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An Essay on

Application of Foraminifera in Petroleum Exploration

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بسم الله الرحمن الرحيم

وَعَلَّمَكَ مَا لَمْ تَكُنْ تَعْلَمُ
وَكَانَ فَضْلُ اللّهِ عَلَيْكَ عَظِيمًا

صدق الله العظيم

النساء 113

Contents

Title	Page No.
List of Figures	--
List of Tables	---
Abstract	---
Chapter 1: Introduction	1
Chapter 2: What is Foraminifera	5
2.1. Classification	5
2.2. Biology	7
2.3. Life Cycle	16
2.4. Preparation Techniques	16
2.5. Observation Techniques	17
Chapter3: Planktonic & Benthic Foraminifera	19
3.1. Planktonic foraminifera and the oceans	19
3.2.Benthic Foraminifera in the deep oceans	21
3.3. Benthic Forams. : what is proxy for what?	25

3.4.Cenozoic benthic foraminiferal events	28
3.5. What is typical in these non-analog 'Greenhouse' faunas?	30
3.6. Greenhouse Faunas Contradiction	30
3.7. Higher primary productivity on sea floor;	30
3.8. K/T boundary: no benthic Foram. extinction	31
3.9. What caused the global benthic foraminiferal extinction?	31
3.10.Cenozoic benthic foraminiferal faunas	32
3.11. Presently most abundant groups in the deep sea	32
Chapter 4:Foraminifera and petroleum exploration: case studies from carbonate and clastic systems	34
4.1. Foraminifera in petroleum exploration	34
4.2.Case studies from clastic systems	39
4.3. Case studies from carbonate systems	44
Chapter 5 : Summary and Conclusion	47
References	49
Arabic Summary	--

List of Figures

Figure		Title	Page No.
Figure (1)	:	Microshell in Foraminifera	1
Figure (2)	:	Foraminifral suborders and their envisaged phylogeny. Redrawn from Tappan and Loeblich (1988). Among the Suborders shown only the fusulinina are extinct.	6
Figure (3)	:	Chamber arrangements	11
Figure (4)	:	Apertures	13
Figure (5)	:	A generalised foraminifera life cycle note alternation between a haploid megalosperic from and diploid microspheric form. Redraw from Goldstein,(1999).	15
Figure (6)	:	Food from surface to bottom	24
Figure (7)	:	formation on Antarctic ice sheets	29
Figure (8)	:	Discrimination of ma- rine environments by cross-plots of foraminiferal morphogroups, (from Murray, 1973).	38
Figure (9)	:	Variation in the ratio of planktonic to benthic foraminifera with depth, (from Hayward, 1990).	38
Figure (10)	:	Eastern Paratethys stratigraphic summary and correlation with the global coastal onlap curve, (from Jones and Simmons, 1993).	40

Con. List of Figures

Figure		Title	Page No.
Figure (11)	:	Comparison of the coastal-onlap curve of the study area (offshore Louisiana), the T-R cycles of Hardenbol et al. (1998) for European basins, and the global curve of Haq et al. (1988), (from Hentz and Zeng, 2003).	43
Figure (12)	:	Spatial distribution of carbonate reservoirs, based on internet data(www.ccreservoirs.com).	44
Figure (13)	:	Distribution patterns of Cenozoic foraminifera reflecting the Standard Facies Zones differentiated by Wilson (1975); platform-basin transect with marginal reefs and ternary diagram, (from Hallock and Glenn, 1986).	46

List of Table

Table		Title	Page No.
Table (1)	:	Geologic Time Scale	4

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Abstract

Amira Fawzy

The Foraminifera are a phylum or class of amoeboidprotisls. They are characterized both by their thin pseudopodia that form an external net for catching food, and they usually have an external shell, or test, made of various materials and constructed in diverse forms.

Most Forams. are aquatic, primarily marine, and the majority of species live on or within the seafloor sediment (benthos) with a small number of species known to be floaters in the water column at various depths (plankton).

