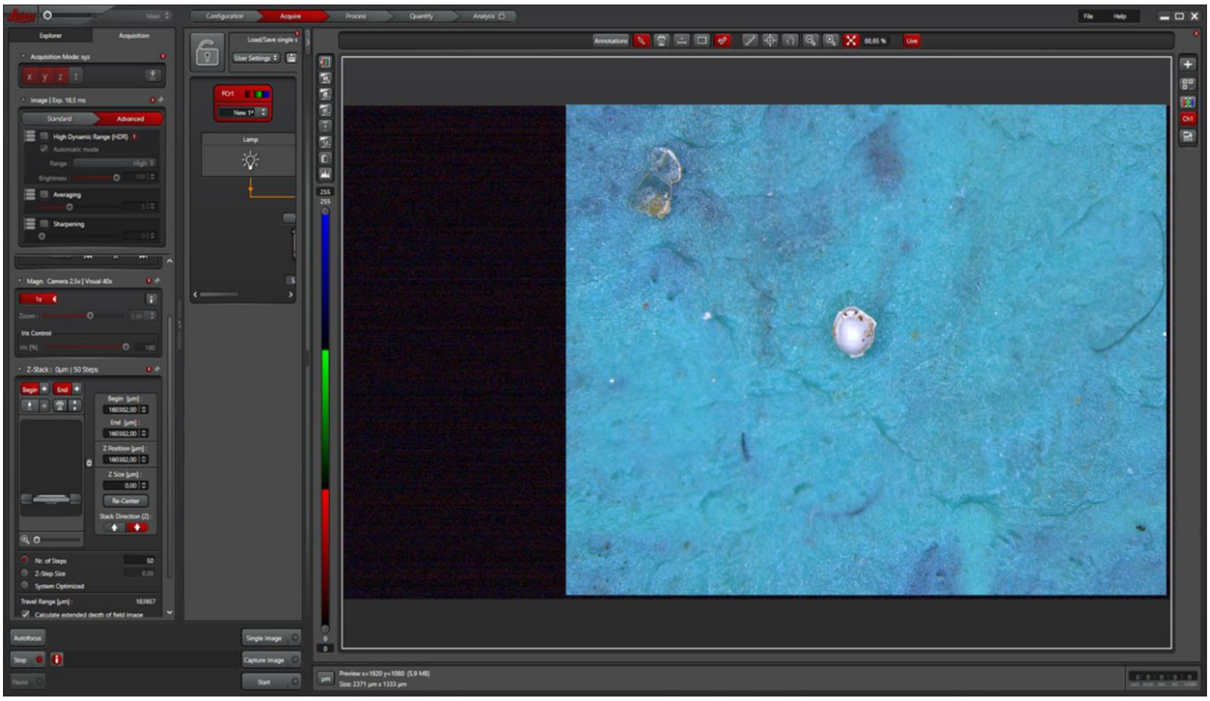

Figure 2.2: Screenshot of the software with Z-stack dialogue box (on the left corner) and other options visible.

3 PREVIOUS STUDIES

The Pliocene marine units and faunas from the Estremadura and Beira Littoral ranges of mainland Portugal have been recognized and studied for more than 100 years (Choffat, 1889; Cox, 1941; Dollfus & Cotter, 1909). They were discovered during extensive stratigraphic and cartographic works in the typhonic valley of Caldas da Rainha and Paredes de Vitória, lately reviewed by Zbyszewski (1959), Zbyszewski *et al*. (1961) and Zbyszewski & Moitinho de Almeida (1960). By this time, several correlative fossil sites were discovered by members of the Portuguese Geological Survey, around the Carnide river drainage streams, near this village of Pombal municipality (Teixeira & Zbyszewski, 1951). They included the main section of Carnide church and additional outcrops with lenticular beds of fossiliferous marine conglomerates and sands, such as Vale de Cabra, Bouchada, and Vale Farpado (Manuppela *et al*., 1978), all of them presently inaccessible or hard to find.

The first micropalaeontological work on Portuguese Pliocene deposits was that of Rocha & Ferreira (1953), who studied foraminifers from samples collected in these scattered outcrops of the Pombal region and found 22 species that were classified into 11 genera. A more in-depth study was carried out by Carvalho & Colom (1954) and later assemblages were focused on by Cardoso (1984)

About three decades later, a new fossil site was discovered during quarry works Vale do Freixo, also near Carnide, who has provided the most diverse and well preserved invertebrate fossil fauna of the Portuguese Pliocene (e.g. Dell Angelo & Da Silva, 2003; Pimentel, 2018; Silva *et al*., 2000). Since this time, this was considered as the focus for the study of the marine beds and fossil assemblages of this age, leaving the presently studied fossil site of Vale Farpado to be forgotten and its location temporarily lost for the scientific community.

3.1 CARVALHO & COLOM (1954)

As stated above, Carvalho & Colom (1954) were pioneers in the study of the Portuguese Pliocene foraminifers. Of the four samples they studied, two came from deposits in the Pombal region and the other two from the deposits in the typhonic valley of Caldas da Rainha.

There were 45 species identified in total and a new species, *Nodosarella pliocenica,* only found in the Carnide deposit, was described in Figure 3.1. Vale Farpado was the richest deposit with 35 species and subspecies identified, followed by Carnide with 20 species, Salir do Porto, with 10 and finally that of Nadadouro, with only three recognized species.

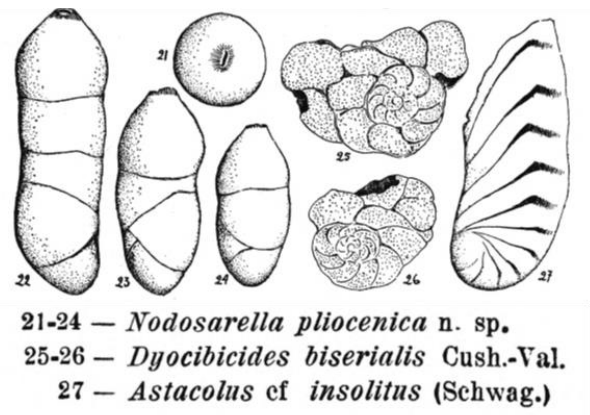

Figure 3.1: Illustration of *Nodosarella pliocenica* from Carvalho & Colom (1954)

3.2 CARDOSO (1984)

Cardoso (1984) studied microfossils (foraminifera and ostracods) of six fossiliferous beds from three deposits namely: Casal do Negrelho (Caldas da Rainha), Vale Farpado, and Carnide. The goal of the work was to extend the list of Foraminifera and Ostracods that are known in the Portuguese Pliocene, to try and clarify the age of the Pliocene deposits using planktonic foraminifera, and to draft a palaeoenvironmental reconstruction of the fossiliferous layers.

The Foraminifers collected were found in all fossiliferous layers and were in poor condition, having been rolled, split, recrystallized, and, in rare cases, pyritized. 94 species and subspecies, distributed across 43 genera and 22 families were recognized.

The relative frequency distribution of each species was as follows [the list does not include very rare species (1 to 2 specimens)]:

Abundant species (more than 15 specimens per layer): *Ammonia beccarii*, *Elphidium crispum*, *Cibicides lobatulus*, *Cibicides refulgens*, *Cibicides pseudoungerianus*, *Globulina gibba*, and *Globocassidulina crassa*.

Common species (6 to 14 specimens per layer): *Spiroplectammina wrighti*, *Textularia sagittula*, *Dorothia gibbosa*, *Globulina inaequalis*, *Bolivina catanensis*, *Bulimina elongata*, *Elphidium fichtellianum, Neoconorbina nitida*, *Cassidulina carinata, Hanzawaia nitidula* and *Osangularia pulchra*.

Rare species (3 to 5 specimens per layer): *Textularia pseudogramen*, *Quinqueloculina longirostra*, *Quinqueloculina viennensis*, *Glandulina pliocenica*, *Trifarina fornasinii*, *Neoconorbina terquemi*, *Cancris oblongus*, *Elphidium macellum*, *Globigerina bulloides*,

Globigerina praebulloides, *Globocassidulina subglobosa*, *Nonion boueanum* and *Mississipina concentrica.*
The list of all the foraminifera found by Cardoso (1984) is presented in Table 3.2.1.

The following conclusions were drawn from the analysis in Cardoso (1984). The dominance of certain species such as *Ammonia beccarii*, *Elphidium crispum*, *Cibicides lobatulus*, corresponded the association to the infralittoral coastal zone. At the same time, the coexistence of other species characteristic of deeper environments such as *Globocassidulina crassa*, *Hanzawaia nitidula*, *Bolivina catanensis*, *Bulimina elongata, Cassidulina carinata,* and *Globocassidulina subglobosa* suggest a coastal zone open to oceanic influences, from where they would arrive, dragged by the seashore current drift or by the waves.
The climatic information provided by species such as *Orbulina universa* and *Globigerinoides ruber*, indicate, in general, hot temperate waters, however, the presence of cold-water species such as *Cassidulina crassa* and *C. laevigata* may be related to greater depth and therefore cold waters. As a whole, the foraminiferal assemblage studied is an indicator of temperate waters.
The age of the deposits could not be clarified as the planktonic foraminifers that were identified were not accurate biostratigraphic indicators.
Thirteen species of ostracods were also recognized:
Bythocypris arcuate, Caudites guinesensis, Callistocythere canaliculate, Costa batei, Kangarina abyssicola, Loxoconcha punctatella, Microcytherura angulosa, Mutilus venetiensis, Paracytheridea triquetra, Pterygocythereis fimbriata, Quadracythere macropora, Semicytherura inversa, Urocythereis favosa.
From a palaeoecological point of view, the fauna of Ostracods indicated a marine environment between the intertidal zone and 50 m deep, with relatively high dynamics. The conclusion is supported by the strong general ornamentation of the valves, and this also supports the conclusions previously obtained by the study of Foraminifers.

Table 3.2.1: List of all Pliocene foraminifera found by Cardoso, 1984. The species in **bold** were found in Vale Farpado.

Benthonic			
Family	**Genus/Species**	**Family**	**Genus/Species**
TEXTULARIIDAE	***Spiroplectammina wrighti*** (Silvestri)	BOLIVINITIDAE	*Bolivina afL aenariensis* (Costa)
	Textularia conica d'Orbigny		***Bolivina catanensis*** Seguenza
	Textularia pseudogramen Chapman & Parr		**Bolivina subspinescens** Cushman
	Textularia sagittula Defrance		***Bolivina robusta*** Brady

Family	Genus/Species	Family	Genus/Species
	Textularia sagittula atrata Cushman	BULIMINIDAE	***Bulimina elongata*** d'Orbigny
	Textularia sagittula jistulosa Brady		***Bulimina elongata subulata*** Cushman & Parker
ATAXOPHRAGMIIDAE	***Dorothia gibbosa*** (d'Orbigny)		***Bulimina gibba*** Fornasini
	Gaudryina rudis Wright		***Reussella afL spinulosa* (Reuss)**
NUBECULARIIDAE	***Spiroloculina dilatata*** d'Orbigny	UVIGERINIDAE	*Hopkinsina bononiensis* (Fornasini)
MILIOLIDAE	***Quinqueloculina akneriana*** d'Orbigny		*Trifarina aff. elongatostriata* (Colom)
	Quinqueloculina aff. disparalis d'Orbigny		***Trifarina aff. fornasinii*** (Selli)
	Quinqueloculina dutemplei d'Orbigny	DISCORBIDAE	***Neoconorbina nitida*** (Williamson)
	Quinqueloculina lata Terquem		***Neoconorbina terquemi*** (RZEHAK)
	Quinqueloculina longirostra d'Orbigny		***Rosalina globularis*** d'Orbigny
	Quinqueloculina seminulum (Linnaeus)		*Cancris auriculus* (Fichtel & Moll)
	Quinqueloculina viennensis Le Calvez		***Cancris oblongus*** (Williamson)
	Sigmoilopsis aff. tenuis (CZJZEK)	GLABRATELLIDAE	*Glabratella australensis* (Heron-Allen & Earland)
NODOSARIIDAE	*Lagena aff. distoma* Parker & JonesS		*Glabratella crassa* Dorreen
	Lagena sulcata laevicostata (Cushman & Gray)	ROTALIIDAE	***Ammonia beccarii*** (Linnaeus)
	Lagena semi-striata (Williamson)		***Ammonia beccarii inflata*** (Seguenza)
	Lagena striata (d'Orbigny)		***Ammonia beccarii punctatogranosa*** (Seguenza)
	Orthomorphina *proxima* (Silvestri)		***Pararotalia serrata*** (Ten Dam & Reinhold)
POLYMORPHINIDAE	***Globulina gibba*** d'Orbigny	ELPHIDIIDAE	***Elphidium advenum*** (Cushman)
	Globulina gibba jissicostata Cushman & Ozawa		***Elphidium fichtellianum*** (d'Orbigny)
	Globulina gibba longitudinalis Cushman & Ozawa		***Elphidium macellum*** (Fichtel & Moll)
	Globulina gibba myristiformis (Williamson)		***Cribroelphidium excavatum*** (Terquem)
	Globulina gibba striata Egger		***Cribrononion afL articulatum*** (d'Orbigny)
	Globulina gibba tuberculata d'Orbigny		***Elphidium crispum*** (Linnaeus)
	Globulina gibba verrucosa Cushman & Ozawa	CIBICIDIDAE	***Cibicides lobatulus*** (Walker & Jacobs)
	Globulina inaequalis Reuss		***Cibicides refulgens*** De Montfort
	Globulina laerima Reuss		***Cibicides pseudoungerianus*** (Cushman)
	Guttulina problema d'Orbigny		*Planorbulina mediterranensis* d'Orbigny
	Sigmomorphina semitecta terquemiana (Fornasini)	CASSIDULINIDAE	***Cassidulina carinata*** Silvestri
GLANDULINIDAE	*Glandulina dimorpha* (Bornemann)		***Cassidulina laevigata*** d'Orbigny
	Glandulina pliocenica (Colom)		***Globocassidulina crassa*** (d'Orbigny)
	Oolina aff. globosa (Montagu)		***Globocassidulina subglobosa*** (Brady)
	Oolina melo d'Orbigny	NONIONIDAE	***Nonion boueanum*** (d'Orbigny)
	Oolina afL seminuda (Brady)		*Nonion elongatum* (d'Orbigny)
	Fissurina bradii Silvestri		***Nonion scaphum*** (Fichtel & Moll)
	Fissurina lacunata (Burrows & Holland)		***Astrononion stelligerum*** (d'Orbigny)
	Fissurina afL marginata Walker & Boys		***Nonionella* sp.**

Family	Genus/Species	Family	Genus/Species
	Fissurina orbignyana Seguenza	OSANGULARIIDAE	***Osangularia pulchra*** (Cushman)
	Fissurina **sp.**	ANOMALINIDAE	***Hanzawaia nitidula*** (Brady)
CERA TOBULIMINIDAE	*Mississipina concentrica* (Parker & Jones)		
Planktonic			
GLOBOROTALIIDAE	***Turborotalia acostaensis pseudopima* (Blow)**		
GLOBIGERINIDAE	**Globigerina bulloides** d'Orbigny		
	Globigerinoides ruber (d'Orbigny)		
	Globigerinoides trilobus (Reuss)		
	Orbulina universa d'Orbigny		
	Globigerina praebulloides Blow		

4 GEOLOGY

The Mesozoic and Cenozoic thick sedimentary infill of the Portuguese central-west Atlantic margin make up the Lusitanian Basin and the post-rift cover of Estremadura and Beira Litoral ranges (e.g. Azerêdo *et al*., 2003; Martín-Chivelet *et al.*, 2019; Soares *et al*., 2012; Wilson *et al.*, 1989) Distensive faulting, in the Middle Eocene (Lutetian) related to the Pyrenean orogen, defied two Tertiary sub-basins: the northern Mondego Basin and the southern Lower Tagus Basin (Cunha *et al*., 1993).

The fossiliferous Pliocene deposits of the Mondego basin to the north of the river Tejo, extend between the regions of Caldas da Rainha, and Pombal and mainly comprise terrestrial sediments (conglomerates, coarse sandstones), nearshore sediments (mudstones with lignite and diatomite), and shallow marine sediments (micaceous fine sandstones) (Cardoso, 1984; Cunha *et al*., 1993; Dell Angelo & Da Silva, 2003; Pais, 2010). The fossil data obtained in previous studies (Brèbion, 1971; Cachão & Silva, 1990; Cardoso, 1984; Diniz, 1984; Diniz & Cachão, 1987; Dollfus & Cotter, 1909; Teixeira, 1979; Zbyszewski, 1959) have shown that the palaeoclimate could have been a warm and humid but started getting colder in the later most Pliocene (Cunha *et al*., 1993).

The Pliocene succession that outcrops on the Pombal region mainly consists of two stratigraphic units organized as a transgressive sequence below, sometimes with a basal lenticular conglomerate with coquinas, followed by regressive deposits of marine, to marginal marine and alluvial fine sandstone. These units are known as the Carnide Formation below, and the Roussa-Paredes Formation above (Silva *et al*., 2000). These deposits lie above the Middle Miocene sediments (Amor Formation). The top of these Miocene beds show signs of erosion that according to Zbyszewski (1959) goes back to the upper Miocene, in the Caldas da Rainha region and might have continued throughout the lowermost Pliocene.

The outcrop which was sampled is located at Vale Farpado, and has the coordinates: 39°53'46.91"N; 008°45'22.42"W. It was correlated with Carnide Formation by Cardoso (1984) based on the lithostratigraphy, sedimentology and the fossils found. The outcrop Figure 4.1 shows the Pliocene basal conglomerate rich on abraded shells is uncomfortably positioned on top of a surface of Miocene yellowish compact claystone from Amor Formation. A total thickness of about 1.2m of an exposed portion of the outcrop was sampled Figure 4.3. The section consists of 0.50m of fossiliferous basal grey conglomerate below and grey sands above, which are overlain by a three-centimeter-thick layer of dark grey claystone.

Figure 4.1: The outcrop that was studied, situated at Vale Farpado, with sample bags placed at the point of sampling.

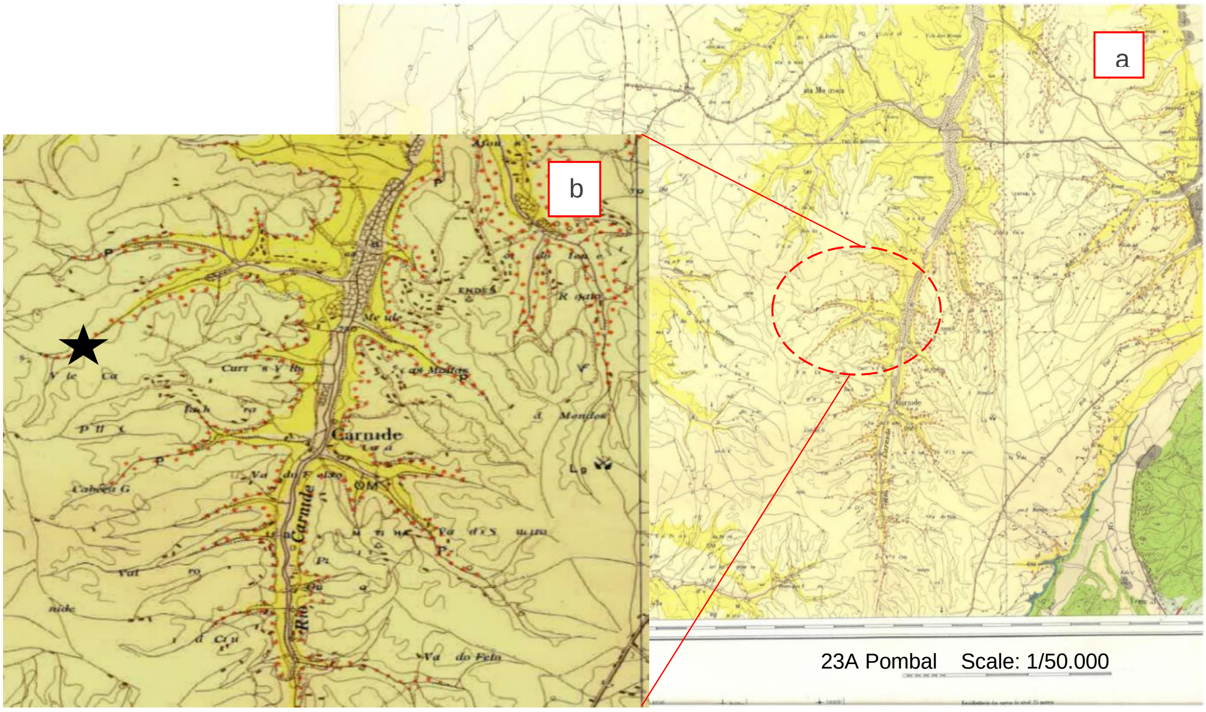

Figure 4.2: a) Location of Vale Farpado (circled in red) on the geological map of Pombal region by Manuppela *et al* (1978) . b) the location enlarged and the outcrop marked by a black star. The yellow colour are Pliocene sediments on top of the cream-coloured Miocene sediments.