A few are known from freshwater or brackish conditions and some soil species have been identified through molecular analysis of small subunit ribosomal DNA.

Foraminifera typically produce a test, or shell, which can have either one or multiple chambers, some becoming quite elaborate in structure.

These shells are commonly made of calcium carbonate (CaCO3) or agglutinated sediment particles. About 275,000 spedes are recognized, both living and fossil. They are usually less than I mm in size, but some are much larger, the largest species reaching up to 20 cm.

Foraminifera

1.1. Introduction:

Foraminifera (Forams. for short) are single-celled protists with shells. Their shells are also referred to as tests because in some forms the protoplasm covers the exterior of the shell. The shells are commonly divided into chambers which are added during growth, though the simplest forms are open tubes or hollow spheres. Depending on the species, the shell may be made of organic compounds, sand grains and other particles cemented together, or crystalline calcite.

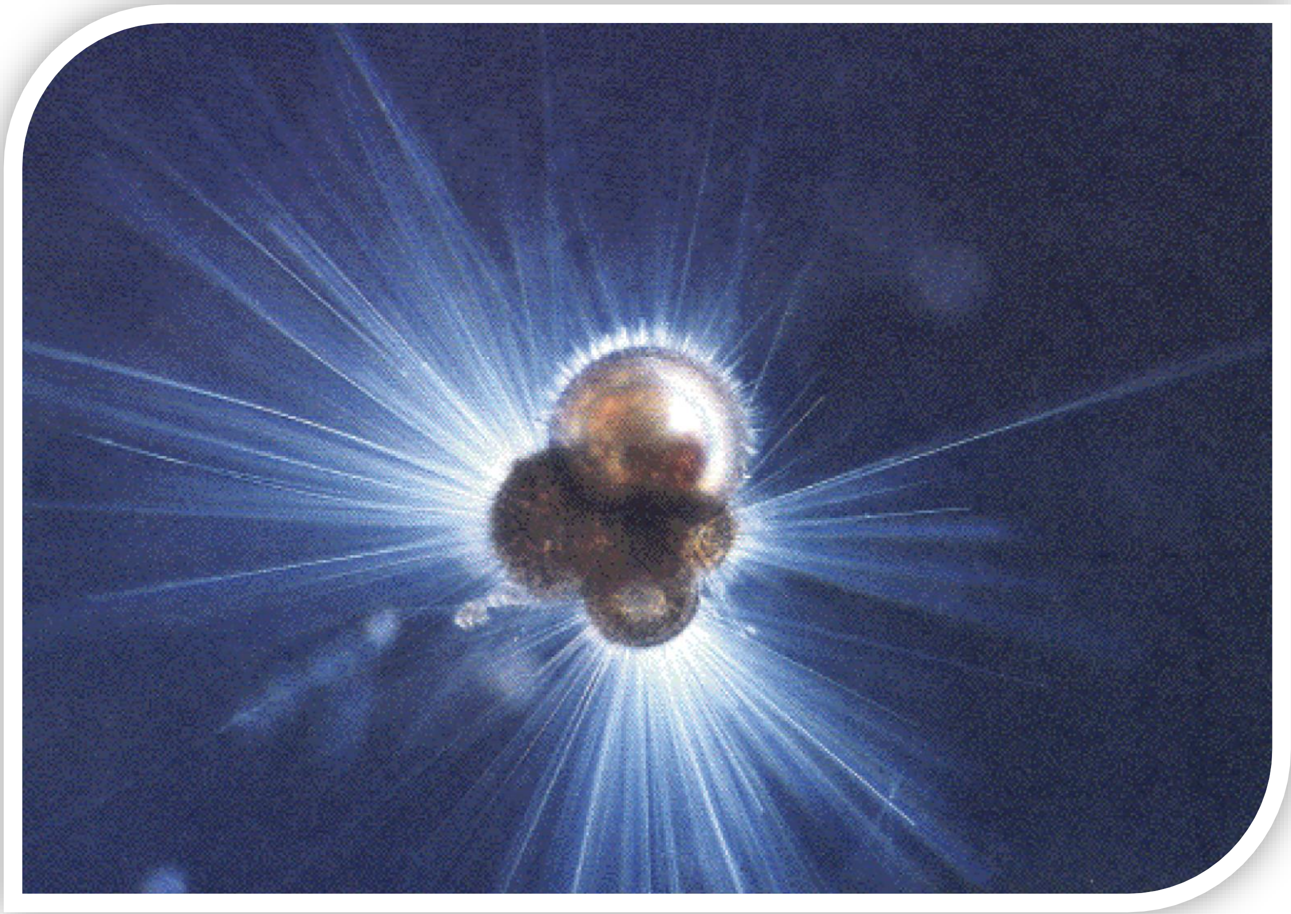


Fig 1: Microshell in Foraminifera

Fully grown individuals range in size from about 100 micrometers to almost 20 centimeters long. A single individual may have one or many nuclei within its cell. The largest living species have a symbiotic relationship with algae, which they "farm" inside their shells. Other species eat foods ranging from dissolved organic molecules, bacteria, diatoms and other single celled phytoplankton, to small animals such as copepods.

They move and catch their food with a network of thin extensions of the cytoplasm called reticulopodia, similar to the pseudopodia of an amoeba, although much more numerous and thinner.

Foraminifera are found in all marine environments, they may be planktic or benthic in mode of life. The generally accepted classification of the foraminifera is based on that of Loeblich and Tappan.

1.2. History of Study

The study of foraminifera has a long history, their first recorded "mention" is in Herodotus (fifth century BC) who noted that the limestone of the Egyptian pyramids contained the large benthic foraminifer Nummulites. In 1835 Dujardin recognised foraminifera as protozoa and shortly afterwards d'Orbigny produced the first classification.