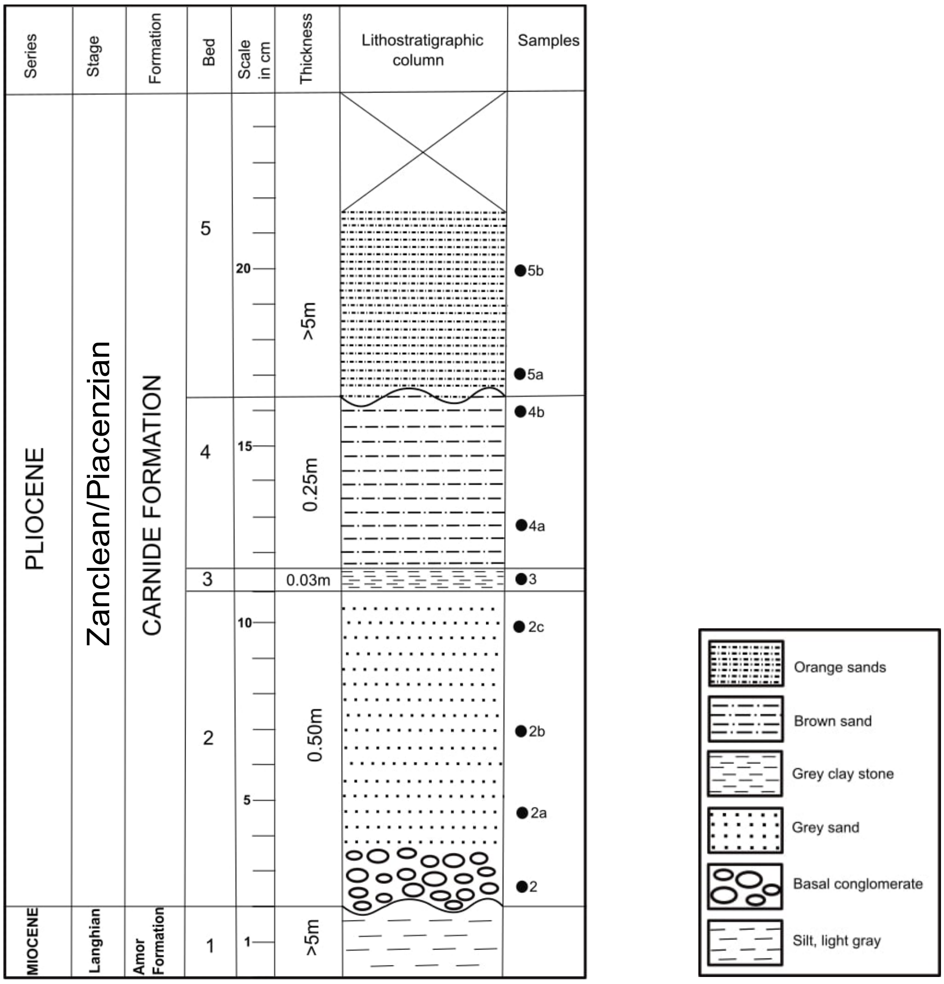

Figure 4.3: Stratigraphic log of Vale Farpado outcrop, with the location of the samples

In another outcrop of Vale Farpado, studied by Teixeira & Zbyszewski (1951), this layer is described to be 1-1.5m thick, thus concluding it to be a lenticular bed. Overlying the grey micaceous sand is a 0.25m thick layer of brown sand comprising many fossil molluscan shells. The top layer of the outcrop is made up of orange sands which are devoid of any fossil matter, including microfossils.

5 SEDIMENTOLOGY

Sedimentology is the study of sediments such as clay, slit and sand and sedimentary rocks in general. It includes the fundamental processes related to the formation of these sediments – weathering, erosion, transportation, deposition and diagenesis. It is a multidisciplinary field that includes geomorphology and hydrology (Wolff & Benedict, 1964).

5.1.1 GRAIN SIZE DISTRIBUTION

Grain size distribution or particle size distributions are very important physical properties of sedimentary rocks. It is usually represented by a list of values that defines the relative amount of particles according to the size of the grains. Grain size distribution has been used to study the sedimentary environment and the palaeosedimentary evolution as it provides important details about transport and depositional history and conditions (Liu *et al*., 2018).

5.1.2 BULK MINERALOGY

It is the study of the mineralogical composition of rocks. Any mineral can exist in a sedimentary rock due to its detrital nature. Clay minerals, the most prevalent mineral in mudrocks, are the most abundant mineral generated by the chemical weathering of rocks. Quartz is the most dominant mineral in sandstones and the second most abundant mineral in mudrocks because it is stable under the conditions present at the Earth's surface and is also a result of chemical weathering. Even though feldspar eventually decomposes into clay particles and quartz, it is the third most common mineral in sedimentary rocks. The study of these minerals provides information about the source rock, weathering regime and transportation (Kumar *et al.,* 2018).

5.1.3 CLAY MINERALOGY

Clay mineralogy is the study of the properties, composition, classification, crystal structure, occurrence and distribution of clay minerals. Changes in clay mineral association type with sample depth might reflect palaeoclimate and palaeoenvironment changes. Therefore, mineralogical data is used by geologists to study palaeoclimate and palaeoenvironment (Shen *et al*., 2012). Common clay minerals include smectite, illite, kaolinite, vermiculite, etc.

- Smectite: It is produced by the weathering of basic rocks in flat to moderately sloping terranes that are poorly drained and alkaline, such as in marine environments, and has high Si and Mg potentials (Borchardt, 1977).

- Illite: It refers to a dioctahedral mica-like clay mineral found in sedimentary rocks, particularly shales (Pevear, 1999).
- Kaolinite: It is most commonly formed in environments with high leaching conditions, such as high rainfall, good drainage, and acidic fluids (Shen *et al*., 2012). Kaolinite clay is abundant in soils created by the chemical weathering of rocks in hot, humid conditions, such as those found in tropical rainforests. As the temperature gets colder kaolinite decreases and other clay minerals such as illite and smectite increase.
- Vermiculite: It is a magnesium aluminum silicate mineral with high water content. Natural weathering, hydrothermal activity, percolating ground fluids, or a mix of these three processes have all been suggested as causes for the formation of vermiculite.

5.2 RESULTS FOR SEDIMENTOLOGY

Sample 2bottom and 2a could not be processed on time for sedimentological analysis of this work as it contained too much organic matter.

5.2.1 GRAIN SIZE DISTRIBUTION

Grain size distribution is based on statistics and the statistical parameters may give information on the environment and links them to particular sedimentary systems. The common parameters are mean, median and mode.

Table 5.2.1: The mean, median mode, Standard Deviation (S.D.) and the skewness of the grain size obtained from the samples.

Sample	Mean	Median	Mode	S. D	Skewness
2b	261.7	313.25	1909	4.6	-0.99
2c	517.95	912.5	1909	4	-1.53
3a	321	414.6	1909	4.7	-0.8
4a	106.99	107.55	105.9	3.4	-0.84
4b	119.4	117	105.9	3.1	-0.74
5a	85.81	101.05	105.9	2	-0.34
5b	86.09	102.4	105.9	2.6	-2.18

Mean is the average size of the entire sample, the median is the diameter where 50% of the particles are above or below the threshold and mode is the particle size that occurs at the highest frequency. The standard deviation (S.D) is a measurement of the spread or dispersion of grain sizes around the average or mean size and is used to classify sediments in terms of

sorting. In aeolian and coastal to inner environments, well-sorted sediments with low standard deviation are prevalent, but fluvial-alluvial deposits are often poorly sorted.
The Skewness is used to quantify the degree of dispersion within a sample, the distribution is more symmetrical if its skewness is closer to 0 (López, 2017). A positive (or fine) skewness refers to the presence of a longer tail in the range of fine-grained particles, whereas a negative (or coarse) skewness indicates the presence of a tail for coarser particles in the grain-size distribution. Coastal deposits have negative skewness in general, but the presence of fine-grained diagenetic populations can result in higher positive skewness in these deposits (Dinis *et al*., 2009).

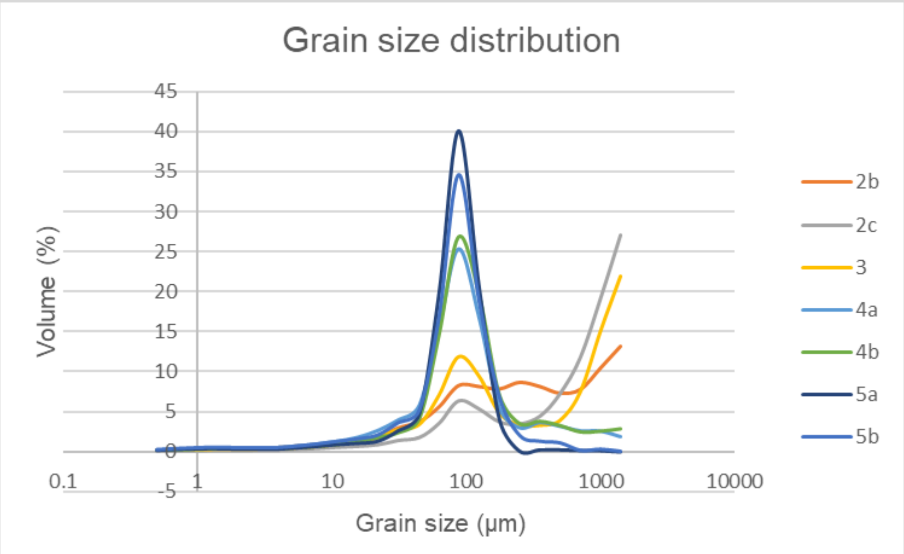

Figure 5.1: Volume percentage curves of each sample.

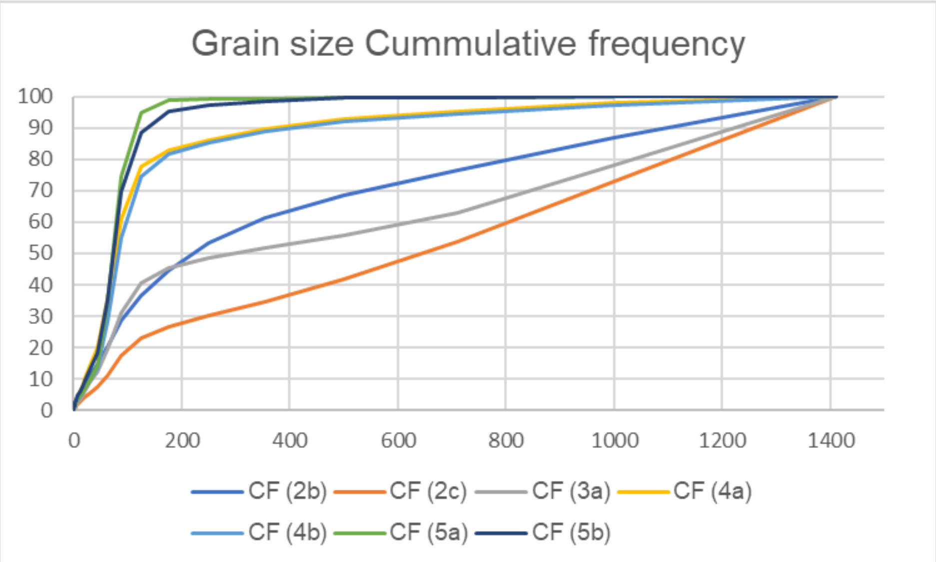

Figure 5.2: Cumulative frequency (C.F) of grain size distribution of all samples.

As we can see from the graph above Figure 5.1, 2b is polymodal with three grain size populations of fine to very fine sand that peak at 31µm, 88µm and 250µm. This multimodality could be due to the complexity of the dynamic environment of the coastal zone. The rest of the samples are unimodal and have a single grain size population of fine and very fine sand that peaks at 88µm. The sudden upward peak is seen in 2b, 2c and 3 graphs may have been the result of larger shell particles that the instrument could not read.

The S.D of our samples as seen in Table 5.2.1 ranges from 2-4.7 and skewness ranges from -2.18 to -0.34. According to (Folk, 1974), if S.D is 2-4 or >4, the grains are poorly sorted and if the skewness is < -0.30 the grains are strongly coarse skewed. The grains are very poorly sorted and are extremely asymmetrical indicating a high energy environment.

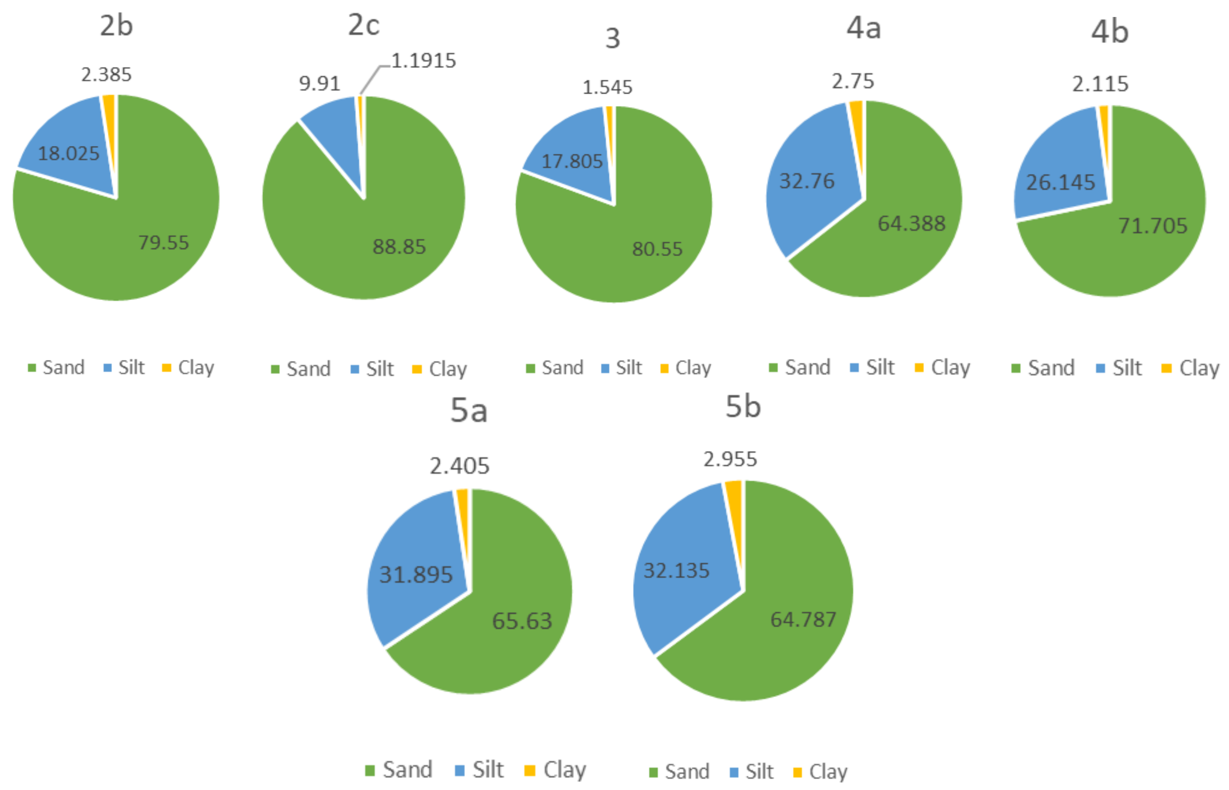

Figure 5.3: Pie chart depicting the proportions of the major size fractions; sand, silt and clay in all samples.

As observed from the pie graphs, sand (2000 µm- 83µm) dominates all the assemblages indicating a varying high energy environment. Assemblage 2c has the highest percentage and assemblage 4a has the lowest. Silt (63µm- 4µm) is the second dominant fraction with 4a having the maximum and 2c having the lowest. Clay (>4µm) only makes up 1-2% of the whole assemblage.

Assemblage 2c with more sand and less silt and clay could be the environment with the most energy and assemblage 4a could be an environment with relatively low energy and finer sediments.

5.2.2 BULK AND CLAY MINERALOGY

The following minerals or groups of minerals were identified in the bulk samples Quartz (30-76%), feldspar (12-30%), phyllosilicates (3-15%), and carbonates (0-45%). Some samples also hold hematite and pyrite in minor proportions. The clay mineral assemblages were dominated by illite (16-73%), followed by smectite (4-69%), kaolinite (16-38%). Vermiculite was found only in the topmost layer and in minor amounts (2%). Most of the fossiliferous layers are dominated by illite and smectite.

Table 5.2.2: The percentage of bulk minerals found in each

Sample	Quartz	Feldspar	Phyllosilicates	Carbonates	Others
VF2b	30	17	6	45	2
VF2c	44	30	3	20	4
VF3	60	21	5	14	0
VF4a	76	12	3	9	0
VF4b	43	33	15	9	0
VF5a	60	29	7	4	0
VF5b	64	27	9	0	0

Table 5.2.3: The percentage of clay minerals found in each sample.

Sample	Smectite	Vermiculite	Mica-Illite	Kaolinite
VF-2b	41	0	30	29
VF-2c	18	0	61	20
VF-3	44	0	31	25
VF-4a	40	0	35	26
VF-4b	69	0	16	16
VF-5a	4	0	73	24
VF-5b	10	2	52	38

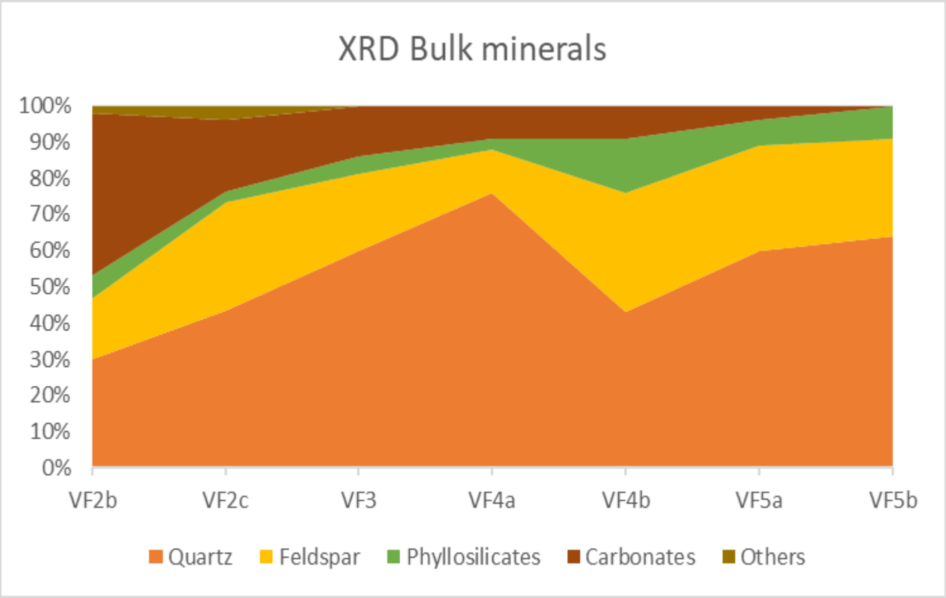

Figure 5.4: The percentage of bulk minerals found in each sample. Almost all the assemblage is dominated by quartz.

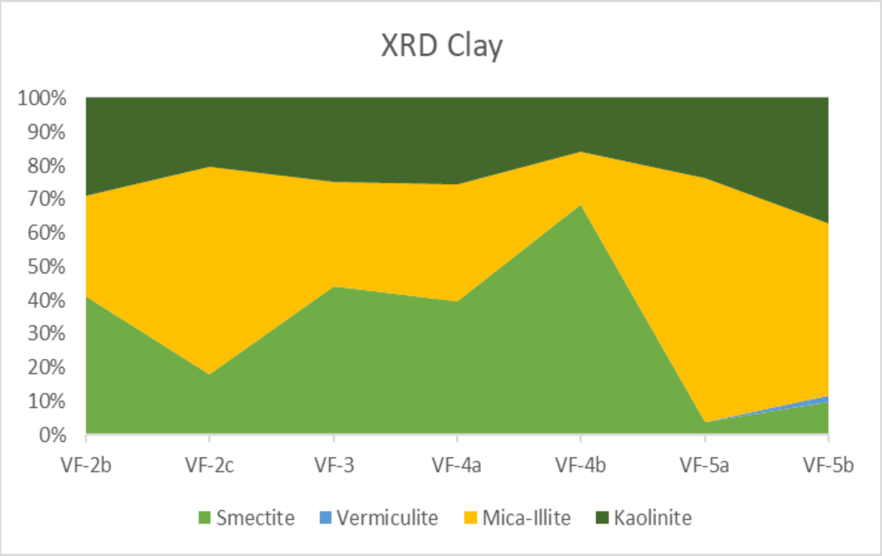

Figure 5.5: The percentage of clay minerals graphically represented. Smectite and Illite dominate the assemblage.

From Table 5.2.2 we can see that the first layer (2b) is dominated by carbonates followed by quartz and felspar with very few phyllosilicates. The dominance of carbonates could be a result of excessive shell fragments. From the second layer onwards, carbonates start decreasing and the quantity of quartz and phyllosilicates starts increasing with little fluctuations.

The clear upward decrease in carbonate content may be partially linked with a diagenetic decomposition of these minerals in well-drained environments. This possibility is compatible with the grain-size distribution obtained for these upper deposits, which are characterized by symmetric and relatively well-sorted distributions with very minor amounts of fine-grained particles. The relative increase in kaolinite in the uppermost deposits also supports this possibility.

From Table 5.2.3 we can see in layer 4b, illite and smectite make up 85% of the assemblage and there is a sharp decrease in kaolinite. The topmost layers, 5a and 5b show a sudden increase in illite and kaolinite and a very significant decrease in smectite.

The clay assemblages have been used to assess sea palaeotemperatures since associations rich in illite can be regarded as indictive of relatively cold environments, whereas, in warmer conditions, kaolinite tends to prevail (Biscaye, 1965; Chamley, 1989; Griffin *et al.*, 1968). However, in the studied deposits, the clay assemblages were likely influenced by hydrodynamic conditions at the time of depositions and by post-depositional transformations. The diagenetic decomposition of feldspar accounts for the increase of kaolinite in the well-sorted upper portion of the succession (5a and 5b). Since smectite is fine-grained and settles in deeper marine settings than kaolinite and illite, its concentration tends to rise with depth under certain climatic conditions (P. A. Dinis, Garzanti, *et al*., 2020; Petschick *et al*., 1996; Šimkevičius *et al.*, 2003). Hence, it can be assumed that water depth increased from the bottom of the succession, reaching a maximum with layer 4b. Some XR Diffractograms of Bulk and Clay minerals are shown below in Figure 5.6 and Figure 5.7.