The famous 1872 HMS Challenger cruise , the first scientific oceanographic research expedition to sample the ocean floor collected so many samples that several scientists, including foraminiferologists such as H.B. Brady were still working on the material well in to the 1880's.

Work on foraminifera continued throughout the 20th century, workers such as Cushman in the U.S.A and Subbotina in the Soviet Union developed the use of foraminifera as biostratigraphic tools. Later in the 20th century Loeblich and Tappan and Bolli carried out much pioneering work.

1.3. Stratgraphic Range of Foraminifera

Foraminifera have a geological range from the earliest Cambrian to the present day. The earliest forms which appear in the fossil record (the allogromiine) have organic test walls or are simple agglutinated tubes.

The term "agglutinated" refers to the tests formed from foreign particles "glued" together with a variety of cements.

Foraminifera with hard tests are scarce until the Devonian, during which period the fusulinids began to flourish culminating in the complex fusulinid tests of the late Carboniferous and Permian times; the fusulinids died out at the end of the Palaeozoic.

The miliolids first appeared in the early Carboniferous, followed in the Mesozoic by the appearance and radiation of the rotalinids and in the Jurassic the textularinids.

The earliest forms are all benthic, planktic forms do not appear in the fossil record until the Mid Jurassic in the strata of the northern margin of Tethys and epicontinental basins of Europe.

They were probably meroplanktic (planktic only during late stages of their life cycle). The high sea levels and "greenhouse" conditions of the Cretaceous saw a diversification of the planktic foraminifera, and the major extinctions at the end of the Cretaceous included many planktic foraminifera forms.A rapid evolutionary burst occurred during the Palaeocene with the appearance of the planktic globigerinids and globorotalids and also in the Eocene with the large benthic forr.minifera of the nummulites, soritids and orbitoids look at (table 1).