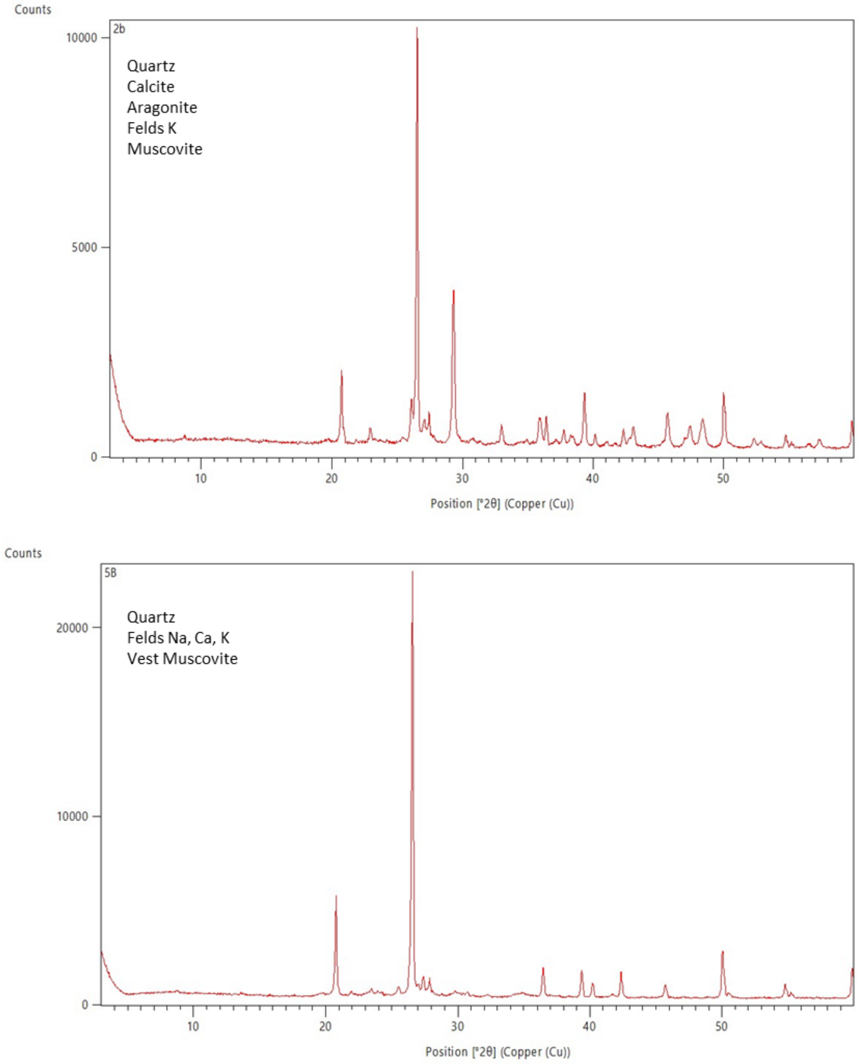

Figure 5.6: Some typical XRD response of bulk samples. A sample with carbonates and quartz in similar amounts, seconded by feldspar and minor phyllosilicates; (above); a quartz-dominated sample with secondary amounts of feldspars and minor phyllosilicates (below).

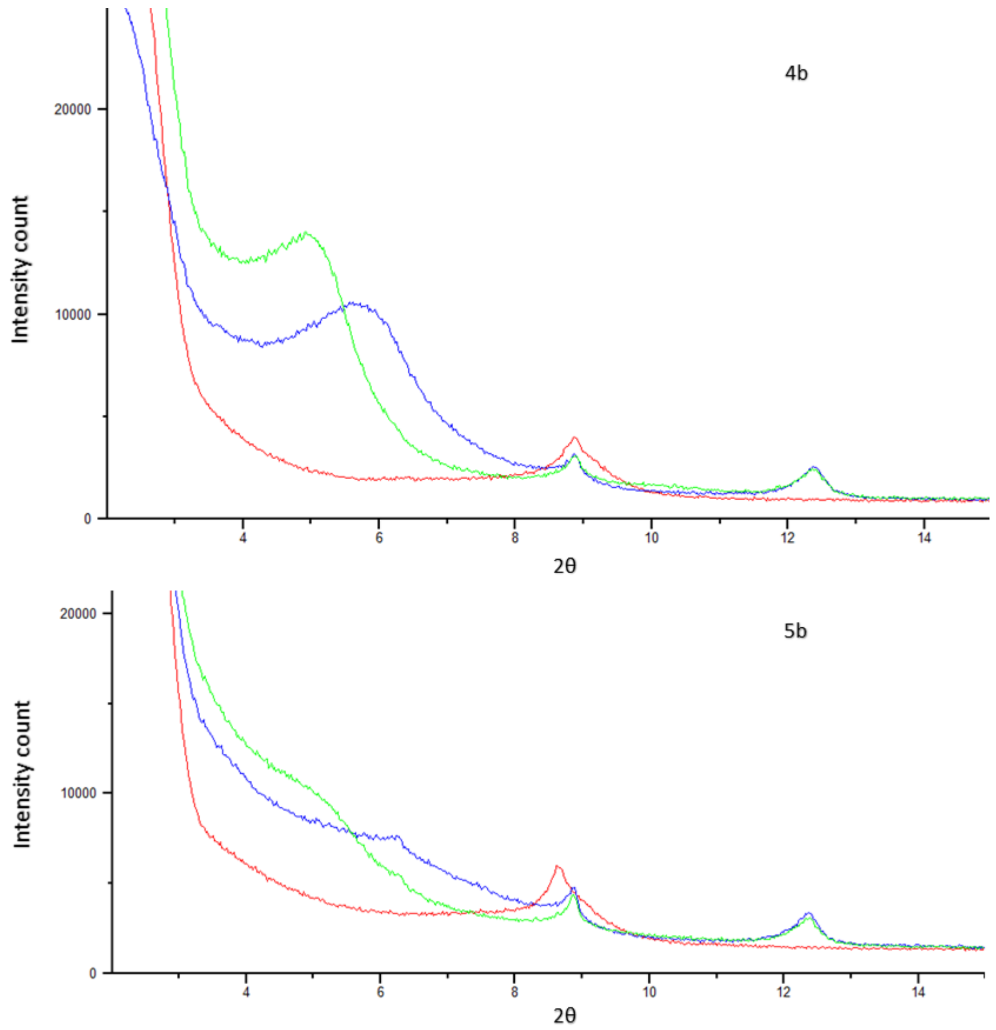

Figure 5.7: Some typical XRD response of clay samples. Blue- normal, green- glycolated, red- heated Smectite-dominated with secondary amounts of illite and kaolinite (above); illte and kaolinite in comparable amounts (below).

6 FORAMINIFERA

6.1 MORPHOLOGY

6.1.1 THE CELL

Foraminifera are single-celled organisms, composed of cytoplasm enclosed within a shell or test. The cell is made up of two layers, the inner endoplasm, and the outer ectoplasm. The endoplasm contains one or more nuclei, and cell organelles such as ribosomes, Golgi apparatus, and mitochondria, it is always protected by the test (Armstrong & Brasier, 2005). The ectoplasm forms a thin layer outside the test and gives rise to reticulose pseudopodia (reticulopodia) for locomotion, feeding, attachment, and test construction (Jones, 2014; Murray, 2006). The reticulopodia are the most important factor in classifying foraminifera as a separate taxonomic group within Protista (Murray, 2006).

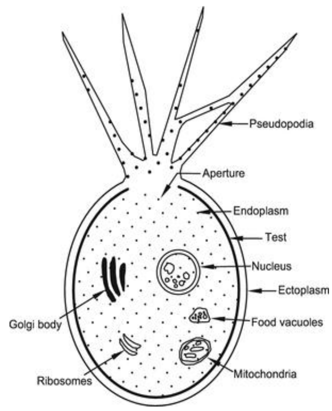

Figure 6.1: A cross-section of a single-celled foraminifera cell (Saraswati & Srinivasan, 2016)

6.1.2 LIFE CYCLE AND MODE OF LIFE

The life cycle of only a few species has been studied. The life expectancy of forams can vary between a few weeks up to a few years. The reproduction of foraminifera takes place in two stages, sexual (gamont generation) and asexual (agamont generation), this is not strictly followed and can vary (Murray, 2006). In some species, the test exhibits dimorphism, where the microspheric agamonts have larger tests and the megalospheric gamont have smaller tests, and in some species, this can be reversed (Armstrong & Brasier, 2005; Murray, 2006). Field studies showed that the duration of reproduction can vary between a few weeks for some small species and a year for larger forms. Reproduction can be initiated by favorable temperatures for some species but the availability of food plays a major role (Murray, 2006).

Foraminifera exhibits two modes of life: benthic (bottom-dwelling) and planktonic (free-floating) and between the benthic, they can be epifaunal and infaunal, some active forms are free moving and some are attached to a substrate. Epifaunal forms live on a soft substrate such as sediments or firm substrates such as shells, rocks, plants, and animals. Infaunal taxa can be attached, clinging, or free (Murray, 2006). The free forms move through the sediments using borrows (Kitazato, 1994). Planktic foraminifera lives at the surface to water depths of about 1000m (Jones, 2014).

6.1.3 The test

Foraminifera test is composed of either agglutinated particles or secreted minerals such as calcite, aragonite, or silica or secreted organic matter such as tectin (Armstrong & Brasier, 2005). After foraminifera die, their tests and test fragments accumulate in deep-sea sediments. Carbonate ooze (or Globigerina ooze) is a kind of carbonate deposition made up of foraminiferal shells that cover nearly half of the ocean bottom. As a result, these fossil species play a key part in the worldwide marine carbon cycle and serve as excellent climate recorders of previous oceanographic circumstances (Kimoto, 2015).

The test size can range from 0.1mm to 1.5mm and in some cases it can be as large as 15cm. The test can be made up of one or more chambers, which contain an opening or aperture called foramen, giving the group its name Foraminifera or aperture bearing (Jones, 2014). The major function of the test is to provide shelter; however, its other functions include aiding reproduction, offering protection from predators, assisting the growth of the cell, and controlling buoyancy. Tests can break as a result of predation and from high-energy environments and therefore the tests in high-energy environments are thicker (Murray, 2006). Test morphology varies from one chamber to numerous chambers. In the classification of the group, the structure, and composition of the test wall play an important role. The basic types of wall structures are agglutinated, calcareous hyaline, micro granular and porcelaneous. Calcareous tests are the most abundant and are found in most suborders, the organic-walled tests belong to the suborder Allogromiina and are generally made from tectin. The suborder Textulariina comprises agglutinated tests, which are made from organic and mineral matter from the seafloor, bound together by an organic, calcareous, or ferric oxide cement. The forms with micro granular tests from the suborder Fusulina (Armstrong & Brasier, 2005).

Calcareous walls can be of three types: porcelaneous imperforate, micro granular, and hyaline perforate. The suborder Miliolina is characteristic of porcelaneous imperforate tests and is milky white in reflected light. The tests are made up of tiny needles of high magnesium calcite and for the most part are randomly arranged Hyaline perforate tests with high to low magnesium calcite are found in many suborders such as Spirillinina, Globigerina, Rotalinna, Involutinina, Robertinina and are glassy in reflected light (Armstrong & Brasier, 2005; Schweizer *et al*., 2008).

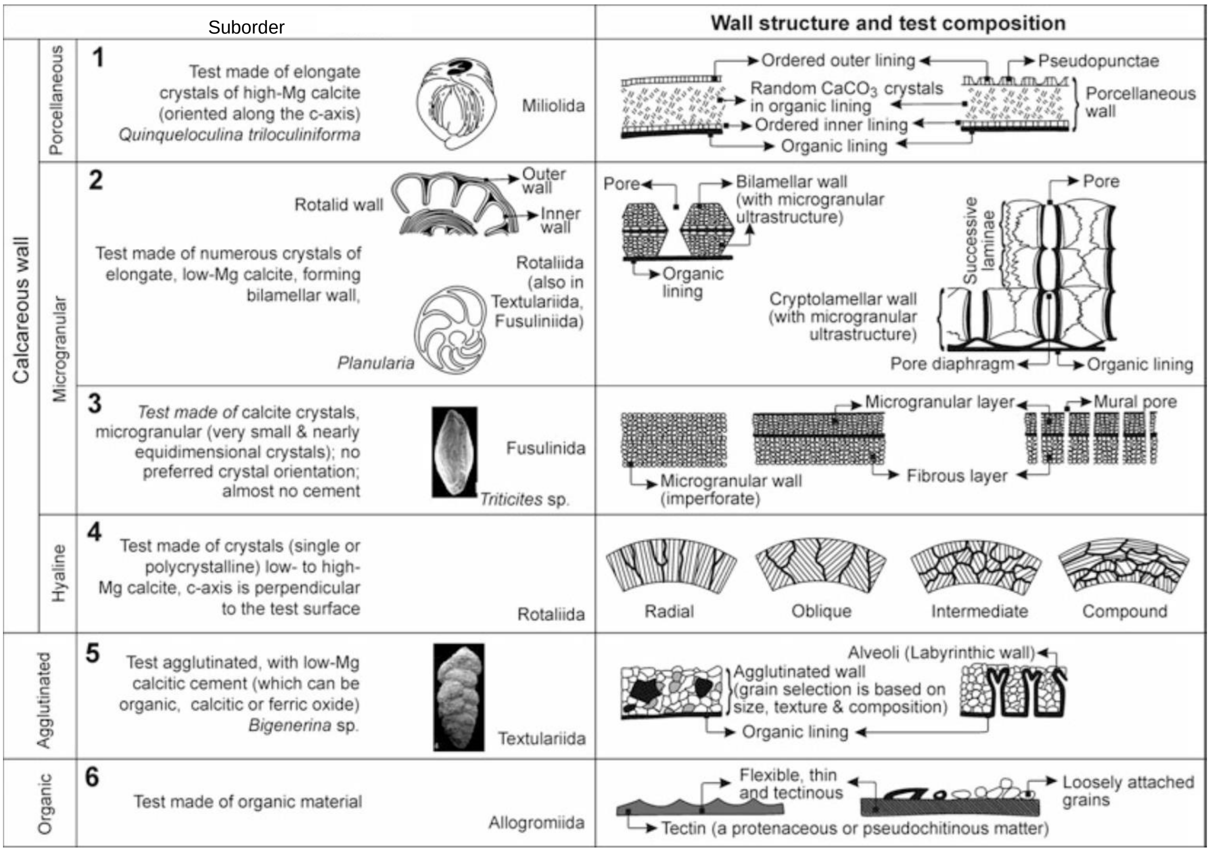

Figure 6.2: Different suborders and their respective wall composition (Jain, 2020)

Most primitive foraminifera have a single chamber or unilocular tests such as open tubes or hollow spears and show contained growth due to lack of space for enlargement. They have to abandon the test and grow a new one or reproduce, this is usually overcome by adding a second tubular chamber. Although such primitive foraminifera are found today, they were predominant in the lower Paleozoic (Armstrong & Brasier, 2005).

Multilocular forms add new chambers at regular intervals by covering the preceding aperture to allow the cytoplasm to flow freely. Each chamber is divided by a septum that limits the aperture and protects the endoplasm. There are three variables: rate of translation, rate of chamber expansion, and the chamber shape that interact with each other to give rise to most multilocular tests (Armstrong & Brasier, 2005; Loeblich & Tappan, 1988).

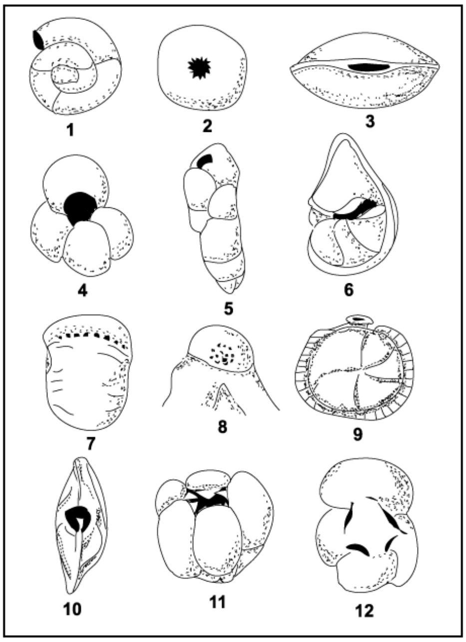

Figure 6.3: Illustrations of aperture types in foraminifera. (Loeblich & Tappan, 1964; Ucl.ac.uk, 2016)

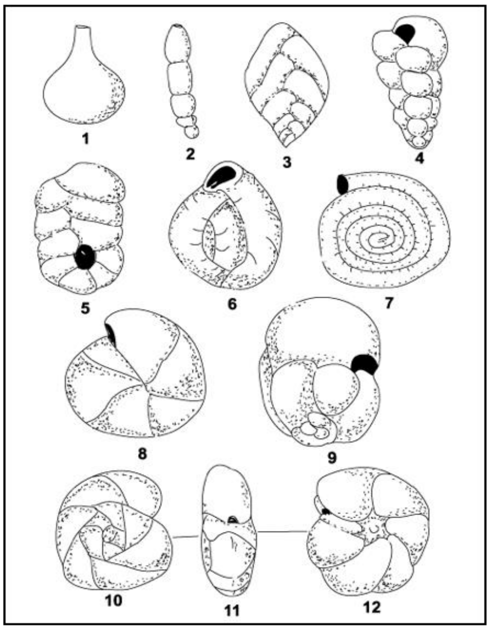

Figure 6.4: Illustrations of chamber arrangement in foraminifera. (Loeblich & Tappan, 1964; Ucl.ac.uk, 2016)

In foraminifera, one chamber is connected to the next by a single or multiple foramina. The opening in the final chamber of foraminifera is called an aperture and can vary in both position and form. The aperture connects the ectoplasm with the endoplasm and allows the passage of food, excretory products, cytoplasm, and nuclei (Armstrong & Brasier, 2005). The position of the aperture remains constant throughout life. With regards to the opening of the primary aperture, 11 types are noted in Figure 6.3

1. Open end of tube
2. Terminal radiate
3. Terminal slit
4. Umbilical
5. Loop shaped
6. Interiomarginal
7. Interiomarginal multiple
8. Areal crbrate,
9. With phialine lip,
10. With bifid tooth,
11. With umbilical teeth, and
12. With umbilical bulla (Loeblich and Tappan, 1964).

The different types of chamber arrangement in foraminifera are Figure 6.4:

1. Unilocular or single-chambered
2. Uniserial: the chambers are arranged in a linear series
3. Biserial: the chambers are arranged in two rows
4. Triserial: chambers arranged in three rows
5. Planispiral to biserial: during growth, the mode of chamber addition changes.
6. Miliolid: the chambers are externally visible and the growth is in varying planes along a vertical axis.
7. Planispial evolute: the chambers are arranged in a coil on a single plane and they are all visible
8. Planispiral involute: the chambers are arranged in a coil on a single plane and only the last chamber is visible
9. Streptospiral: the chambers are irregularly enrolled.
10. Trochospiral: the chambers are spirally arranged (helical coil), in which the umbilical side is involute and the spiral side is evolute (10-11 in Figure 6.4) (Jain, 2020; Loeblich & Tappan, 1964)

Planktic foraminifera are divided into three superfamilies based on their test morphology:

1. Globigerinoidea are characterized by trochospiral coiling and are spinose.
2. Globorotaloidea have trochospiral to streptospiral coiling and are non–spinose.
3. Heterohelicoidea display biserial to triserial coiling and are non-spinose with micro-perforations on the surface.

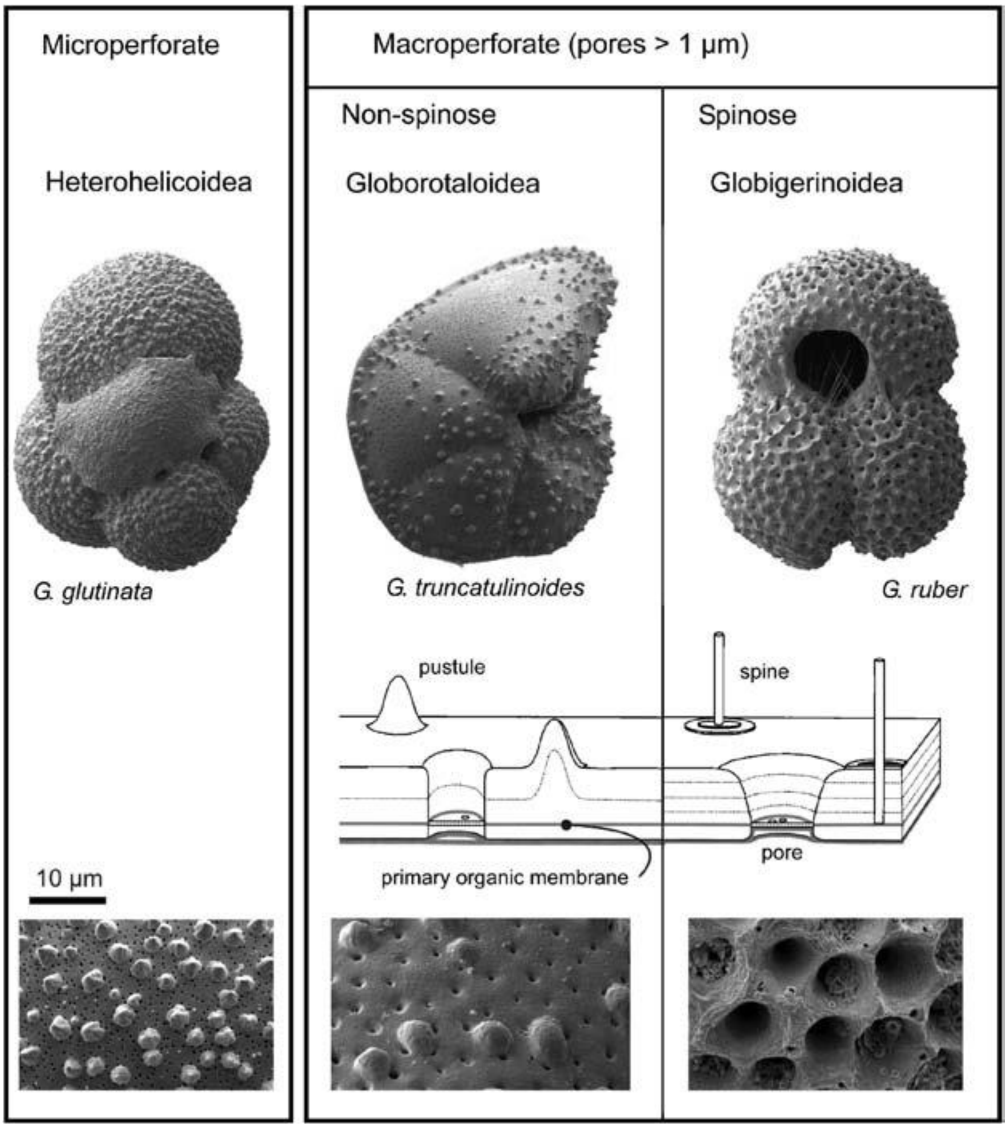

Figure 6.5: Classification of three main groups of planktonic foraminifera. Typical morphology and wall ornament shown by the representative specimens (not to scale) (Kucera, 2007).

6.2 CLASSIFICATION OF FORAMINIFERA

Although foraminifera have been recorded since classical times, it was only in the 18th century that an attempt was made to classify them. In the publication of the twelfth edition of *Systema Naturae,* Linnaeus (1766) recognized 15 species of foraminifera and classified 14 of them in the cephalopod genus *Nautilus* and placed the remaining one in the genus *Serpula.* The authors that came later such as Fichtel and Moll (1798, 1803) followed the example of Linnaeus and grouped the forams found in the genus *Nautilus.* In the later years, new genera were introduced such as *Ammonia* Briinnich (1772), and *Lagena* Walker and Boys (1784); both of which are valid genera even today (Richardson, 1990).

In 1826, Alcide d'Orbigny named the group Foraminifères and placed them in a separate order within the class Cephalopoda in his first published classification of foraminifera, *Tableau Methodique* (d'Orbigny, 1826). The reason for this separation was their perceived internal shell; lack of siphon; the presence of a final, closed chamber; and the existence of one or more apertures. He classified them further into families based on the plan of growth, or chamber arrangement. In this work, he also proposed 87 generic names introduced by de Montfort (1808), Lamarck (1801-1822) and Defrance (1816-1825) according to Richardson (1990) and Saraswati & Srinivasan (2016).

Felix Dujardin (1835) was the first author to point out the protozoan nature of foraminifera. Williamson (1858) suggested that the foraminiferal species can be separated by the means of its wall texture; arenaceous, porcelaneous, and hyaline. The modern-day foraminifera suborders such as Textulariina, Miliolina and Rotaliina all correspond to Williamson's arenaceous, calcareous imperforate and calcareous perforate divisions (Richardson, 1990).

Brady (1884) classified the foraminifera found during the challenger expedition (1872- 1876), based on multiple characteristics such as the number of apertures, plan of growth, wall texture and composition, test shape and chamber arrangement. This scheme of classification was monumental at the time as it focused on a combination of characters rather than just fundamental characters. His classification consisted of ten families and twenty-nine subfamilies. He graded his families from the most primitive (Gromidae), in which he placed chitinous forms to the most structurally advanced family (Nummulinidae), in which he placed the Miliolininae and other single-chambered and spiral coiled forms (Richardson, 1990).

Joseph A Cushman, in (Cushman, 1928) revolutionised the study of foraminiferal classification by introducing phylogeny, with a strong emphasis on developmental stages. He classified them into families based on their evolutionary characteristics and their first appearance in the geological record, starting with the most primitive forms, the chitinous Allogromiidae although, there is no geological record of this group because of their shells, followed by the arenaceous and later the calcareous. He was also the first to propose a practical application of the study of foraminifera to subsurface stratigraphy (Richardson, 1990).

6.3 FORAMINIFERA AND ITS USE IN PALAEOENVIRONMENTAL ANALYSIS

Palaeoecology is the study of how fossil organisms interacted with each other and their environment in the geological past. The formation of sedimentary rocks records the environment in which it was deposited and can be interpreted with the theoretical basis of uniformitarianism. Palaeoenvironmental analysis involves studying palaeoecology and sedimentary rocks to determine the nature of the ancient environment. The fossils that are useful in palaeoenvironmental analysis should have restricted environmental tolerances, they should also be abundant, well preserved and easy to identify. A fossil that marks all these criteria is called a facies fossil.

Foraminifera in most cases classifies as a facies fossil and is most commonly used for dating rocks through time. The extant forms of Cenozoic and Mesozoic taxa are used to interpret the environment based on taxonomic uniformitarianism and in the case of extinct taxa, the palaeoenvironment is interpreted based on associated fossils and sedimentary facies example Gebhardt (1997) and Grossi & Gennari (2008).

Fossil foraminifera are useful in estimating the sediment and depositional environment age due to fast evolution rate and hence a short stratigraphic range. The petroleum industry in the early twentieth century studied the assignment of lithostratigraphic unit ages and their correlation by using foraminifera.

6.3.1 Ecology

Most foraminifera are marine organisms but as a group, their broad ecological tolerances to salinity, depth and temperature can lead them to also occur in estuaries, lagoons and fresh water. However, individual species have narrow ecological distribution and this makes them useful in palaeoenvironmental interpretation. The composition of foraminiferal assemblage is controlled by various biotic and abiotic factors such as salinity, light, temperature, food, nutrients, substrate and dissolved oxygen. This makes foraminifera good indicators of specific environments or environmental change.

- ***Salinity:*** Foraminifera are most diversified in normal marine or euhaline conditions (35‰). Agglutinated foraminifera prefer water with low salinity or hyposaline conditions (0- 33‰). Porcelaneous forms thrive in hypersaline conditions. In total foraminifera can tolerate fresh water to hypersaline conditions (0-70‰) (Armstrong & Brasier, 2005; Murray, 2006).
- ***Temperature:*** The upper-temperature limit of any marine organism is 45ºC. Foraminifera species adapted to a short temperature range are called stenothermal and those tolerant of a wide range of temperature are called eurythermal (Murray, 2006). Each species are adapted to a specific temperature range in which successful reproduction can take place (Armstrong & Brasier, 2005).
- ***Light:*** Foraminifera tend to be more abundant in the photic zone due to high primary production, availability of substrates such as sea grass and protection. Planktonic forams that feed on diatoms also fluctuate according to seasonal cycles (Armstrong & Brasier, 2005).

- ***Food supply:*** Foraminifera feed a wide range of food such as unicellular algae, diatoms, bacteria and other bacteria and some have symbionts or husband chloroplasts (Murray, 2006). Food supply is one of the main factors that affect the diversity of foraminifera and in areas of low food supply, foraminiferal densities tend to be lower (Schmiedl *et al*., 1997).
- ***Dissolved oxygen:*** The critical range of foraminifera if from anoxic (0 dissolved oxygen) to dysoxia and once an environment is oxic there is no stress from oxygen. The forams that thrive in anoxic, dysoxic and oxic environments are called anaerobic, dysaerobic and aerobic respectively. The concentration of oxygen depends on the temperature and salinity of water (Murray, 2006).
- ***Nutrients:*** These are chemicals that are required for plants to produce food through photosynthesis. If there is low primary production, then foraminiferal diversity also tends to be lowered.

The organic-walled foraminifera are usually not well preserved because of their delicate tests and therefore not useful in palaeoenvironmental interpretation. Forams belonging to the order Miliolida with porcelaneous walls and calcareous walls and forams belonging to Nodosariida, Buliminida, Robertinida and Rotaliida occur from marginal to deep marine environments and tolerate hypersaline to hyposaline conditions (Jones, 2014; Saraswati & Srinivasan, 2016). The larger benthic foraminifera (LBFs) prefer shallow marine with carbonate platforms and reef environments.

7 SYSTEMATICS AND CLASSIFICATION

Loeblich and Tappan classified foraminifera into suborders based on their test morphology such as wall structure and composition, ultrastructure, and method of test formation. The number of chambers of the test, the existence of wall perforations, canal systems, canaliculi and major aperture features were used to further divide into superfamilies. They were again divided into families based on their mode of life (free-living or attached), mode of chamber addition, the chamber interior being simple or undivided, and modification in the aperture. At species level surface ornamentation played an important role (Loeblich & Tappan, 1988).

Foraminiferal classification systematics of this study was based on those of Loeblich & Tappan (1988) and for the genus and species levels Hayward *et al*. (2021) was referred. For planktonic foraminifera, Kennett & Srinivasan (1983) was used. foraminifera.eu was also used to identify the forams.

Specimens with more than half-shells were picked and counted. The total benthic forams for each sample are 2bottom – 255, 2a – 691, 2b – 246, 2c – 340, 3 – 242, 4 – 252, 4b – 289 and planktonic were – 2bottom – 14, 2a – 6, 2b – 4, 2c – 10, 3 – 29, 4a- 19, 5b – 25. The complete list of all the species benthic and planktonic can be seen in tables Table 7.2.1 and Table 7.5.1 and images can be seen in Plate 7.1, Plate 7.2 and Plate 7.3.

The following Remarks are from observations and the papers used as guidelines were Berggren *et al*. (1986), Brun *et al.* (1984), Debenay (2012), Lei & Li (2016), Milker & Schmiedl (2012) and Tóth & Görög (2008).

7.1 ORDER FORAMINIFERIDA EICHWALD, 1830

7.2 SUBORDER LAGENIDA DELAGE AND HEROUARD, 1896

7.2.1 FAMILY LAGENIDAE REUSS, 1862

GENUS *LAGENA* WALKER AND JACOB, 1798

***Lagena striata* (d'Orbigny, 1839)**

Original name *Oolina striata* d'Orbigny, 1839

Synonymy

Oolina striata d'Orbigny, 1839

2012, *Lagena striata* (d'Orbigny, 1839) - Milker & Schmiedl, p.70, fig 18.33

2016, *Lagena striata* (d'Orbigny, 1839) - Lei & Li, p. 167, fig.18

Remarks

Test unilocular and ovate. There is an ornamentation of many longitudinal striae on the test surface and no ornamentation on the neck. The aperture is in the terminal position on a short neck. The wall is calcareous and hyaline.

Table 7.2.1: List of all the benthic foraminifera identified from Vale Farpado in this work. The species in **bold** were not mentioned in Cardoso (1984) Carvalho & Colom (1954).

Family	Genera	Species
Bulimenidae	*Bulimina*	***Bulimina aculeata*** **d'Orbigny, 1826**
		Bulimina elongata d'Orbigny, 1826
Bolivinidae	*Bolivina*	***Bolivina antiqua*** **d'Orbigny 1846**
		Bolivina catanensis Seguenza, 1862
		Bolivina robusta (Brady, 1881)
		Bolivina subspinescens Cushman, 1922
	Sigmavirgulina	***Sigmavirgulina tortuosa*** **(Brady,1881)**
Cassidulinidae	*Cassidulina*	*Cassidulina carinata* Silvestri, 1896
	Globocassidulina	*Globocassidulina crassa* (d'Orbigny, 1839)
Bagginidae	*Cancris*	*Cancris auriculus* (Fichtel & Moll, 1798)
Reussellidae	*Reussella*	*Reussella spinulosa* (Reuss, 1850)
Rosalinidae	***Rosalina***	***Rosalina globularis*** **d'Orbigny, 1826**
		Rosalina macropora **(Hofker, 1951)**
Cibicididae	*Cibicides*	*Cibicides refulgens* Montfort, 1808
	Cibicidoides	***Cibicidoides wuellerstorfi*** **(Schwager, 1866)**
		Cibicidoides ungerianus **(d'Orbigny, 1846)**
	Lobatula	*Lobatula lobatula* (Walker & Jacob, 1798)
Planorbulinidae	*Planorbulina*	*Planorbulina mediterranensis* d'Orbigny, 1826
Asterigerinatidae	***Asterigerinata***	***Asterigerinata mamilla*** **(Williamson, 1858)**
	Biasterigerina	***Biasterigerina planorbis*** **(d'Orbigny, 1846)**
Nonionidae	*Nonion*	*Nonion commune* (d'Orbigny, 1846)
	Nonionoides	***Nonionoides grateloupii*** **(d'Orbigny,1839)**
Rotaliidae	*Ammonia*	*Ammonia beccarii* (Linnaeus, 1758)
Elphidiidae	*Cribroelphidium*	*Cribroelphidium excavatum* (Terquem, 1875)
	Elphidium	*Elphidium crispum* (Linnaeus, 1758)
		Elphidium fichtellianum (d'Orbigny, 1826)
		Elphidium advenum (Cushman, 1922)
		Elphidium aculeatum **(d'Orbigny 1846)**
		Elphidium macellum (Fichtel & Moll, 1798)
Glabratellidae	*Glabratella*	*Glabratella australensis* (Heron-Allen & Earland, 1932)
Lagenidae	*Lagena*	***Lagena hispida*** **Reuss, 1858**
		Lagena ollula **Buchner, 1940**
		Lagena striata (d'Orbigny, 1839)
	Seguenzaella	***Seguenzaella lacunata*** **(Burrows & Holland, 1895)**
Ellipsolagenidae	***Favulina***	***Favulina hexagona*** **(Williamson, 1848)**
	Oolina	*Oolina seminuda* (Brady, 1884)
	Fissurina	***Fissurina eburnea*** **(Buchner, 1940)**
		Fissurina marginata (Montagu, 1803)
		Fissurina orbignyana Seguenza, 1862
Polymorphinidae	*Globulina*	*Globulina gibba* (d'Orbigny in Deshayes, 1832)
		Globulina gibba var. fissicostata Cushman & Ozawa, 1930
		Globulina inaequalis **Reuss, 1850**
	Guttulina	***Guttulina communis*** **(d'Orbigny, 1826)**
	Vasiglobulina	*Vasiglobulina myristiformis* (Williamson, 1858)
Cribrolinoididae	*Adelosina*	*Adelosina dutemplei* (d'Orbigny, 1846)
Hauerinidae	*Biloculinella*	***Biloculinella globulus*** **(Bornemann, 1855)**
Spiroloculinidae	*Spiroloculina*	*Spiroloculina dilatata* d'Orbigny, 1846
	Quinqueloculina	*Quinqueloculina akneriana* d'Orbigny, 1846
		Quinqueloculina lata Terquem,1876
		Quinqueloculina disparilis d'Orbigny, 1826

Family	Genera	Species
		Quinqueloculina seminulum (Linnaeus, 1758)
Eggerellidae	***Bannerella***	***Bannerella gibbosa*** (d'Orbigny, 1826)
Spiroplectamminidae	*Spiroplectammina*	*Spiroplectammina atrata* (Cushman, 1911)
	Spiroplectinella	*Spiroplectinella wrighti* (Silvestri, 1903)
Textulariidae	*Sahulia*	*Sahulia conica* (d'Orbigny, 1839).
	Textularia	*Textularia pseudogramen* Chapman & Parr, 1937
		Textularia sagittula Defrance, 1824
		Textularia truncata Höglund, 1947

***Lagena hispida* Reuss, 1858**

Original name *Lagena hispida* Reuss, 1858

Synonymy

Oolina hispida (Reuss, 1858)

Pygmaeoseistron hispidum (Reuss, 1863)

2016, *Lagena hispida* Reuss, 1858 - Lei & Li, p. 172, fig.21

Remarks

Test ovate to elongate with a neck in the anterior portion. The posterior end is rounded bluntly. It has a rounded terminal aperture on the neck. The test wall is hyaline and the surface is nebulous. The neck is smooth without any striae.

***Lagena* cf. *ollula* Buchner, 1940**

Original name *Lagena ollula* Buchner, 1940

Remarks

Test ovate to elongate with a neck in the anterior portion. It has a rounded terminal aperture at the end of the neck. The test is hyaline and smooth with no ornamentation.

GENUS *SEGUENZAELLA* MARGEREL, 2009

***Seguenzaella lacunata* (Burrows & Holland, 1895)**

Original name *Lagena lacunata* Burrows & Holland in Jones, 1895

Synonymy

Cerebrina lacunata (Burrows & Holland, 1895)

Entosolenia lacunata (Burrows & Holland, 1895)

Entosolenia orbignyana subsp. lacunata (Burrows & Holland in Jones, 1895)

Fissurina lacunata (Burrows & Holland, 1895)

Lagena lacunata Burrows & Holland in Jones, 1895

Lagena orbignyana var. lacunata Burrows & Holland, 1895

Palliolatella lacunata (Burrows & Holland, 1895)

2012, *Fissurina lacunata* (Burrows and Holland, in Jones 1895)- Milker & Schmiedl, p.76, fig 19.10-11

Remarks

Test subovate in section and ovate in outline. Three prominent keels are present on the periphery and the middle is more elevated. The slit like aperture is terminal and is bordered by a lip. The wall is calcareous and hyaline. The test surface is ornamented with irregularly arranged perforations and pittings.

7.2.2 Family ELLIPSOLAGENIDAE Silvestri, 1923

7.2.3 Subfamily OOLININAE Loblich and Tappan, 1961

Genus *Favulina* Patterson and Richardson, 1987

Favulina hexagona **(Williamson, 1848)**

Original name *Entosolenia squamosa var. hexagona* Williamson, 1848

Synonymy

Entosolenia hexagona Williamson, 1848

Entosolenia squamosa var. hexagona Williamson, 1848

Lagena favosa Reuss, 1863

Lagena hexagona (Williamson, 1848)

Oolina hexagona (Williamson, 1848)

2012, *Favulina hexagona* (Williamson, 1848) - Milker & Schmiedl, p.76, fig 19.4

2012, *Favulina hexagona* (Williamson, 1848) – Debenay p.144.

2016, *Favulina hexagona* (Williamson, 1848) - Lei & Li, p. 184, fig.28

Remarks

Test is unilocular and ovate. The aperture is rounded and terminal. The wall is calcareous and translucent. The test surface is ornamented with ridges that are polygonally arranged.

Genus *Oolina* d'Orbigny, 1839

Oolina seminuda **(Brady, 1884)**

Original name *Lagena seminuda* Brady, 1884

Synonymy

Lagena seminuda Brady, 1884

Remarks

Test is unilocular and ovate. The aperture is small, rounded and covered by a rim. It is in the terminal position. The wall is calcareous, the bottom half of the shell is covered by polygonal ridges and the top half is smooth.

7.2.4 Subfamily ELLIPSOLAGENINAE Silvestri, 1923

Genus *Fissurina* Reuss, 1850

Fissurina eburnea **(Buchner, 1940)**

Original name *Lagena eburnea* Buchner, 1940

Synonymy

Lagena eburnea Buchner, 1940

Remarks

Test globose to ovate. It only has a single pyriform chamber. The aperture is slit and in terminal position. the test surface is smooth. The wall is calcareous and translucent.

***Fissurina marginata* (Montagu, 1803)**

Original name *Vermiculum marginatum* Montagu, 1803

Synonymy

Entosolenia marginata (Montagu, 1803)

Entosolenia submarginata Boomgaart, 1949

Fissurina submarginata (Boomgaart, 1949)

Lagena (Fissurina) marginata (Montagu, 1803)

Lagena marginata (Montagu, 1803)

Lagena sulcata var. marginata (Montagu, 1803)

Serpula marginata (Montagu, 1803)

Vermiculum marginatum Montagu, 1803

2012, *Fissurina marginata* (Montagu, 1803) - Milker & Schmiedl, p.76, fig 19.12

Remarks

The unilocular test is subovate in section and subrounded in outline. The aperture is slit like and terminal. The wall is calcareous, hyaline and finely perforate. The test surface is smooth. It has three keels on the periphery and the middle is more elevated. There is a visible free and straight entosolenian tube.

***Fissurina orbignyana* Seguenza, 1862**

Original name *Fissurina orbignyana* Seguenza, 1862

Synonymy

Entosolenia orbignyana (Seguenza, 1862)

Fissurina (Fissurina) orbignyana Seguenza, 1862·

Lagena orbignyana (Seguenza, 1862)

Oolina orbignyana (Seguenza, 1862)

Palliolatella orbignyana (Seguenza, 1862)

2012, *Fissurina orbignyana* Seguenza, 1862 - Milker & Schmiedl, p.76, fig 19.13

Remarks

Test unilocular and is ovate in outline and subovate in section. The aperture is slit like bordered by a lip and terminal. The wall is calcareous and hyaline. The test surface is ornamented with perforations and pittings that are irregularly arranged. There are three keels visible in the periphery, the middle is more elevated.

7.2.5 FAMILY POLYMORPHINIDAE D'ORBIGNY, 1839

7.2.5.1 *SUBFAMILY POLYMORPHININAE D'ORBIGNY, 1839*

GENUS *GLOBULINA* D'ORBIGNY, 1839

***Globulina gibba* (d'Orbigny in Deshayes, 1832)** Plate 2, Fig 16

Original name *Polymorphina gibba* d'Orbigny in Deshayes, 1832

Synonymy

Globulina aequalis d'Orbigny, 1846

Globulina rugosa d'Orbigny, 1846

Globulina tubulosa d'Orbigny, 1846

Guttulina gibba (d'Orbigny in Deshayes, 1832)

Polymorphina gibba d'Orbigny in Deshayes, 1832

2012, *Globulina gibba* (d'Orbigny in Deshayes, 1832) – Debenay p.239.

Remarks

Test unilocular, spherical in shape, rounded at the base and somewhat compressed. There are three compactly joined and overlapped chambers that are visible. The terminal aperture is radiate and covered by fistulose overgrowth.

***Globulina gibba var. fissicostata* Cushman & Ozawa, 1930**

Original name *Globulina gibba var. fissicostata* Cushman & Ozawa, 1930

Remarks

Test unilocular and spherical. The aperture is terminal. The test is calcareous and is ornamented by numerous fine, broken, longitudinal costae, covering the entire surface.

***Globulina inaequalis* Reuss, 1850**

Original name *Globulina inaequalis* Reuss, 1850

Synonymy

Globulina amygdaloides Reuss, 1851

Globulina translucida d'Orbigny, 1850

Polymorphina translucida d'Orbigny, 1826

1935, *Globulina inaequalis* Reuss, 1850 – Cushman, p.181, pl 9, Fig. 22.

Remarks

The test is ovate, more or less compressed. The chambers are inflated, overlapping and triserially arranged. Sutures are depressed, distinct. The aperture is radiate. The test wall is smooth, translucent. Test is calcareous.

GENUS *GUTTULINA* D'ORBIGNY, 1839

***Guttulina communis* (d'Orbigny, 1826)** Plate 2, Fig 13

Original name *Polymorphina (Guttuline) communis* d'Orbigny, 1826

Synonymy

Guttulina problema (d'Orbigny in Egger, 1857)

Polymorphina (Guttulina) problema d'Orbigny in Egger, 1857

Polymorphina (Guttuline) communis d'Orbigny, 1826

Polymorphina (Guttuline) problema d'Orbigny, 1826

Polymorphina communis d'Orbigny, 1826

Polymorphina problema d'Orbigny in Egger, 1857

Remarks

The test is fusiform. The chambers are elongated and arranged in a quinqueloculine series. Sutures are distinct and depressed. The aperture is radiate. The wall is calcareous and smooth.

GENUS *VASIGLOBULINA* POAG, 1969

***Vasiglobulina myristiformis* (Williamson, 1858)** Plate 2, Fig 12

Original name *Polymorphina myristiformis* Williamson, 1858

Synonymy

Globulina gibba var. myristiformis (Williamson, 1858)

Globulina myristiformis (Williamson, 1858)

Polymorphina myristiformis Williamson, 1858

Remarks

Test unilocular and subovate. The aperture is terminal and radiate. The test is calcareous has longitudinal striate as ornamentation.

7.3 SUBORDER MILIOLINA DELAGE AND HEROUARD, 1896

7.3.1 FAMILY CRIBROLINOIDIDAE HAYNES, 1981

GENUS *ADELOSINA* D'ORBIGNY, 1826

***Adelosina dutemplei* (d'Orbigny, 1846)**

Original name *Quinqueloculina dutemplei* d'Orbigny, 1846

Synonymy

Miliolina dutemplei (d'Orbigny, 1846)

Quinqueloculina dutemplei d'Orbigny, 1846

Remarks

The test is oval in outline. The last three chambers are keeled. The sutures are depressed. The aperture is ovate and has a tooth. The wall is porcelaneous and is ornamented by longitudinal striae.