The orbitoids died out in the Miocene, since which time the large foraminifera have dwindled. Diversity of planktic forms has also generally declined since the end of the Cretaceous with brief increases during the warm climatic periods of the Eocene and Miocene.

Table 1: Geologic Time Scale

Eon	Era	Period	Epoch	Age Ma
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	1.64
		Neogene	Pliocene	5.2
			Miocene	23.3
		Palaeogene	Oligocene	35.4
			Eocene	56.5
			Palaeocene	65.0
	Mesozoic	Cretaceous		145.6
		Jurassic		208.0
		Triassic		245.0
	Palaeozoic	Permian		290.0
		Carboniferous		362.5
		Devonian		408.5
		Silurian		439.0
		Ordovician		510.0
		Cambrian		570.0
Proterozoic				2500
Archean				4000

What is Foraminifera

2.1. Classification

Foraminifera are classified primarily on the composition and morphology of the test. Three basic wall compositions are recognised, organic (protinaceous mucopoly saccharide i.e. the allogromina), agglutinated and secreted calcium carbonate (or more rarely silica). Agglutinated forms, i.e the Textulariina, may be composed of randomly accumulated grains or grains selected on the basis of specific gravity, shape or size; • some forms arrange particular grains in specific parts of the test. Secreted test foraminifera are again subdivided into three major groups, microgranular (i.e. Fusulinina), porcelaneous (i.e. Miliolina) and hyaline (i.e. Globigerinina). Microgranular walled forms (commonly found in the late Palaeozoic) are composed of equidimensiona Isubspherical grains of crystalline calcite.

Porcelaneous forms have a wall composed of thin inner and outer veneers enclosing a thick middle layer of crystal laths, they are imperforate and made from high magnesium calcite. The hyaline foraminifera add a new lamella to the entire test each time a new chamber is formed; various types of lamellar wall structure have been recognised, the wall is penetrated by fine pores and hence termed perforate. A few "oddities" are also worth mentioning, the Suborder Spirillinina has a test constructed of an optically single crystal of calcite, the Suborder Silicoloculinina as the name suggests has a test composed of silica.

Another group (the Suborder Involutina) have a two chambered test composed of aragonite. The Robertinina also have a test composed of aragonite and the Suborder Carterina is believed to secrete spicules of calcite which are then weakly cemented together to form the test.The morphology of foraminifera tests varies enormously, but in terms of classification two features are important. Chamber arrangement and aperture style, with many subtle variations around a few basic themes. These basic themes are illustrated in the following two diagrams but it should be remembered that these are only the more common forms and many variations are recognized.