7.3.2 Family HAUERINIDAE Schwager, 1876

7.3.3 Subfamily Miliolinellinae Vella, 1957

Genus *Biloculinella* Wiesner, 1931

Biloculinella globulus **(Bornemann, 1855)**

Original name *Biloculina globulus* Bornemann, 1855

Synonymy

Biloculina globulus Bornemann, 1855

Biloculinella globula (Bornemann, 1855)

Pyrgo globulus (Bornemann, 1855)

Remarks

Test ovate in outline and globular. The chambers are one-half coil in length. The sutures are distinct. The aperture is terminal and is covered by a broad apertural flap and only a thin crescentic opening is visible. The wall is calcareous, imperforate, porcelaneous, fine and smooth.

7.3.4 Family SPIROLOCULINIDAE Wiesner, 1920

Genus *Spiroloculina* d'Orbigny, 1826

Spiroloculina dilatata **d'Orbigny, 1826**

Original name *Spiroloculina dilatata* d'Orbigny, 1826

1826, *Spiroloculina dilatata* d'Orbigny, p. 271, pl.16, fig. 16-18.

2012, *Spiroloculina dilatata* d'Orbigny, 1826 - Milker & Schmiedl, p.49, fig. 13.1-2

Remarks

The test is fusiform and the periphery is bicarinate. The early stage is made up of a rounded proloculus and a tubular second chamber. The chamber arrangement is in spiroloculine form. It has a subquadratic aperture on a short neck bordered by a rim. The test is ornamented with many grooves. The wall is porcelaneous with a rough surface.

7.3.5 Subfamily HAUERININAE Schwager, 1876

Genus *Quinqueloculina* d'Orbigny, 1826

Quinqueloculina akneriana **d'Orbigny, 1846** Plate 2, Fig 14

Original name *Quinqueloculina akneriana* d'Orbigny, 1846

Synonymy

Miliolina akneriana (d'Orbigny, 1846)

Quinqueloculina pauperata d'Orbigny, 1846

Remarks

Test oval with quinqueloculine chamber arrangement. The aperture is rounded with a uniform tooth. The wall is porcelaneous, smooth.

***Quinqueloculina disparilis* d'Orbigny, 1826** Plate 2, Fig 15

Original name *Quinqueloculina disparilis* d'Orbigny, 1826

Synonymy

Quinqueloculina disparilis d'Orbigny, 1826

Quinqueloculina guancha d'Orbigny, 1839

1826, *Quinqueloculina disparilis* d'Orbigny, p. 302, no. 21

2012, *Quinqueloculina disparilis* d'Orbigny, 1826 - Milker & Schmiedl, p.57, fig. 15.10-12

Remarks

The test is subrounded with a quinqueloculine chamber arrangement. Three chambers are visible from one side and four chambers are visible form the other side. The aperture is rounded and bordered by a rim. It is provided with a long bifid tooth. The test is ornamented with a thick, longitudinal costae. The wall is porcelaneous and imperforate.

***Quinqueloculina lata* Terquem,1876**

Original name *Quinqueloculina lata* Terquem,1876

1876, *Quinqueloculina lata* Terquem, p. 82, pl.11, fig. 8a-c

2012, *Quinqueloculina lata* Terquem,1876 - Milker & Schmiedl, p.57, fig. 15.16

Remarks

In lateral view, the test is subrectangular with the peripheral margin being rounded. The chamber arrangement is quinqueloculine. Four chambers are visible on one side and three from the other. The aperture is ovate and has a short broad and bifid tooth. The wall is porcelaneous and imperforate. The test surface is smooth.

***Quinqueloculina seminulum* (Linnaeus, 1758)**

Original name *Serpula seminulum* Linnaeus, 1758

Synonymy

Miliolina seminulum (Linnaeus, 1758)

Quinqueloculina seminula (Linnaeus, 1758)

Quinqueloculina triangularis d'Orbigny, 1826

Quinqueloculina triangularis d'Orbigny, 1846

Serpula seminulum Linnaeus, 1758

2009, *Quinqueloculina seminula* (Linnaeus, 1758) Milker *et al*., p. 216, pl.2 figs. 3,4

2012, *Quinqueloculina seminula* (Linné, 1758)- Milker & Schmiedl, p.57, fig. 15.30-31

Remarks

The test is triangular in the apertural view and ovate to subrounded in lateral view. The chamber arrangement is quinqueloculine. Four chambers are visible on one side and three on the other. The aperture is subrounded, provided with a long tooth. The wall is porcelaneous and imperforate and the test surface is smooth.

7.4 Suborder TEXTULARIIDA Delage & Hérouard, 1896

7.4.1 Family EGGERELLIDAE Cushman, 1937

7.4.2 Subfamily Dorothiinae Balakhmatova, 1972

Genus *Bannerella* Loeblich & Tappan, 1985

***Bannerella gibbosa* (d'Orbigny, 1826)**

Original name *Textularia gibbosa* d'Orbigny, 1826

Synonymy

Dorothia gibbosa (d'Orbigny, 1826)

Palaeotextularia gibbosa (d'Orbigny, 1826)

Textilaria oviformis d'Orbigny

Textularia gibbosa d'Orbigny, 1826

Textularia oviformis d'Orbigny, 1826

Textularia punctulata d'Orbigny, 1826

Remarks

The test is subtriangular. The chambers have a biserial arrangement. The sutures are not visible. The aperture is at the base of the final chamber and is an arch. The wall is agglutinated.

7.4.3 Family SPIROPLECTAMMINIDAE Cushman, 1927

7.4.4 Subfamily Spiroplectammininae Cushman, 1927

Genus *Spiroplectammina* Cushman, 1927

***Spiroplectammina atrata* (Cushman, 1911)**

Original name *Textularia sagittula var. atrata* Cushman, 1911

Synonymy

Textularia atrata Cushman, 1911

Textularia sagittula var. atrata Cushman, 1911

Remarks

The test is subtriangular. The initial chambers are planispiral and the later chambers are biserial. The chambers gradually increase in size as added. The sutures are distinct and slightly curved. The aperture is a slit located at the base of the apertural face. The test is agglutinated.

7.4.5 SUBFAMILY SPIROPLECTAMMININAE CUSHMAN, 1927

GENUS *SPIROPLECTINELLA* KISEL'MAN, 1972

***Spiroplectinella wrighti* (Silvestri, 1903)**

Original name *Spiroplecta wrighti* Silvestri, 1903

Synonymy

Prolixoplecta wrightii (Silvestri, 1903)

Spiroplecta wrighti Silvestri, 1903

Spiroplecta wrightii Silvestri, 1903

Spiroplectammina higuchii Takayanagi, 1953

Spiroplectammina wrighti (Silvestri, 1903)

Remarks

The test is subtriangular. The initial chambers are planispiral and the later chambers are arranged biserially. The chambers gradually increase in size as added. The sutures are curved and depressed. The aperture is an indistinct slit located at the base of the apertural face. The wall is agglutinated. In most of our assemblages the final few chambers and the aperture of this species is either broken or not visible and was identified based on the coiling and chamber arrangement. However, according to Rasmussen (2005) *Spiroplectinella wrighti* is identical to *Textularia sagittula*, for this work smaller and broader specimen were assigned to *Spiroplectinella wright* and more elongated specimen with more chambers were assigned to *Textularia sagittula*.

7.4.6 FAMILY TEXTULARIIDAE EHRENBERG, 1838

7.4.7 SUBFAMILY TEXTULARIINAE EHRENBERG, 1838

GENUS *SAHULIA* LOEBLICH & TAPPAN, 1985

***Sahulia conica* (d'Orbigny, 1839)**

Original name *Textularia conica* d'Orbigny, 1839

Synonymy

Siphotextularia conica (d'Orbigny, 1839)

Textilina conica (d'Orbigny, 1839)

Textularia andenensis Asano, 1950

Textularia conica d'Orbigny, 1839

2016, *Sahulia conica* (d'Orbigny, 1839) - Lei & Li, p. 59, fig.27

Remarks

Test conical in shape with a subacute peripheral margin. The chambers are broad and low and are rapidly increasing in size. Sutures are nearly horizontally arranged. The aperture is a slit with a lip and is located across the center of the flattened terminal face. The wall is agglutinated.

GENUS *TEXTULARIA* DEFRANCE, 1824

***Textularia pseudogramen* Chapman & Parr, 1937**

Original name *Textularia pseudogramen* Chapman & Parr, 1937

Remarks

Test subtriangular and elongate. The chambers are biserially arranged and increase in size as added. The sutures are depressed and curved. The aperture is basal and is an arcuate lunar arch. The wall is agglutinated.

***Textularia sagittula* Defrance, 1824** Plate 1, Fig 5

Original name *Textularia sagittula* Defrance, 1824

Synonymy

Prolixoplecta sagittula (Defrance, 1824)

Semivulvulina sagittula (Defrance, 1824)

Spiroplectammina sagittula (Defrance, 1824)

Spiroplectinella sagittula (Defrance, 1824)

Textularia saggitula Defrance, 1824

2012, *Spiroplectinella sagittula* (Defrance, 1824) - Milker & Schmiedl, p.31, fig. 9.19-21.

2016, *Spiroplectammina sagittula* (Defrance, 1824) - Lei & Li, p. 32, fig.12

Remarks

The test is elongate to subtriangular. The early chambers are planispirally arranged and the later chambers are arranged biserially and gradually increase in size. The sutures are depressed and curved. The aperture is in the base of the final chamber and is a low arch. The wall is agglutinated.

***Textularia truncata* Höglund, 1947**

Original name *Textularia truncata* Höglund, 1947

Synonymy

Textularia subantarctica Vella, 1957

Remarks

The test is elongate. The chambers are biserially arranged. The sutures are depressed and curved. The aperture is an arcuate lunar arch and is the base of the final chamber. The wall is agglutinated.

7.5 Suborder ROTALIIDA Delage and Herouard, 1896

7.5.1 Superfamily BULIMINACEA Jones, 1875

7.5.1.1 Family BULIMENIDAE Jones, 1875

Genus Bulimina d'Orbigny, 1826

***Bulimina aculeata* d'Orbigny, 1826**

Original name *Bulimina aculeata* d'Orbigny, 1826

1826, *Bulimina aculeata* d'Orbigny, p. 269, no.7

2009, *Bulimina aculeata* d'Orbigny, 1826 - Milker *et al*., p. 216, pl.2, fig. 21

2012, *Bulimina aculeata* d'Orbigny, 1826 - Milker & Schmiedl, p. 83, fig 20.19

Remarks

The test is ovate. The chambers are inflated and triserially arranged. Sutures are depressed and oblique. The test surface is smooth, the earlier chambers have larger pseudospines and the later chambers have shorter pseudospines. In some specimen the pseudospines are absent in the later chambers. The aperture is loop-shaped, bordered by an everted rim and is on the face of the final chamber.

***Bulimina elongata* d'Orbigny, 1846**

Original name: *Bulimina elongata* d'Orbigny, 1846

1846, *Bulimina elongata* d'Orbigny, p.187, pl.11, figs. 19,20

2012, *Bulimina elongata* d'Orbigny, 1846 - Milker & Schmiedl, p. 83, fig 20.21

Remarks

The test is elongate. The chambers are inflated and triserially arranged. The sutures are depressed and oblique. The test surface is smooth with no ornamentation but some forms have short spines in the lower chamber. The aperture is on the face of the final chamber and is loop shaped. The test wall is calcareous and finely perforate.

7.5.1.2 Family BOLIVINIDAE Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839

***Bolivina antiqua* d'Orbigny 1846**

Original name *Bolivina antiqua* d'Orbigny 1846

1846, *Bolivina antiqua* n. sp. – d'Orbigny, p. 240, pl. 14, figs. 11-13.

2008, *Bolivina antiqua* d'Orbigny 1846 - Tóth & Görög p. 213, pl. 1, fig. 7-8.

Remarks

Test elongate and flattened with a subacute periphery. The test has biserial arrangement of chambers. The chambers are low and broad and gradually increasing in size. The sutures are slightly depressed. The aperture is a loop at the apertural face. The wall is calcareous and hyaline.

***Bolivina catanensis* Seguenza, 1862**

Original name *Bolivina catanensis* Seguenza, 1862

Synonymy *Brizalina catanensis* (Seguenza, 1862)

Remarks

The test is elongate, compressed with a subacute periphery. The sutures are slightly oblique. The test is finely perforate and has no ornamentation.

***Bolivina robusta* (Brady, 1881)**

Original name *Bulimina (Bolivina) robusta* Brady, 1881

Synonymy

Brizalina robusta (Brady, 1881)

Bulimina (Bolivina) robusta Brady, 1881

Bulimina robusta Brady, 1881

1881, *Bolivina robusta* Brady, p. 57

1884, *Bolivina robusta* Brady, p. 421, pl. 53, figs. 7-9.

2016, Bolivina robusta Brady, 1881- Lei & Li p. 205, fig.4.

Remarks

The test is ovate and is laterally compressed. The test has biserial coiling with depressed sutures. The aperture is a narrow loop at the base of the apertural face. The test wall is calcareous, hyaline and transparent with many pores throughout the wall surface.

Bolivina subspinescens* Cushman, *1922

Original name *Bolivina subspinescens* Cushman, 1922

Synonymy

Brazalina subspinescens (Cushman, 1922)

Sagrinella subspinescens (Cushman, 1922)

2012, *Bolivina subspinescens* Cushman, 1922 - Milker & Schmiedl, p. 76, fig 19.24

Remarks

Test elongate with subrounded periphery. The chambers are inflated, increasing in size and are biserially arranged. The sutures are depressed. The aperture is terminal and ovate. The wall is calcareous and hyaline.

GENUS *SIGMAVIRGULINA* LOEBLICH AND TAPPAN, 1957

***Sigmavirgulina tortuosa* (Brady,1881)**

Original name *Bulimina (Bolivina) tortuosa* Brady, 1881

Synonymy *Bulimina (Bolivina) tortuosa* Brady, 1881

1982, *Sigmavirgulina tortuosa* (Brady,1881)**,** Buzas & Severin p.71, pl.10, fig 10

Remarks

The test is elongate. The chambers are triangular to trapezoid and biserially arranged with slightly rotating axis of coiling. The sutures are curved. The aperture is a slit with tooth and in the terminal position. The wall is hyaline and is porous.

7.5.2 SUPERFAMILY CASSIDULINACEA D'ORBIGNY, 1839

7.5.3 FAMILY CASSIDULINIDAE D'ORBIGNY, 1839

7.5.4 SUBFAMILY CASSIDULININAE, D'ORBIGNY, 1839

GENUS *CASSIDULINA* D'ORBIGNY, 1826

***Cassidulina carinata* Silvestri, 1896**

Original name: *Cassidulina laevigata var. carinata* Silvestri, 1896

Synonymy

Cassidulina laevigata subsp. carinata Silvestri, 1896

Cassidulina laevigata var. carinata Silvestri, 1896

Remarks

The test has biserial coiling. The aperture form is slit with a lip and the primary aperture is in the basal position. The sutures are depressed and curved. The wall is calcareous.

GENUS *GLOBOCASSIDULINA* VOLOSHINOVA, 1960

***Globocassidulina crassa* (d'Orbigny, 1839)** Plate 2, Fig 11

Original name *Cassidulina crassa* d'Orbigny, 1839

Synonymy

Cassidulina crassa d'Orbigny, 1839

Smyrnella crassa (d'Orbigny, 1839)

2016, *Globocassidulina crassa* (d'Orbigny, 1839) - Lei & Li p. 213, fig.8.

Remarks

Test globose to ovate with biserial coiling. The chambers are pyriform. The primary aperture is in the basal position and is slit with a lip. The sutures are slightly depressed and curved. The wall is calcareous and perforate and the surface is smooth and polished with no ornamentation. The aperture is a slit with a lip and is in the basal position.

7.5.5 SUPERFAMILY DISCORBACEA EHRENBERG, 1838

7.5.6 FAMILY BAGGINIDAE CUSHMAN, 1927

7.5.7 SUBFAMILY BAGGININAE CUSHMAN, 1927

GENUS *CANCRIS* DE MONTFORT, 1808

***Cancris auricula* (Fichtel and Moll, 1798)** Plate 1, Fig 1

Original name *Nautilus auricula* Fichtel & Moll, 1798

Synonymy

Cancris auricula (Fichtel & Moll, 1798)

Cancris auriculatus Montfort, 1808

Pulvinulina auricula (Fichtel & Moll, 1798)

Rotalia (Rotalie) brongniartii d'Orbigny, 1826

Rotalia (Rotalie) eliptica d'Orbigny, 1826

Rotalia auriculus (Fichtel & Moll, 1798)

Rotalia brongnartii d'Orbigny, 1826

Rotalia elliptica d'Orbigny, 1826

Rotalina brongniartii d'Orbigny, 1846

1798, Cancris auriculus Fichtel & Moll, p. 108, pl.20 figs. a, c, e, f.

2012, *Cancris auricula* (Fichtel & Moll, 1798) - Milker & Schmiedl, p. 91, fig 21.14-15.

2016, *Cancris auricula* (Fichtel & Moll, 1798) - Lei & Li p. 237, fig.20.

Remarks

Test auriculate with trochospiral coiling and no ornamentation. The chambers are triangular to trapezoid. The aperture is slit and is a low interiomarginal opening on the umbilical side. The sutures are curved. The wall is calcareous and perforate.

7.5.7.1 FAMILY REUSSELLIDAE CUSHMAN, 1933

GENUS *REUSSELLA* GALLOWAY, 1933

***Reussella spinulosa* (Reuss, 1850)**

Original name *Verneuilina spinulosa* Reuss, 1850

Synonymy

Reussia spinulosa (Reuss, 1850)

Verneuilina spinulosa Reuss, 1850

2009, *Reussia spinulosa* (Reuss, 1850) - Milker *et al*., p. 218, pl.2, fig. 4,5

2012, *Reussia spinulosa* (Reuss, 1850) - Milker & Schmiedl, p. 91, fig 21.6-7

Remarks

Test is triangular with triserially arranged chambers that gradually increase in size as added. The aperture is slit like and is interiomarginal. The sutures are thickened and distinct.

The wall is calcareous and perforate. The test surface along the carinate chamber margins is ornamented with short pseudospines.

7.5.7.2 FAMILY ROSALINIDAE REISS, 1963

GENUS *ROSALINA* D'ORBIGNY, 1826

Rosalina globularis **d'Orbigny**, **1826**

Original name *Rosalina globularis* d'Orbigny, 1826

Synonymy

Discorbina globularis (d'Orbigny, 1826)

Rosalina semistriata d'Orbigny, 1826

1826, *Rosalina globularis* d'Orbigny, p. 271, pl.13, fig. 1-4.

2012, *Rosalina globularis* d'Orbigny, 1826 - Milker & Schmiedl, p. 96, fig. 22.15-16.

Remarks

The test has trochospiral coiling and is planoconvex to concavoconvex with rounded periphery. The spial side is convex with depressed and curved sutures whereas the umbilical side is flattened with subtriangular chambered and radial to oblique sutures. The aperture is an interiomarginal extraumbilical elongate slit that extends into the open umbilicus. The test surface is smooth.

Rosalina macropora (Hofker, 1951) Plate 2, Fig 10

Original name *Discopulvinulina macropora* Hofker, 1951

Synonymy

Discopulvinulina macropora Hofker, 1951

1951, *Rosalina macropora* Hofker, p. 460, figs. 312, 313.

2009, *Rosalina macropora* (Hofker, 1951) - Milker *et al.*, p. 218, pl.3, fig. 4,5.

2012, *Rosalina macropora* (Hofker, 1951) - Milker & Schmiedl, p. 96, fig 22.17-18.

Remarks

Test trochospiral and planoconvex. The periphery is carinate and imperforate. The spiral side is evolute and convex with crescentic chambers. The chambers on the spiral side are coarsely and densely perforated with raised, thickened and finely perforate sutures. The umbilical side is involute with sutures that are curved backward and even with the surface. The chambers on the umbilical side are subtriangular. The aperture is an interiomarginal, extraumbilical arched slit. The test wall is calcareous.

7.5.8 SUPERFAMILY NONIONACEA SCHULZE, 1854

7.5.8.1 FAMILY NONIONIDAE SCHULZE, 1854

7.5.9 SUBFAMILY NONIONINAE SCHULZE, 1854

GENUS *NONION* DE MONTFORT, 1808

***Nonion commune* (d'Orbigny, 1825)** Plate 1, Fig 8

Original name *Nonionina communis* d'Orbigny, 1846

Synonymy

Florilus communis (d'Orbigny, 1839)

Florilus scaphum (Fichtel & Moll, 1798)

Nautilus scapha Fichtel & Moll, 1798

Nonion acutidorsatum Ten Dam, 1944

Nonion communis (d'Orbigny, 1846)

Nonion scapha (Fichtel & Moll, 1798)

Nonion scaphum (Fichtel & Moll, 1798)

Nonion scaphus (Fichtel & Moll, 1798)

Nonionella communis (d'Orbigny, 1846)

Nonionina communis d'Orbigny, 1846

Nonionina scapha (Fichtel & Moll, 1798)

Nonionoides scaphum (Fichtel & Moll, 1798)

2008, *Nonion commune* (d'Orbigny, 1825) - Tóth & Görög p. 213, pl. 2, fig. 11

Remarks

Test ovate with a rounded periphery. The test is planispiral and involute. The chambers increase rapidly in size. The sutures are depressed and curved. The aperture is a low interiomarginal and equatorial slit at the base of the apertural face.

GENUS *NONIONOIDES* SAIDOVA, 1975

***Nonionoides grateloupii* (d'Orbigny, 1839)** Plate 2, Fig 9

Original name *Nonionina grateloupii* d'Orbigny, 1839

Synonymy

Florilus grateloupii (d'Orbigny, 1839)

Nonion grateloupii (d'Orbigny, 1839)

Nonionella grateloupii (d'Orbigny, 1839)

Nonionina grateloupi d'Orbigny, 1826

Nonionoides grateloupii (d'Orbigny, 1826)

Pseudononion grateloupii (d'Orbigny, 1826)

Remarks

The test is small, longer than broad and planispiral. Chambers increase gradually in size. The sutures are distinct and curved. The aperture is slit at the base of the last formed chamber. The wall is hyaline and translucent.

7.5.10 Superfamily PLANORBULINACEA Schwager, 1877

7.5.11 Family CIBICIDIDAE Cushman, 1927

7.5.12 Subfamily CIBICIDINAE Cushman, 1927

GENUS *CIBICIDES* DE MONFORT, 1808

***Cibicides refulgens* Montfort, 1808** Plate 1, Fig 7

Original name *Cibicides refulgens* Montfort, 1808

Synonymy

Planorbulina refulgens (Montfort, 1808)

Truncatulina refulgens (Montfort, 1808)

2009, *Cibicides refulgens* Montfort, 1808 - Milker *et al.*, p. 220, pl.4, fig 9,10.