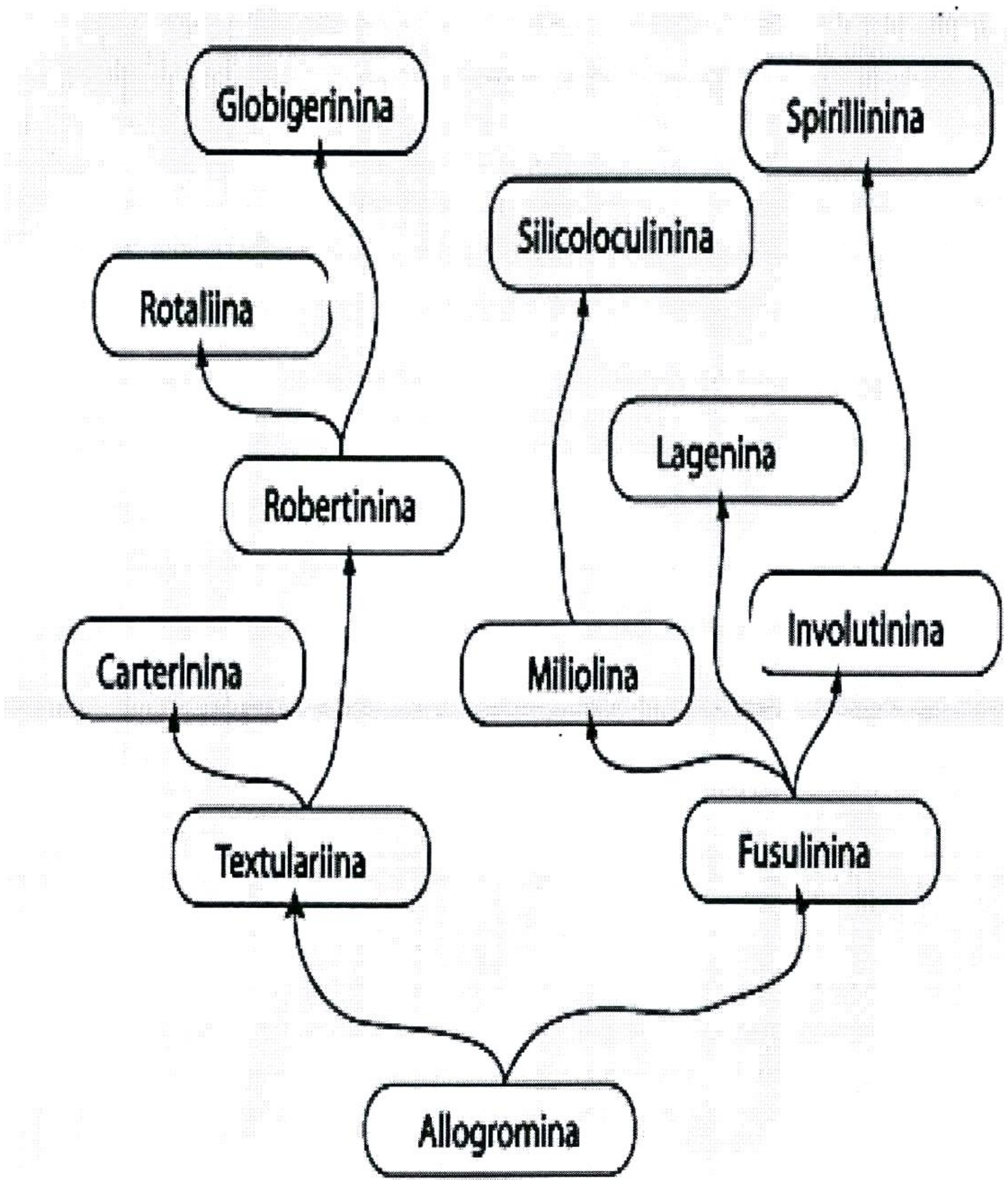


Fig2: Foraminifral suborders and their envisaged phylogeny. Redrawn from Tappan and Loeblich (1988). Among the Suborders shown only the fusulinina are extinct.

2.2. Biology

Studies of living foraminifera, in controlled laboratory environments, have provided limited information regarding trophic strategies but much has been inferred by relating test morphology to habitat. Foraminifera utilise a huge variety of feeding mechanisms, as evidenced by the great variety of test morphologies that they exhibit. From the variety of trophic habits and test morphologies a few generalisations may be made.

Branching benthic foraminifera such as Notodendrodesantarctikos ,which resembles a microscopic tree, absorbs dissolved organic matter via a "root" system. . Other sessile benthic foraminifera exhibit test morphologies dependent on the substrate on or in which they live, many are omnivorous opportunistic feeders and have been observed to consume autotrophic and heterotrophic protists (including other foraminifera), metazoans and detritus. Some suspension feeding foraminifera utilise their pseudopodia to capture food from the water column, or interstitial pore waters, Elphidiumcrispum forms a "spiders web" between the stipes of coralline algae. Infaunal forms are probably detritivores and commonly have elongate tests to facilitate movement through the substrate.

Benthic and planktonic foraminifera which inhabit the photic zone often live symbolically with photosynthesising algae such as dinoflagellates, diiatoms and chlorophytes. It is thought the large benthic, discoidal and fusiform foraminifera attain their large size in part because of such associations. Foraminifera are preyed upon by many different organisms including worms, Crustacea, gastropods, echinoderms, and fish, It should be remembered that the biocoenosis (life assemblage) will be distorted by selective destruction by predators.

2.2.1. Test formation in Forams.

Calcite, hyaline:

- Endoplasm combines with pseudopods, assumes shape of next chamber 'anlage' (logarithmic size increase), sometimes whole test surrounded by cyst (collected grains, including sediment, algae, etc.)
- Organic lining forms around 'anlage'; pseudopods active
- Precipitation of calcite on one (monolamellar) or both sides of lining (bilamellar) and over earlier formed chambers

Foraminifera cover calcite wall of earlier chambers, and walls between chambers are (in bilamellar forms) existing of 4 layers (one from each adjoining chamber), so that one should be careful in using spot-analysis (laser-zapping) of foraminiferal subsequent chambers and septa in foraminifera with the aim of using these analysis for very high resolution records. As an additional complexity: some (porcellaneous) foraminifera have been shown to take up a droplet of water within the cytoplasm, then use ions in the 'internal pool' to form thin craysallites within that droplet, thus causing chemical/isotopic heterogeneity.

Other use ions from droplet, but appear to keep that droplet open to exchange with sea water. Some species (e.g., hyaline Amphistegina) use 'pooled ions', others (e.g., porcellaneous Amphisorus) do not. We do not know whether these are typical for the larger groups or not; at least another few small hyaline species also used 'pooled ions". What do we know about deep-sea Forams? Much early data on deep-sea benthic foraminifera (and on other deep-sea groups) were collected on the 1872-1876 Challenger Expedition (benthic foraminifera described by Brady, 1881, 1884). For updated taxonomy and re-publication of plates see Jones, 1994.

2.2.2. The function of the test of benthic foraminifera.

Probably not support (small organisms in water - no support needed) Probably not protection (many are swallowed whole by predators, although some predators drill holes in tests). Metabolism - get rid of salts? (but some forms precipitate calcite from undersaturated water).Vaiying functions: keep nucleus/nuclei protected, keep symbionts together, light for symbionts. Structures direct pseudopods - feeding importance. Granuloreticulate pseudopods, the main distinguishing character of foraminifera. Cytoplasm different from main mass within test (endoplasm -ectoplasm).Granules are various organelles (e.g., mitochondria, microtubules, phagosomes). Main mass exits from aperture; also protoplasm around test Anastomizing; bidirectional flow; streaming process not understood. Membrane, surrounding microtubules. Pseudopodia: fundamental importance, mechanism through which forams interact with environment. Form complex "spiderweb', continually remodeling as while transporting material towards and away from main body.Motility, attachment, collecting material, extruding material, feeding, exchange gases, chamber formation, protection. Digestion (partially).

2.2.3. Basic terminology for Foram.tests.

- Chamber: cavity containing cytoplasm.
- Chambers separated by septa; connected by foramina (holes) in septa.
- Foramen in last chamber is called aperture.
- External lines of junction of chamber walls and septa: sutures.
- Chambers enveloping earlier ones: involute.
- Chambers leaving earlier ones visible: evolute.
- Disk-shaped spiral where two sides look the same: planispiral.
- Disk-shaped spiral with one evolute, one involute side: trochospiral.

2.2.4. Chamber arrangements

1. Single chamber (unilocular, monothalamous).
2. Uniserial.
3. Biserial.
4. Triserial.
5. Planispiral to biserial.
6. Milioline.
7. Planispiralevolute.
8. Planispiral involute.
9. Streptospiral.

10-12. Trochospiral.