2012, *Cibicides refulgens* Montfort, 1808 - Milker & Schmiedl, p.105, fig 24.14-16.

Remarks

Test trochospiral and planoconvex with the umbilical side convex and the spiral side flattened to slightly concave. The sutures on the umbilical side are curved and depressed and more limbate on the spiral side. The aperture is in the interiomargin. The wall is calcareous and finely perforate on both sides.

GENUS *LOBATULA* FLEMING, 1828

***Lobatula lobatula* (Walker and Jacob, 1798)** Plate 1, Fig 6

Original name *Nautilus lobatulus* Walker & Jacob, 1798

Synonymy

Anomalina variolata d'Orbigny, 1846

Cibicides elongatus (d'Orbigny, 1850

Cibicides lobatulus (Walker & Jacob, 1798)

Lobatula vulgaris Fleming, 1828

Planorbulina lobatula (Walker & Jacob, 1798)

Planulina incerta d'Orbigny, 1826

Truncatulina elongata d'Orbigny, 1850

Truncatulina infractuosa d'Orbigny, 1852

Truncatulina lobatula (Walker & Jacob, 1798)

Truncatulina tuberculata d'Orbigny, 1826

Lobatula lobatula (Walker & Jacob, 1798) (according to the research on DNA work by Schweizer *et al.* 2009)

1798, *Nautilus lobatulus* Walker and Jacob, p. 642, pl. 14, fig.36.

2009, *Cibicides lobatulus* (Walker & Jacob, 1798) - Milker *et al*., p. 220, pl.4, fig. 6-8.

2012, *Lobatula lobatula* (Walker and Jacob, 1798) - Milker & Schmiedl, p.105, fig 24.17-20.

2016, *Lobatula lobatula* Brady, 1881- Lei & Li, p. 262, fig.32.

Remarks

The test has trochospiral coiling and is planoconvex. The spiral side is flat and evolute while the umbilical side is convex and involute and in some specimens is irregularly arranged. The chambers are triangular to trapezoidal. Aperture is in the form of a slit at the basal interiomargin and has a lip. The sutures are depressed. The wall is calcareous with the spiral side, coarsely perforate while the surface near the aperture is imperforate with a smooth surface. It has 6-8 chambers in the last whorl.

GENUS *CIBICIDOIDES* THALMANN, 1939

***Cibicidoides ungerianus* (d'Orbigny, 1846)**

Original name *Rotalina ungeriana* d'Orbigny, 1846

Synonymy

Cibicides ungerianus (d'Orbigny, 1846) (According to DNA work of Schweizer *et al.*, 2009)

Planorbulina farcta var. ungeriana (d'Orbigny, 1846)

Rotalina ungeriana d'Orbigny, 1846

Truncatulina ungeriana (d'Orbigny, 1846)

2007, *Cibicides ungerianus* (d'Orbigny, 1846) - Oblak, p.315, pl. 2, fig 2a-c.

Remarks

Test trochospiral and biconvex. The umbilical side is involute and the spiral side is evolute both the sides have an umbo. The chambers have a crescentic shape. The sutures are cured backward. The aperture is interiomarginal narrow arch that is bordered by a thin lip.

***Cibicidoides wuellerstorfi* (Schwager, 1866)**

Original name *Anomalina wuellerstorfi* Schwager, 1866

Synonymy

Anomalina wuellerstorfi Schwager, 1866

Cibicides wuellerstorfi (Schwager, 1866) (According to DNA work of Schweizer *et al.,* 2009)

Fontbotia wuellerstorfi (Schwager, 1866)

Planorbulina wuellerstorfi (Schwager, 1866)

Planulina wuellerstorfi (Schwager, 1866)

Truncatulina wuellerstorfi (Schwager, 1866)

Remarks

The test has trochospiral coiling and is planoconvex with the spiral side flat and evolute and the umbilical side convex and involute with a large umbo. The sutures are limbate, curved, thickened. It is elevated on the spiral side and is depressed on the umbilical side. The aperture is in the basal interiomargin. The wall is calcareous and transparent. The spiral side is coarsely perforate and the umbilical side is finely perforate. It has 8-10 chambers in the final whorl.

7.5.13 FAMILY PLANORBULINIDAE SCHWAGER, 1877

7.5.14 SUBFAMILY PLANORBULININAE SCHWAGER, 1877

GENUS *PLANORBULINA* D'ORBIGNY, 1826

***Planorbulina mediterranensis* d'Orbigny, 1826**

Original name *Planorbulina mediterranensis* d'Orbigny, 1826

Synonymy

Asterodiscus forskalii Ehrenberg, 1839

Planorbulina caribbeana Hofker, 1976

Planorbulina vulgaris d'Orbigny, 1839

2012, *Planorbulina mediterranensis* d'Orbigny,1826 - Milker & Schmiedl, p.105, fig 24.21-24.

Remarks

The test is planoconvex with a rounded periphery. The sutures are depressed. It has - multiple interiomarginal and extraumbilical apertures. The wall is calcareous with coarse and dense perforations. The test surface is smooth.

7.5.15 FAMILY ASTERIGERINATIDAE REISS, 1963

GENUS *ASTERIGERINATA* BERMUNDEZ, 1949

***Asterigerinata mamilla* (Williamson, 1858)**

Original name *Rotalina mamilla* Williamson, 1858

Synonymy

Discorbis mamilla (Williamson, 1858)

Eoeponidella mamilla (Williamson, 1858)

Rotalia mamilla (Williamson, 1858)

Rotalina mamilla Williamson, 1858

2012, *Asterigerinata mamilla* (Williamson, 1858), Milker & Schmiedl, p.109, fig 25.10-13

Remarks

The test is trochospirally coiled and conical in peripheral view. The periphery is acutely carinate. The spiral side is convex and evolute. The umbilical side is involute. The chambers on the spiral side increase in breadth as added with the final chamber occupying approximately one-third of the periphery. On the spiral side, the sutures are curved, thickened, imperforated and flush with the surface. The sutures on the umbilical side are curved, oblique and slightly depressed. Aperture is a low interiomarginal umbilical arch at the base of the final chamber. The test surface is smooth and the wall is calcareous.

GENUS *BIASTERIGERINA* SEIGLIE & BERMÚDEZ, 1965

***Biasterigerina planorbis* (d'Orbigny, 1846)**

Original name: *Asterigerina planorbis* d'Orbigny, 1846

Synonymy

Amphistegina rosacea (d'Orbigny in Parker, Jones & Brady, 1865)

Asterigerina planorbis d'Orbigny, 1846

Asterigerina rosacea (d'Orbigny, 1826)

Asterigerinata planorbis (d'Orbigny, 1846)

Biasterigerina rosacea

Discorbina planorbis (d'Orbigny, 1846)

Discorbina rosacea d'Orbigny in Parker, Jones & Brady, 1865

Discorbis rosacea (d'Orbigny, 1826)

Rotalia (Rotalie) rosacea d'Orbigny, 1826

Rotalia rosacea d'Orbigny, 1826

2000, *Biasterigerina planorbis* (d'Orbigny, 1846), Baggley, p.1077, pl.1, fig 5-6

Remarks

The test is trochospirally coiled. The chambers are crescentic. The spiral side is convex and evolute, the umbilical side is flat and involute. The sutures are curved. The aperture is an extraumbilical slit. The wall is hyaline and the test surface is smooth.

7.5.16 Superfamily ROTALIACEA Ehrenberg, 1839

7.5.17 Family ROTALIIDAE Ehrenberg, 1839

7.5.18 Subfamily AMMONIINAE Saidova, 1981

Genus *Ammonia* Brunnich, 1972

***Ammonia beccarii* (Linne, 1758)** Plate 1, Fig 2

Original name *Nautilus beccarii* Linnaeus, 1758

Synonymy

Nautilus beccarii Linnaeus, 1758

Rosalina beccarii (Linnaeus, 1758)

Rotalia (Turbinuline) crassa d'Orbigny, 1826

Rotalia (Turbinuline) tortuosa d'Orbigny, 1826

Rotalia tortuosa d'Orbigny, 1826

Rotalina beccarii (Linnaeus, 1758)

Streblus beccarii (Linnaeus, 1758)

Turbinulina crassa d'Orbigny in Fornasini, 1908

2008, *Ammonia beccarii* (Linne, 1758) - Tóth & Görög p. 213, pl. 2, fig. 14-18.

2012, *Ammonia beccarii* (Linne, 1758) - Milker & Schmiedl, p.215, fig 27.1-2.

2016, *Ammonia beccarii* (Linne, 1758) - Lei & Li, p. 315, fig.60.

Remarks

The test is trochospiral. It is more convex on the spiral side and some have an umbilical plug on the umbilical side. The aperture is an interiomarginal extraumbilical arch. The sutures are depressed and straight. There are 8-12 chambers in the final whorl that increase in size gradually. The wall is calcareous and finely perforate and the test surface is smooth.

7.5.19 FAMILY ELPHIDIIDAE GALLOWAY, 1933

7.5.20 SUBFAMILY ELPHIDIINAE GALLOWAY, 1933

GENUS *CRIBROELPHIDIUM* CUSHMAN & BRÖNNIMANN, 1948

***Cribroelphidium excavatum* (Terquem, 1875)**

Original name *Polystomella excavata* Terquem, 1875

Synonymy

Cribrononion excavatum (Terquem, 1875)

Elphidium excavatum (Terquem, 1875)

Elphidium excavatum f. excavatum (Terquem, 1875)

Polystomella excavata Terquem, 1875

Remarks

The test has planispiral coiling. The chambers are triangular to trapezoid in shape and the sutures are depressed and curved and the length of the suture is covered by ponticuli. It has multiple apertures in the form of pores. It has hispid to pustulose ornamentation. The test wall is calcareous and hyaline.

GENUS *ELPHIDIUM* DE MONFORT, 1808

***Elphidium advenum* (Cushman, 1922)**

Original name: *Polystomella advena* Cushman, 1922

Synonymy

Cribrononion advenum (Cushman, 1922)

Elphidium (Polystomella) advenum (Cushman, 1922)

Elphidium advenum subsp. advenum (Cushman, 1922)

Elphidium advenum subsp. gorokuense Takayanagi, 1950

Elphidium hanzawai Asano, 1939

Polystomella advena Cushman, 1922

2012, *Elphidium advenum* (Cushman, 1922) - Milker & Schmiedl, p.118, fig 27.7-8.

2016, *Elphidium advenum* (Cushman, 1922) - Lei & Li, p. 357, fig.82

Remarks

The test has planispiral coiling and an umbilical plug on both sides. The test form is crescentic. The periphery is carinate and bordered. The aperture is an interiomarginal rounded opening. There are 10 chambers in the last whorl. The sutures are deep and curved and ponticuli can be found along the length of the suture. The wall is calcareous and perforate.

***Elphidium aculeatum* (d'Orbigny, 1846)**

Original name *Polystomella aculeata* d'Orbigny, 1846

Synonymy

Polystomella aculeata d'Orbigny, 1846

2008, *Elphidium aculeatum* (d'Orbigny, 1846) - Tóth & Görög p. 213, pl. 3, fig. 5-6

2012, *Elphidium aculeatum* (d'Orbigny, 1846) - Milker & Schmiedl, p.217, fig 27.5-6

Remarks

Test planispiral and involute. The periphery is carinate. There are numerous chambers. The sutures are curved and depressed. It has multiple interiomarginal apertures. The test has ponticuli and is ornamented at the base with spines. The test surface is smooth and the wall is calcareous and except for the periphery is finely and densely perforate. Only one specimen of this species was identified in sample 4b.

***Elphidium crispum* (Linne, 1758)** Plate 1, Fig 4

Original name *Nautilus crispus* Linnaeus, 1758

Synonymy

Polystomella crispa (Linnaeus, 1758)

Themeon rigatus Montfort, 1808

2008, *Elphidium crispum* (Linne, 1758) - Tóth & Görög p. 213, pl. 3, fig. 7-8.

2012, *Elphidium crispum* (Linne, 1758) - Milker & Schmiedl, p.217, fig 27. 13-14

2016, *Elphidium crispum* (Linne, 1758) - Lei & Li, p. 362, fig.84

Remarks

Test is planispiral. Both the sides have an umbilical plug. The periphery is angular and carinate. It has multiple apertures in the interiomarginal pores. The sutures are deep and curved with well-developed ponticuli. The test has 18-21 chambers. The wall is calcareous and the surface of the umbilical plug area has several pits. The last chamber is keeled.

***Elphidium fichtelianum* (d'Orbigny, 1846)** Plate 1, Fig 3

Original name *Polystomella fichtelliana* d'Orbigny, 1846

Synonymy

Elphidium fichtellianum (d'Orbigny, 1846)

Polystomella fichtelliana d'Orbigny, 1846

Polystomella jenseni Cushman, 1924

Cribroelphidium jenseni (Cushman, 1924)

Elphidium jenseni (Cushman, 1924)

Elphidium subplanatum Cushman, 1936

2008, *Elphidium fichtelianum* (d'Orbigny, 1846) - Tóth & Görög p. 213, pl. 3, fig. 9.

Remarks

The test is planispiral and the periphery is crescentic. It has multiple apertures in the interiomarginal pores. The sutures are depressed, curved and ponticuli. The test has 17-20 chambers. The wall is calcareous. The last chamber is keeled.

Elphidium macellum

Original name *Nautilus macellus* Fichtel & Moll, 1798

Synonymy

Elphidium sculpturatum Cushman, 1936

Nautilus macellum Fichtel & Moll, 1798

Nautilus macellus Fichtel & Moll, 1798

Nautilus macellus var. beta Fichtel & Moll, 1798

Nautilus strigilatus var. alpha Fichtel & Moll, 1798

Nautilus strigilatus var. beta Fichtel & Moll, 1798

Polystomella macella (Fichtel & Moll, 1798)

Remarks

The test is planispiral. The chambers are crescentic in shape and the sutures are depressed and curved. it has multiple apertures in the form of pores. It has costate ornamentation and the last chamber is keeled. The wall is calcareous and hyaline.

7.5.21 FAMILY GLABRATELLIDAE LOEBLICH & TAPPAN, 1964

GENUS *GLABRATELLA* DORREEN, 1948

***Glabratella australensis* (Heron-Allen & Earland, 1932)**

Original name *Discorbis australensis* Heron-Allen & Earland, 1932

Synonymy

Discorbis australensis Heron-Allen & Earland, 1932

Glabratellina australensis (Heron-Allen & Earland, 1932)

Pileolina australensis (Heron-Allen & Earland, 1932)

Remarks

Test trochospiral with lobate periphery. The chambers are almost crescentic and the sutures are curved. The aperture is not visible. The wall is calcareous.

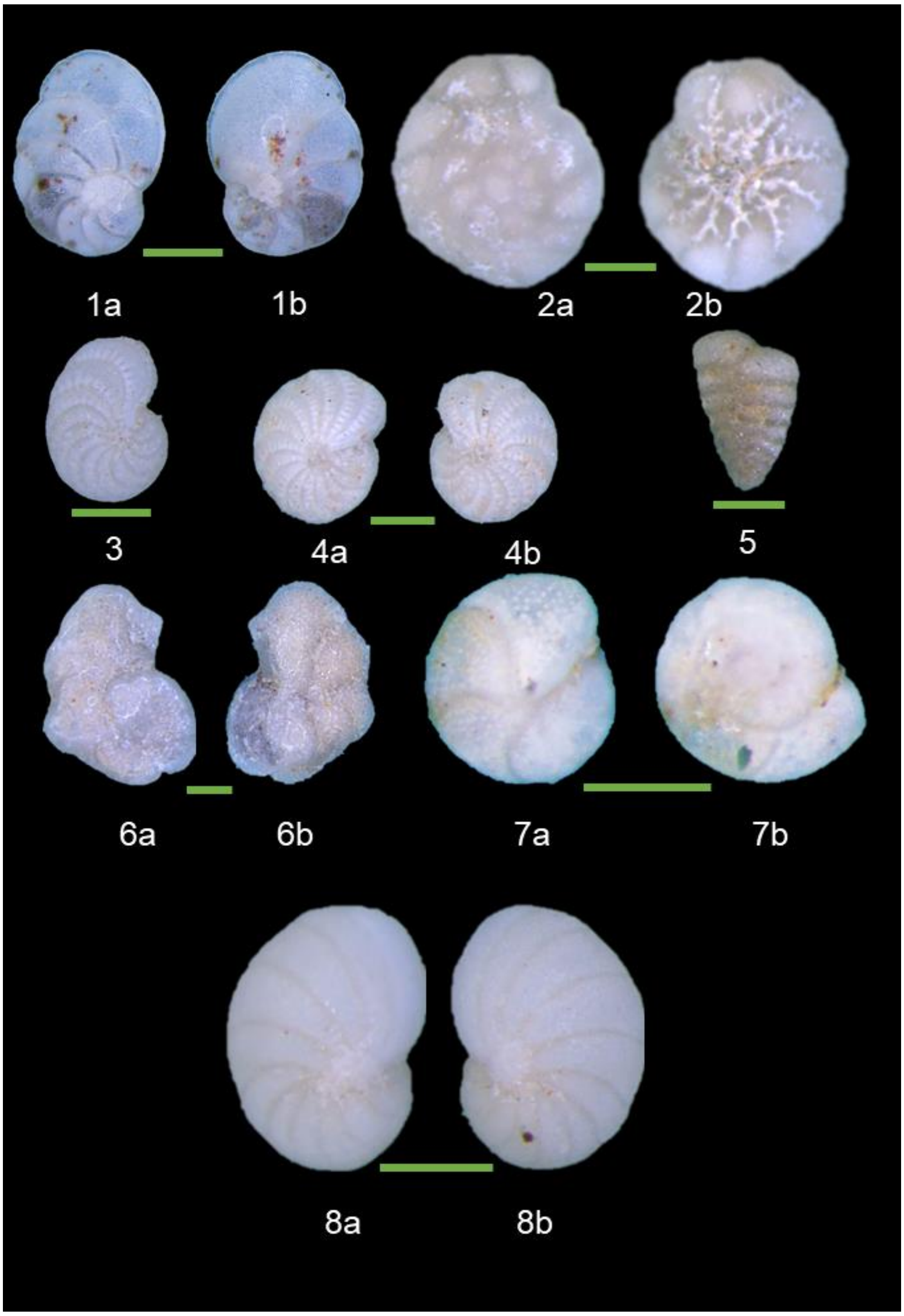

Plate 7.1: **Scale- 250µm. Fig 1**: *Cancris auricula,* **a**-dorsal side, **b**-ventral side; **Fig 2**: *Ammonia beccarii*, **a**-dorsal side, **b**-ventral side; **Fig 3**: *Elphidium fichtelianum*; **Fig 4**: *Elphidium crispum*; **Fig 5:** *Textularia sagittula*; **Fig 6**: *Lobatula lobatula*, a- ventral side, b-dorsal side; **Fig 7**: *Cibicides refulgens*, **a**- Ventral side, **b**-dorsal side. **Fig 8**: *Nonion commune.*

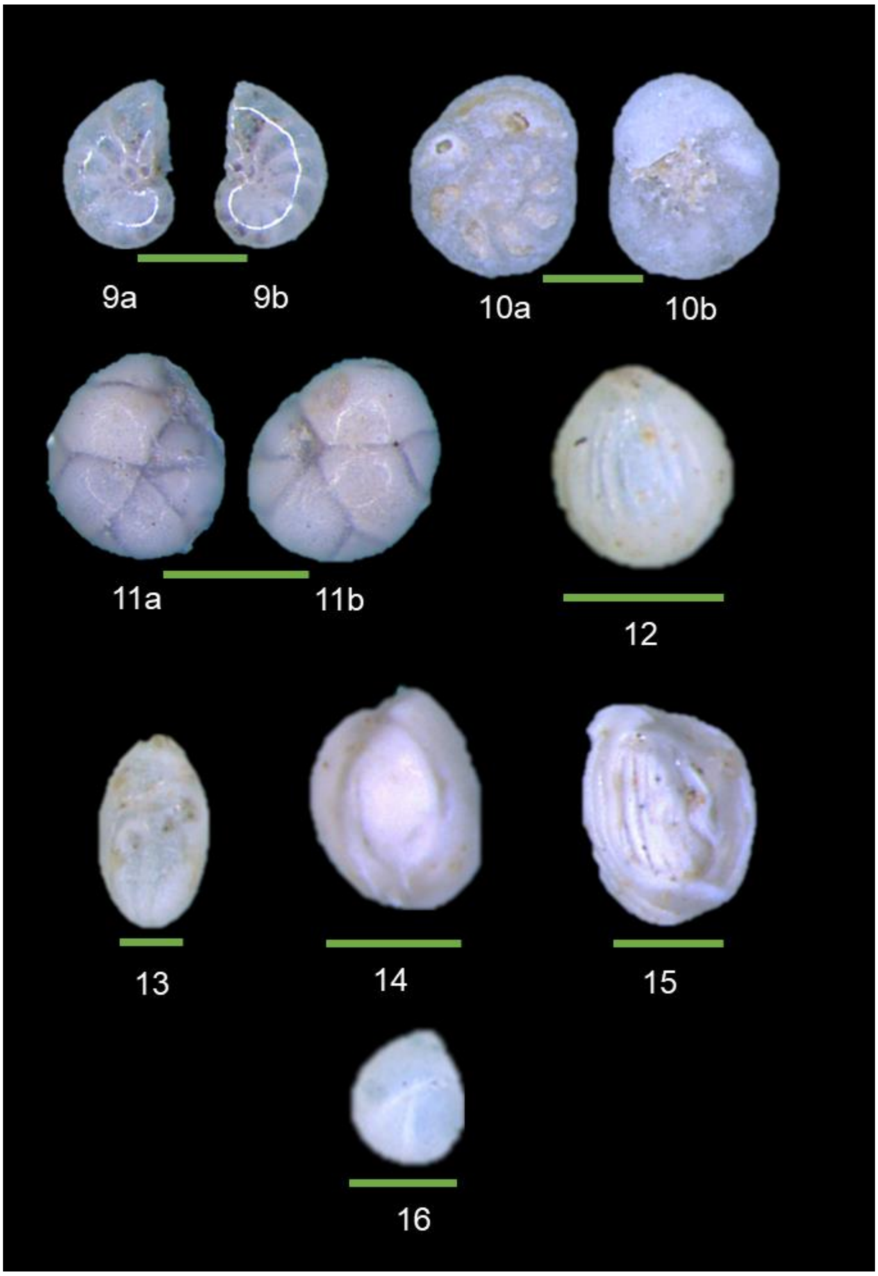

Plate 7.2: **Scale- 250µm. Fig 9**: *Nonionoides grateloupii*; **Fig 10**: *Rosalina macropora*, **a**-dorsal side, **b**-ventral side; **Fig 11**: *Globocassidulina crassa*, **a**-ventral side, **b**-dorsal side, **Fig 12**: *Vasiglobulina myristiformis*; **Fig13**: *Guttulina communis*; **Fig 14**: *Quinqueloculina akneriana*; **Fig 15**: *Quinqueloculina disparilis*; **Fig 16**: *Globulina gibba*.

7.5.22 Superfamily GLOBIGERINOIDEA Carpenter *et al.*, 1862

7.5.23 Family GLOBIGERINIDAE Carpenter *et al.*, 1862

7.5.24 Subfamily Globigerininae Carpenter *et al.*, 1862

Genus *Globigerinoides* Cushman, 1927

***Globigerinoides ruber* (d'Orbigny, 1839)** Plate 3, Fig 3

Original name *Globigerina rubra* d'Orbigny, 1839

Synonymy

Globigerina bulloides var. rubra d'Orbigny, 1839

Globigerina bulloides var. rubra pyramidalis van den Broeck, 1876

Globigerina cyclostoma Galloway & Wissler, 1927

Globigerina pyramidalis van den Broeck, 1876

Globigerina rubra d'Orbigny, 1839

Globigerinoides pyramidalis

Globigerinoides rubra (d'Orbigny, 1839)

Remarks

Test trochospiral with a broadly rounded periphery. There are three subspherical chambers in the final whorl that increase gradually in size. The sutures are radial and strongly depressed. An interiomarginal primary aperture is on the umbilical side, it has a wide–arched opening that is bordered by a rim. There are two supplementary sutural apertures situated opposite the sutures of earlier chambers. The wall texture is cancellate.

Geological range

Last occurrence: Extant

First occurrence: within N14 zone (10.46-11.63Ma, Serravallian age) (Chaisson & Pearson, 1997).

***Globigerinoides diminutus* Bolli, 1957**

Original name *Globigerinoides diminutus* Bolli, 1957

Synonymy

Globigerinoides diminuta Bolli, 1957

Remarks

The test is small, trochospiral with a broadly rounded periphery. There are three chambers in the final whorl that increase moderately in size. The sutures are radial and depressed. The primary aperture is interiomarginal on the umbilical side. The supplementary apertures are not visible as the test is covered in matrix.

Geological range

Last occurrence: within N9 zone (14.24-15.10Ma, Langhian age)

First occurrence: within N7 zone (16.38-17.54Ma, Burdigalian age) (Kennett & Srinivasan, 1983)

GENUS *GLOBIGERINELLA* CUSHMAN, 1927

Globigerinella obesa **(Bolli, 1957)** Plate 3, Fig 4

Original name *Globorotalia obesa* Bolli, 1957

Synonymy

Globigerina praebulloides Blow, 1959

Globigerina praebulloides subsp. praebulloides Blow Em. Blow & Banner, 1962

Globorotalia obesa Bolli, 1957

Remarks

Test low trochospiral with a broadly rounded periphery. The chambers are globular and there are four chambers in the final whorl that increase rapidly in size. The sutures area straight, moderately depressed. The umbilicus is small and is enclosed by the surrounding chambers. The aperture is a low arch that is umbilical-extraumbilical. The wall texture is cancellate.

Geological range

Last occurrence: early Pliocene Zanclean age (3.60-5.33Ma)

First occurrence: within O1 zone (32.10-33.90Ma, Priabonian age) (Spezzaferri *et al*., 2018).

Globigerinella pseudobesa **Salvatorini 1967** Plate 3, Fig 5

Original name *Turborotalia pseudobesa* Salvatorini, 1967

Synonymy

Turborotalia pseudobesa Salvatorini, 1967

Remarks

Test low trochospiral with broadly rounded periphery. Chambers are spherical to subspherical and there are four rapidly enlarging chambers in the final whorl. In one of the specimens there are four and half chambers in the final whorl. The sutures on the spiral side are radial and depressed and on the umbilical side is slightly curved and radial. The aperture is an umbilical-extraumbilical, medium-wide arch that extends to the spiral side of the test. The wall texture is cancellate.

Geological range

Last occurrence: within N19 zone (4.37-5.20Ma, Zanclean age)

First occurrence: within N13 zone (11.63-11.79Ma, in Serravallian age) (Kennett & Srinivasan, 1983)

***Globigerinella siphonifera* (d'Orbigny, 1839)**

Original name *Globigerina siphonifera* d'Orbigny, 1839

Synonymy

Globigerina aequilateralis Brady, 1879

Globigerina aequilateralis var. involuta Cushman, 1917

Globigerina hirsuta d'Orbigny, 1839

Globigerina siphonifera d'Orbigny, 1839

Globigerinella aequilateralis (Brady, 1879)

Hastigerina (Hastigerina) siphonifera (d'Orbigny, 1839)

Hastigerina aequilateralis (Brady, 1879)

Hastigerina siphonifera (d'Orbigny, 1839)

Remarks

The test is covered in a matrix that surrounds the aperture and is identified as *Globigerinella siphonifera* because of the chamber arrangement. The test is planispiral, evolute with a broadly rounded periphery. The chambers are globular to subglobular. There are five to six rapidly increasing chambers in the final whorl. The aperture as mentioned earlier is not visible.

Geological range

Last occurrence: Extant

First occurrence: within N12 zone (11.79-13.41Ma, Serravallian age) (Kennett & Srinivasan, 1983).

GENUS *GLOBOTURBOROTALITA* HOFKER, 1976

***Globoturborotalita apertura* (Cushman, 1918)**

Original name *Globigerina apertura* Cushman, 1918

Synonymy

Globigerina apertura Cushman, 1918

Remarks

Test low trochospiral and periphery is broadly rounded. The chambers are spherical to subspherical which increase uniformly as added. There are four chambers in the final whorl. The sutures are depressed, slightly curved. The aperture is umbilical. It is very large, semi-circular with a distinct apertural rim. The wall texture is cancellate.

Geological range

Last occurrence: lower part of PT1a subzone (1.6Ma, Calabrian age)

First occurrence: lower part of M11 zone (11.1Ma, Tortonian age) (Wade *et al.*, 2011)

GENUS *GLOBIGERINA* D'ORBIGNY, 1826

***Globigerina bulloides* d'Orbigny, 1826** Plate 3, Fig 6

Original name *Globigerina bulloides* d'Orbigny, 1826

Remarks

Test low trochospiral and the periphery is broadly rounded. The chambers are globular. There are four chambers in the final whorl that increase rapidly in size. The sutures are straight and moderately depressed. The umbilicus is large and open. The aperture is umbilical and is a broad arch bordered by a rim. The wall structure is cancellate.

Geological range

Last occurrence: Extant

First occurrence: Within O5 zone (26.93-28.09Ma, Chattian age) (Spezzaferri *et al*., 2018).

GENUS *TRILOBATUS* SPEZZAFERRI, KUCERA, PEARSON, WADE, RAPPO, POOLE, MORARD & STALDER, 2015

***Trilobatus trilobus* (Reuss, 1850)**

Original name: *Globigerina triloba* Reuss, 1850

Synonymy

Globigerina triloba Reuss, 1850

Globigerinoides triloba (Reuss, 1850)

Globigerinoides trilobus (Reuss, 1850)

Trilobigerina triloba (Reuss, 1850)

Remarks

The test is low trochospiral, subtriangular. There are there subspherical chambers in the last whorl that increase rapidly in size. The sutures are depressed, straight on both sides. The primary aperture is an umbilical-extraumbilical elongated slit.

Geological range

Last occurrence: Extant

First occurrence: within M1a subzone (22.44-22.96Ma, Aquitanian age) (Spezzaferri *et al*., 2018).

7.5.25 SUBFAMILY ORBULININAE SCHULTZE, 1854

GENUS *ORBULINA* D'ORBIGNY, 1839

***Orbulina universa* d'Orbigny, 1839** Plate 3, Fig 1

Original name *Orbulina universa* d'Orbigny, 1839

Synonymy

Globigerina bilobata d'Orbigny, 1846

Orbulina bilobata (d'Orbigny, 1846)

Orbulina gemina Terrigi, 1891

Orbulina imperfecta Rhumbler, 1911

Orbulina parva Rhumbler, 1949

Remarks

The test is spherical and consists of a single chamber. The surface is densely perforate with many small openings.

Geological range

Last occurrence: Extant

First occurrence: within N9 zone (14.24-15.10Ma, Langhian age) (Kennett & Srinivasan, 1983).

7.5.26 SUPERFAMILY GLOBOROTALIODIA CUSHMAN, 1927

7.5.27 FAMILY GLOBOROTALIIDAE CUSHMAN, 1927

GENUS *NEOGLOBOQUADRINA* BANDY, FRERICHS & VINCENT, 1967

***Neogloboquadrina acostaensis* (Blow, 1959)** Plate 3, Fig 2

Original name *Globorotalia acostaensis* Blow, 1959

Synonymy

Globorotalia (Turborotalia) acostaensis Blow, 1959

Globorotalia (Turborotalia) acostaensis subsp. tegillata Brönnimann & Resig, 1971

Globorotalia acostaensis Blow, 1959

Remarks

The test is low trochospiral with a broadly rounded periphery. The chambers are inflated and about five to five and a half chambers can be found in the final whorl. The sutures on the spiral side are radial and depressed and on the umbilical side, narrow and deep. The aperture is interiomarginal, extraumbilical-umbilical. It is a low arch with a rim which covers much of the umbilicus.

Geological range

Last occurrence: within PT1a subzone (0.61-1.88Ma, Ionian age) (Chaisson & Pearson, 1997)

First occurrence: base of M13a subzone (Tortonian age) (Wade *et al.*, 2011)

7.5.28 SUPERFAMILY GLOBIGERINITOIDEA BERMÚDEZ, 1961

7.5.29 FAMILY GLOBIGERINITIDAE BERMÚDEZ, 1961

GENUS *TENUITELLA* FLEISHER, 1974

***Tenuitella angustiumbilicata* (Bolli, 1957)**

Original name *Globigerina ciperoensis subsp. angustiumbilicata* Bolli, 1957

Synonymy

Globigerina angustiumbilicata Bolli, 1957

Globigerina ciperoensis subsp. angustiumbilicata Bolli, 1957

Globigerinita stainforthi subsp. praestainforthi Blow, 1969

Tenuitellinata angustiumbilicata (Bolli, 1957)

Turborotalia angustiumbilicata (Bolli, 1957)

Remarks

The test is low trochospiral with a broadly rounded periphery. There are 4-5 chambers in the final whorl. They are globular to subquadrate and increase slowly in size. The aperture is extraumbilical-peripheral. It is arched. All the specimens of this species were extremely petrified and showed signs of remobilisation.

Geological range

Last occurrence: within M2 (19.30-21.12Ma, Burdigalian age)

First occurrence: within O1 zone (32.10-33.90Ma, Priabonian stage) (Pearson *et al.,* 2018)

The following table shows the list of all planktonic foraminifera identified in this work.

Table 7.5.1: List of all the planktonic foraminifera identified from Vale Farpado in this work. The species in **bold** are species that were not mentioned in Cardoso (1984) and Carvalho & Colom (1954).

Family	**Genera**	**Species**
Globigerinidae	*Globigerinoides*	*Globigerinoides ruber* (d'Orbigny, 1839)
		Globigerinoides diminutus Bolli, 1957
	Globigerinella	***Globigerinella obesa*** Bolli, 1957
		Globigerinella pseudobesa Salvatorini 1967
		Globigerinella siphonifera (d'Orbigny, 1839)
	Globoturborotalita	*Globoturborotalita apertura* (Cushman, 1918)
	Globigerina	*Globigerina bulloides* d'Orbigny, 1826
	Trilobatus	*Trilobatus trilobus* (Reuss 1850)
	Orbulina	*Orbulina universa* d'Orbigny, 1839
Globorotaliidae	*Neogloboquadrina*	*Neogloboquadrina acostaensis* (Blow, 1959)
Globigerinitidae	*Tenuitella*	***Tenuitella angustiumbilicata*** (Bolli, 1957)

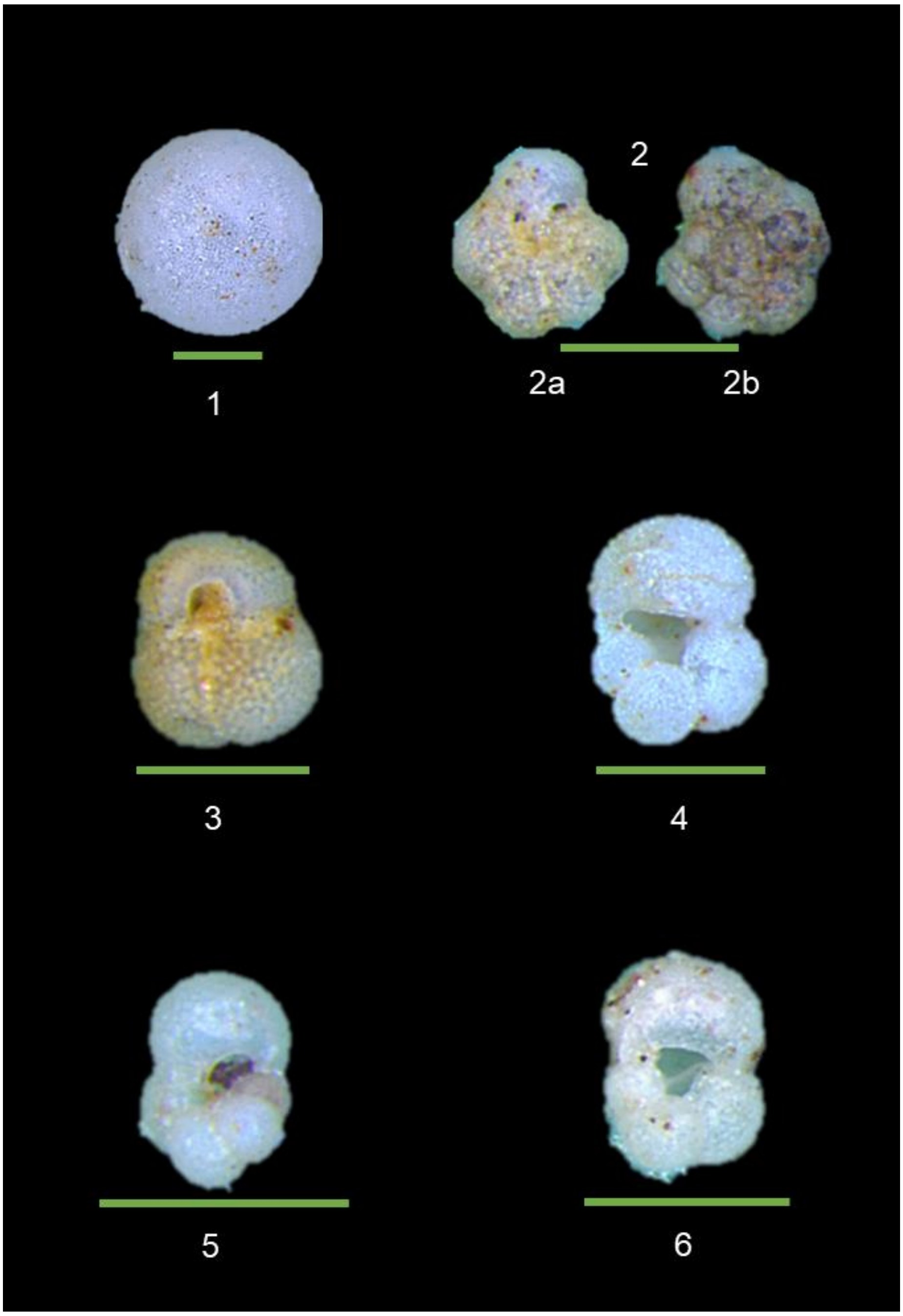

Plate 7.3: **Scale- 250µm. Fig 1:** *Orbulina universa* **Fig 2:** *Neogloboquadrina acostaensis* **Fig 3:** *Globigerinoides ruber;* **Fig 4:** *Globigerinella obesa*; **Fig 5:** *Globigerinella pseudobesa*; **Fig 6:** *Globigerina bulloides*

8 RESULTS AND DISCUSSION

8.1 ANALYSIS OF WALL STRUCTURE

In the table below the percentages of wall structures in each assemblage were calculated with the total number of benthic species. All the assemblages are dominated by Hyaline- Agglutinated walls with less than 5% Porcelaneous forms. A ternary plot was then plotted. All the samples are in the left corner side of the ternary diagram. This is typical of many environments such as shelf seas, brackish estuaries and lagoons and deep seas. However, these environments are fundamentally different at the species level.

Table 8.1.1: The number and percentage of porcelaneous, agglutinated, hyaline tests in each sample

Sample	Porcelaneous	Agglutinated	Hyaline	Total	P%	A%	H%
2 bottom	12	50	191	253	4.74%	19.76%	75.49%
2a	4	76	610	690	0.58%	11.01%	88.41%
2b	3	34	209	246	1.22%	13.82%	84.96%
2c	8	24	307	339	2.36%	7.08%	90.56%
3a	6	12	220	238	2.52%	5.04%	92.44%
4a	5	23	221	249	2.01%	9.24%	88.76%
4b	4	30	254	288	1.39%	10.42%	88.19%

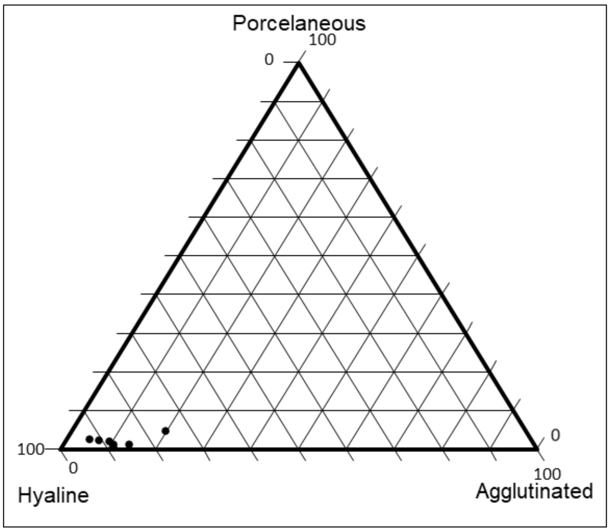

Figure 8.1: Ternary plot of walls for all the samples (triangle corners represent 100% of the labelled components).

8.2 Foraminifera species analysis

Foraminiferal assemblage is well diversified in all the beds. The beds 5a and 5b did not yield any fossils. Benthic foraminifera were the most dominant in all the assemblages, constituting 22 families, 37 genera and 58 species. Planktonic foraminifera is represented by 3 families, 8 genera and 11 species.

Table 8.2.1: The percentage of individual planktonic species in each sample.

Species	**2 bottom**	**%**	**2a**	**%**	**2b**	**%**	**2c**	**%**	**3**	**%**	**4a**	**%**	**4b**	**%**
Globigerinoides ruber	1	7%	0	0%	1	25%	2	20%	0	0%	2	11%	1	4%
Globigerinoides diminutus	1	7%	0	0%	0	0%	0	0%	0	0%	1	5%	0	0%
Globigerinella obesa	6	43%	1	17%	1	25%	2	20%	5	17%	3	16%	1	4%
Globigerinella pseudobesa	1	7%	0	0%	0	0%	0	0%	1	3%	0	0%	0	0%
Globigerinella siphonifera	1	7%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Globoturborotalita apertura	1	7%	1	17%	1	25%	0	0%	2	7%	0	0%	2	8%
Globigerina bulloides	1	7%	0	0%	0	0%	4	40%	10	34%	4	21%	2	8%
Orbulina universa	1	7%	1	17%	0	0%	0	0%	1	3%	1	5%	8	32%
Neogloboquadrina acostaensis	1	7%	0	0%	0	0%	1	10%	0	0%	0	0%	1	4%
Trilobatus trilobus	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%
Tenuitella angustiumbilicata	0	0%	3	50%	0	0%	0	0%	0	0%	0	0%	0	0
Unrecognisable	0	0%	0	0%	1	25%	0	0%	10	34%	8	42%	4	21%
Total	14		6		4		10		29		19		19	

Table 8.2.2: The percentage of individual benthic species in each sample. The shaded parts represent dominance. The darker the shade more dominant the species.

Species	2 bottom	%	2a	%	2b	%	2c	%	3	%	4a	%	4b	%
Adelosina dutemplei	2	1%	0	0%	1	0%	0	0%	2	1%	0	0%	0	0%
Ammonia beccarii	10	4%	18	3%	21	9%	18	5%	5	2%	4	2%	10	3%
Asterigerinata mamilla	0	0%	0	0%	0	0%	2	1%	3	1%	2	1%	2	1%
Bannerella gibbosa	1	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Biasterigerina planorbis	0	0%	0	0%	2	1%	1	0%	0	0%	0	0%	0	0%
Biloculinella globulus	1	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Bolivina antiqua	1	0%	1	0%	2	1%	0	0%	1	0%	0	0%	2	1%
Bolivina catanensis	0	0%	1	0%	1	0%	1	0%	1	0%	0	0%	0	0%
Bolivina robusta	1	0%	0	0%	1	0%	1	0%	1	0%	1	0%	1	0%
Bolivina sp.	0	0%	0	0%	1	0%	0	0%	0	0%	1	0%	0	0%
Bolivina subspinescens	1	0%	0	0%	0	0%	0	0%	1	0%	0	0%	0	0%
Bulimina aculeata	0	0%	1	0%	3	1%	7	2%	4	2%	3	1%	6	2%
Bulimina elongata	2	1%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Cancris auricula	3	1%	0	0%	1	0%	2	1%	3	1%	5	2%	2	1%
Cassidulina carinata	8	3%	1	0%	2	1%	10	3%	0	0%	6	2%	3	1%
Cibicides refulgens	83	33%	238	34%	69	28%	71	21%	27	11%	43	17%	56	19%
Cibicidoides ungerianus	3	1%	5	1%	2	1%	8	2%	11	5%	5	2%	5	2%
Cibicidoides wuellerstorfi	5	2%	1	0%	4	2%	8	2%	2	1%	8	3%	4	1%
Cribroelphidium excavatum	1	0%	0	0%	1	0%	1	0%	0	0%	0	0%	1	0%
Elphidium aculeatum	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Elphidium advenum	10	4%	9	1%	6	2%	27	8%	9	4%	10	4%	15	5%
Elphidium crispum	28	11%	144	21%	19	8%	41	12%	51	21%	45	18%	52	18%
Elphidium fichtellianum	4	2%	9	1%	5	2%	14	4%	1	0%	10	4%	16	6%
Elphidium macellum	0	0%	5	1%	0	0%	0	0%	0	0%	0	0%	0	0%
Favulina hexagona	1	0%	0	0%	1	0%	0	0%	1	0%	0	0%	1	0%
Fissurina eburnea	0	0%	0	0%	1	0%	0	0%	0	0%	0	0%	0	0%
Fissurina marginata	0	0%	0	0%	1	0%	0	0%	1	0%	0	0%	1	0%
Fissurina orbignyana	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Glabratella australensis	0	0%	0	0%	1	0%	0	0%	0	0%	0	0%	0	0%
Globocassidulina crassa	7	3%	48	7%	5	2%	21	6%	2	1%	13	5%	12	4%
Globulina gibba	1	0%	1	0%	0	0%	1	0%	1	0%	0	0%	0	0%
Globulina gibba var. fissicostata	0	0%	1	0%	1	0%	0	0%	0	0%	0	0%	0	0%
Globlina inaequalis	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Guttulina communis	0	0%	1	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Lagena hipsida	0	0%	0	0%	0	0%	0	0%	1	0%	0	0%	0	0%
Lagena ollula	0	0%	0	0%	0	0%	1	0%	0	0%	0	0%	0	0%
Lagena striata	1	0%	0	0%	0	0%	0	0%	1	0%	0	0%	0	0%
Lobatula lobatula	4	2%	110	16%	46	19%	57	17%	79	33%	61	24%	56	19%
Nonion boueanum	4	2%	0	0%	1	0%	5	1%	0	0%	0	0%	3	1%
Nonion commune	3	1%	1	0%	0	0%	4	1%	10	4%	0	0%	0	0%
Nonionoides grateloupii	1	0%	1	0%	2	1%	2	1%	0	0%	0	0%	0	0%
Oolina seminuda	0	0%	0	0%	1	0%	0	0%	0	0%	3	1%	0	0%
Oolina sp.	0	0%	0	0%	0	0%	1	0%	3	1%	0	0%	1	0%
Planorbulina mediterranensis	3	1%	0	0%	0	0%	0	0%	1	0%	1	0%	0	0%
Quinqueloculina akneriana	4	2%	1	0%	1	0%	3	1%	1	0%	0	0%	0	0%
Quinqueloculina lata	3	1%	3	0%	0	0%	0	0%	0	0%	3	1%	1	0%
Quinqueloculina disparilis	1	0%	0	0%	0	0%	0	0%	0	0%	1	0%	0	0%
Quinqueloculina seminulum	1	0%	0	0%	0	0%	3	1%	3	1%	1	0%	1	0%
Quinqueloculina sp.	2	1%	0	0%	0	0%	2	1%	2	1%	0	0%	2	1%
Reussella spinulosa	0	0%	1	0%	1	0%	1	0%	2	1%	3	1%	1	0%
Rosalina globularis	1	0%	5	1%	4	2%	2	1%	0	0%	0	0%	0	0%

Species	2 bottom	%	2a	%	2b	%	2c	%	3	%	4a	%	4b	%
Rosalina macropora	4	2%	8	1%	3	1%	1	0%	0	0%	0	0%	0	0%
Sahulia conica	8	3%	1	0%	3	1%	6	2%	4	2%	3	1%	3	1%
Seguenzaella lacunata	1	0%	0	0%	1	0%	0	0%	0	0%	0	0%	0	0%
Sigmavirgulina tortuosa	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
Spiroloculina dilatata	0	0%	0	0%	2	1%	0	0%	0	0%	0	0%	0	0%
Spiroplectammina atrata	5	2%	0	0%	8	3%	0	0%	0	0%	4	2%	5	2%
Spiroplectinella wrighti	16	6%	26	4%	10	4%	13	4%	4	2%	7	3%	10	3%
Textularia pseudogramen	5	2%	0	0%	4	2%	3	1%	2	1%	2	1%	2	1%
Textularia sagittula	8	3%	47	7%	7	3%	2	1%	0	0%	4	2%	9	3%
Textularia truncata	0	0%	2	0%	0	0%	0	0%	2	1%	2	1%	0	0%
Textularia sp.	7	3%	0	0%	0	0%	0	0%	0	0%	1	0%	0	0%
Vasiglobulina myristiformis	0	0%	1	0%	1	0%	0	0%	0	0%	0	0%	0	0%
Total	255		691		246		340		242		252		289	

Table 8.2.3: Planktonic specimen (P) divided by the total foraminiferal assemblage (P+P/B) shown in percentage. (2 bot- 2 bottom).

Taxa	2 bot	%	2a	%	2b	%	2c	%	3	%	4a	%	4b	%
Benthic (B)	255		691		246		340		242		252		289	
Planktonic (P)	14		6		4		10		32		18		11	
Total assemblage	269		697		250		350		274		270		300	
P/P+B (%)		5%		1%		2%		3%		12%		7%		4%

Foraminifera abundances can be categorized into 3 groups, genera with an occurrence of

1. More than 15% - abundant
2. 2-14% - common
3. Less than 2% - rare.

As seen from Table 8.2.2 and Table 8.2.1 the most abundant genera in all the assemblages are *Cibicides* and *Elphidium*, the common genera being *Ammonia, Cassidulina, Globocassidulina, Lobatula, Spiroplectinella, Spiroplectammina, Textularia,* and *Nonion.* Rare genera include B*olivina, Bulimina, Cancris, Oolina, Nonionoides, Planorbulina, Rosalina, Reussella, Seguenzaella, Spiroloculina* and *Quinqueloculina* and among the planktonic species: *Globigerinella obesa, Globigerinoides ruber, Globoturborotalita apertura and Globigerina bulloides* are common.

There were 20 species identified for the first time in the Pliocene of Portugal. Which include *Bulimina aculeata*, *Bolivina antiqua, Sigmavirgulina tortuosa, Rosalina globularis, Rosalina macropora, Cibicidoides wuellerstorfi, Cibicidoides ungerianus, Asterigerinata mamilla, Biasterigerina planorbis, Nonionoides grateloupii, Elphidium aculeatum, Lagena hispida, Lagena ollula, Seguenzaella lacunata, Favulina hexagona, Fissurina eburnean, Globlina inaequalis, Guttulina communis, Biloculinella globulus, Bannerella gibbose.*

The assemblage 2 bottom has overall well-preserved forams, although a few specimens of *Ammonia*, *Elphidium* and *Cibicides* are yellow and broken indicating that the specimens could be allochthonous. It is dominated by *Cibicides refulgens* (33%), *Elphidium crispum* (11%), *Spiroplectinella wrighti* (6%) and *Ammonia beccari* (4%) *Elphidium advenum* (4%). Cibicides refulgens is an epifaunal species that live attached to hard substrates in high-energy areas, whereas *Elphidium crispum* is an epifaunal species that can be found in the ocean today and lives attached to seagrass in shallow marine environments (Langer, 1993; Murray, 2006).

Assemblage 2a also has well-preserved forams with a few *Elphidium, Ammonia and Cibicides* showing signs of transportation such as yellow stains and abrasion. *Cibicides refulgens* dominate the assemblage accounting for 34% of it, subsequently, *Elphidium crispum* makes up 21% of the assemblage. *Lobatula lobatula* constitutes 16%, *Globocassidulina crassa* and *Textularia sagittula* make up 7% of the assemblage each. The first two dominating species in this assemblage is the same as the previous assemblage. *L. lobatula* is a species that lives attached to seagrass or rhizomes (Langer, 1993). *T. sagittula* is an epifaunal species that are attached to a substrate and lives in shelf environments (Murray, 2006). The species such as *G. crassa, A. becarri, C.refulgens, L. lobatula* along with the other species mentioned are the major dominating species found in temperate shelf seas (Murray, 2006).
Both the above assemblages have a few specimens that show signs of transportation. This could be an indication that there was water flowing in, supporting the idea of a high-energy environment.

The dominance of *Cibicides refulgens* (28%) characterizes the assemblage 2b, followed by *Lobatula lobatula* (19%), *Ammonia beccarii* (9%) and *Elphidium crispum* with (8%). The assemblage 2c also has the same dominant species, with *C. refulgens* (21%), *L. lobatula* (17%) and *E. crispum* (12%). *Spiroplectinella wrighti* makes up 4% of both assemblages. All the specimens are well preserved in these and the following assemblages. There is a spike in the abundance of *Globocassidulina crassa* (6%) in 2c signifying more influx of cooler water. Here the second dominant species is different than the previous assemblages. However, that doesn’t change much of the predicted palaeoenvironment. These assemblages could also indicate a temperate shelf environment with lots of seagrasses (Murray, 2006).

In assemblage 3, we start seeing some changes in the order of the dominating species. It is characterized by dominant *L. lobatula* (33%), *E. crispum* (21%) and *C. refulgens* (11%). All the specimens are exceptionally well preserved in this sample. This assemblage also has the greatest number of well-preserved planktonic forams in the whole outcrop, resulting in the highest P/P+B ratio of 12%. The sudden disappearance of species such as *Cassidulina* *carinata* and both the *Rosalina sp.* and the increase in the number of *Bolivina* and *Bulimina* species indicates an environment with low organic flux and dissolved oxygen (anoxic) but the presence of *Cassidulina carinata* depends more on the sediment grain size than the organic flux (Altenbach *et al*., 1999; Elshanawany *et al*., 2011; Murray, 2003).

4a is characterized by the dominance of *L. lobatula* (24%), *E. crispum* (18%) and *C. refulgens* (17%). The fine grain sediments in this layer are very suitable for foraminifera such as *Cancris auricula* (which can be found in relatively higher numbers). Assemblage 4b is dominated by *L. lobatula* (19%), *C. refulgens* (19%) and *E. crispum* (18%). These assemblages are similar to assemblage 3a with a few not so well-preserved specimens of *C. carinata* showing up. The major dominating species are still the same and indicate an environment of temperate shelf sea.

Overall the presence of only smooth and striate forms of *Quinqueloculina* and the dominance of *Cibicides, Lobatula* is common only in cool temperate shelf seas (Murray, 1987, 2006).

8.3 Planktonic foraminifera and geological age

Planktonic foraminifera were very few in comparison to benthic forams (Table 8.2.3). The two most dominating planktonic species in all the assemblages are *Globigerinella obesa* and *Globigerina bulloides* (Table 8.2.1). *G. bulloides* is a species that is dominant in major upwelling and colder zones (Darling *et al*., 2017). The most dominating in 2 bottom is *G. obesa.* The presence of *Globigerinoides diminutus* in this assemblage could be because of the erosion and redeposition of Miocene deposits of the Amor Formation. We can also find *Globigerinella pseudobesa*. Assemblage 2a has very few planktonic forams preserved. Petrified specimens of *Tenuitella angustiumbilicata* were found in sample 2a (Table 8.2.1). These specimens could have been remobilized from the Miocene deposits. Assemblage 2b has the least number of planktonic forams. It is mainly dominated by *Orbulina universa.* 2c is mainly dominated by *G. bulloides.* Assemblage 3 has the greatest number of planktonic specimens among all the samples. The dominance of *G. bulloides* in the planktonic assemblage 3 could also support that layer 3 can be the deepest layer. We can find *Globigerinella pseudobesa* in this layer as well. 4a is mainly dominated by *G. bulloides* and *G. obesa.* The assemblage 4b is mostly dominated by *O. universa* followed by *G. bulloides.*

Below Table 8.3.1 shows planktonic species and their last and first occurrence. *G. obesa* is found in all the layers at varying levels and is maximum at 2 bottom (Table 8.2.1) and when combined with the presence of Globigerinella pseudobesa in some samples, does not rule out the possibility that the sediments are Zanclean in age. *Globigerinoides diminutus* is a middle Miocene marker (Kennett & Srinivasan, 1983) as its last and the first occurrence is within Burdigalian to Langhian age (17.54 – 14.24Ma). This species could have been remobilized from the Miocene sediments below (Amor Formation). This means the age of the Miocene sediments could be within the N7-N9 zone (17.54-14.2Ma) (Kennett & Srinivasan, 1983) late Burdigalian – Langhian which is in accordance with the dating based on vertebrates MN5 (17 – 15Ma) by Antunes & Mein (1981).

Table 8.3.1: Planktonic species and its last and first occurrence. Important species are shaded.

Species	**Last occurrence**	**First occurrence**
Globigerinoides ruber	Extant	10.46-11.63Ma, Serravallian age
Globigerinoides diminutus	14.24-15.10Ma, Langhian age	16.38-17.54Ma, Burdigalian age
Globigerinella obesa	3.60-5.33Ma Zanclean age	32.10-33.90Ma, Priabonian age
Globigerinella pseudobesa	4.37-5.20Ma, Zanclean age	11.63-11.79Ma, in Serravallian age
Globigerinella siphonifera	Extant	11.79-13.41Ma, Serravallian age
Globoturborotalita apertura	1.6Ma, Calabrian age	11.1Ma, Tortonian age
Globigerina bulloides	Extant	26.93-28.09Ma, Chattian age
Orbulina universa	Extant	22.44-22.96Ma, Aquitanian age
Neogloboquadrina acostaensis	Extant	14.24-15.10Ma, Langhian age
Trilobatus trilobus	0.61-1.88Ma, Ionian age	Tortonian age
Tenuitella angustiumbilicata	19.30-21.12Ma, Burdigalian age	32.10-33.90Ma, Priabonian stage

8.4 Diversity indexes

Diversity indexes such as the Fisher alpha index which helps identify the relationship between the number of individuals and the number of species in an assemblage (Fisher *et al.*, 1943), the information function, or Shannon- Weaver index (H) (Shannon and Weaver, 1963) and Dominance (D) ranging from 0 (all taxa are equally present) to 1 (one taxon is completely dominant in the whole assemblage). This was calculated only for the benthic species.

Table 8.4.1: Calculation of diversity indexes of all assemblages.

Diversity indexes	**2 bottom**	**2a**	**2b**	**2c**	**3**	**4a**	**4b**
Taxa_S	40	29	39	33	33	28	35
Individuals	255	691	246	340	242	252	289
Dominance_D	0.1295	0.1985	0.1302	0.1033	0.1677	0.1268	0.1172
Shannon_H	2.872	2.038	2.724	2.72	2.45	2.577	2.659
Fisher_alpha	13.32	6.125	13.05	9.03	10.32	8.06	10.42

The Dominance D in all the assemblages does not vary much, the assemblage with almost equal dominance among species is 2c (0.10) and the assemblage with one or two species dominating almost entirely is 2a (0.19) followed by 3 (0.16). Shannon-Weaver index (H) accounts for both the abundance and evenness of species. According to Murray (2006) in shelf environments, H ranges from 1.51-3.50 and Fisher alpha ranges from 5-15. As seen in the above table, the assemblages also have H ranging from 2.038- 2.872 and Fisher alpha ranging from 6.125-13.32, which is within the range described. Thus, we can further confirm the environment to be a shelf environment.

The graph below represents species diversity data from this work with fisher alpha against H and on the left is a figure from Murray (2006), that represents a summary of species diversity showing fields for the main values and relative to different types of environments. The graph Figure 8.3 is plotted from the values obtained from this work plot along with H; 2-3 and Fisher alpha between 5-15 and fits well with the shelf domain of the diagram Figure 8.2.

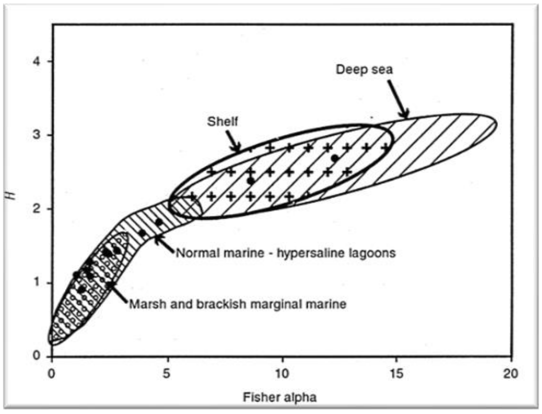

Figure 8.2: Shows the summary of species-diversity data from Murray (2006, fig 8.4)

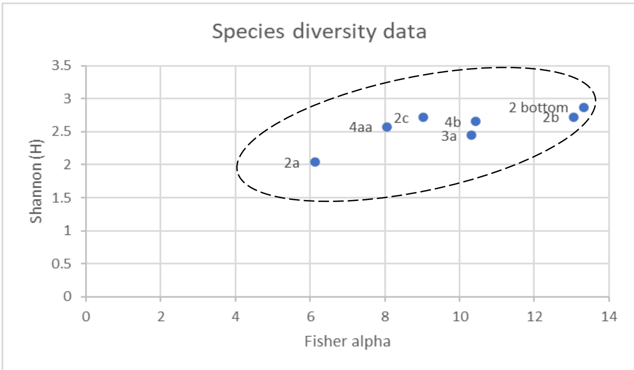

Figure 8.3: Graph plotted for fisher alpha index against H showing the values from each assemblage.

8.5 DEPTH

Van der Zwaan *et al*. (1990) proposed a formula for calculating the palaeobathymetry by using the planktonic/benthic ratio; Depth = $e^{(3.58718+\{0.03534*\%P\})}$. Using this formula for our assemblages gives us the following average depth of ±36.193m with the deepest layer being 3 and the shallowest layer being 2a with a depth of 36.285m and 36.144m respectfully. The difference is only a few centimeters from the shallowest to the deepest. However, this formula does not accurately predict the bathymetry as physical factors such as variations in preservation, signs of dissolution and the effects of redeposition, especially of fine-grained sediments, are difficult to detect (Van der Zwaan *et al*., 1990).

An important factor to notice here is that less than 14% of planktonic foraminifera is usually characteristic of an infralittoral environment. In Portugal, the infralittoral environment is around 25m which is closer to the depth obtained from the formula.

This does not agree with the sedimentological results, which suggest that the layer deposited under deepest conditions is 4b. Several theories can be considered to explain this apparent disagreement. To start, clay mineralogy is influenced by more than one process, therefore, one cannot safely assume that the fluctuations in smectite are exclusively related to water depth. Even if they were, since, the predicted environment is a continental shelf prone to constant upwelling, the cold conditions as estimated from foraminiferal assemblages might not be associated with depth in this case. In addition, hydrodynamic conditions are likely influenced by oceanic currents which may be responsible for heterogeneous patterns of smectite distribution. Thus, it is not surprising that these two types of data do not agree with each other in terms of the exact deposits associated with maximum depth.

9 CONCLUSION

The following conclusions can be drawn from the work above:

1. Sand dominates all the assemblages followed by silt (30%) and clay that makeup only 1-2% of the whole assemblage.
2. The grains are very poorly sorted and are extremely asymmetrical indicating a high energy environment.
3. Most of the fossiliferous layers are dominated by smectite and illite. Since smectite is a mineral that settles in deep water conditions we can assume that the depth increased from the bottom of the succession reaching a maximum at 4b.
4. Benthic foraminifera dominated all the assemblages, comprising 22 families, 37 genera and 58 species. Planktonic foraminifera are represented by 3 families, 8 genera and 11 species.
5. 25 species identified were not mentioned in Cardoso (1984) Carvalho & Colom (1954. They include: *Bulimina aculeata*, *Bolivina antiqua*, *Sigmavirgulina tortuosa, Rosalina globularis, Rosalina macropora*, *Cibicidoides wuellerstorfi*, *Cibicidoides ungerianus*, *Asterigerinata mamilla, Biasterigerina planorbis, Nonionoides grateloupii, Elphidium aculeatum, Lagena hispida, Lagena ollula, Seguenzaella lacunata, Favulina hexagona, Fissurina eburnea, Globlina inaequalis, Guttulina communis, Biloculinella globulus, Bannerella gibbosa, Globigerinoides diminutus*, *Globigerinella obesa*, *Globigerinella pseudobesa*, *Globigerinella siphonifera* and *Tenuitella angustiumbilicata.*
6. The wall type analysis of the benthic foraminifera using tri-plot concluded that all the assemblages were dominated by 90-95 % of hyaline-agglutinated forams and with less than 5% porcelaneous forms, could belong to environments such as shelf seas, brackish estuaries and lagoons and deep seas.
7. The foraminiferal species such as *Cibicides refulgens, Lobatula lobatula, Elphidium crispum* dominated almost all the assemblages.
8. Carbonate environments such as reefs, lagoons and shelf seas all show a similar pattern of foraminifera but the presence of only smooth and striate forms of *Quinqueloculina* and the dominance of *Cibicides* is common only in cool temperate shelf seas (Murray, 1987, 2006). The coldness of the sea could be due to upwelling, as it is common in shelf seas.
9. The species diversity data showed Shannon and Weaver (H) index range from 2.038 - 2.872 and Fisher alpha index ranges from 6.125 - 13.32, which is within the ranges suggested for shelf environment (H from 1.51 - 3.50 and Fisher alpha from 5 -15).

10. From the Planktonic/Benthic ratio, we can assume that layer 3, having the highest percentage could be the deepest. This is supported by the dominance of *Globigerina bulloides* in the planktonic assemblage as well as from the formula proposed by Van der Zwaan *et al*. (1990).
11. The water depth according to sedimentology and foraminiferal analysis does not support one another due to varying factors that influence both the deposition of smectite and the preservation of foraminifera. Hence the depth could be maximum somewhere between 3 and 4b.
12. *Globigerinella obesa* occurs in all the samples and is maximum in layer 2bottom and along with *Globigerinella pseudobesa*, found in layers 2bottom and 3 could be indicators of age as the last occurrence of these species is in the N19 Zone (4.37-5.20Ma) (Kennett & Srinivasan, 1983) this does not rule out the possibility that the sediments are Zanclean at age.
13. *Globigerinoides diminutus* remobilized by the erosion of the Miocene deposits can be found in layers 2bottom and 4a. It suggests the age of the Miocene sediments to be within the N7-N9 zone (17.54-14.2Ma) (Kennett & Srinivasan, 1983) late Burdigalian – Langhian which is in accordance with the dating based on vertebrates MN5 (17 – 15Ma) by Antunes & Mein (1981).

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Quantitative analysis of foraminifera and sedimentology of the marine Pliocene of Vale Farpado (Pombal, West Portugal) and its palaeoenvironmental interpretation.

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

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