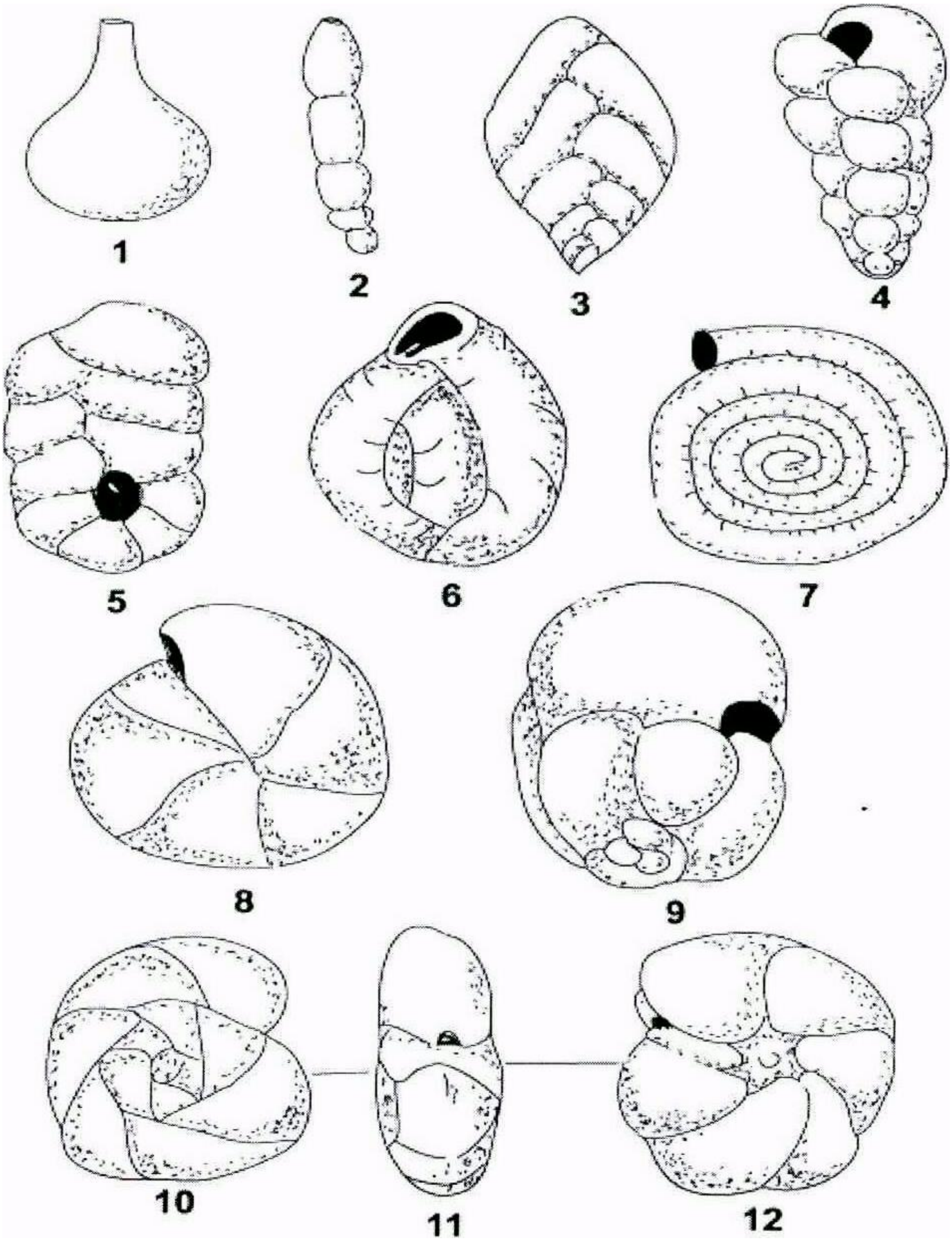


Fig3: Chamber arrangements

2.2.5. Apertures

1. Open end of tube.
2. Terminal radiate.
3. Terminal slit.
4. Umbilical.
5. Loop shaped.
6. Interiomarginal.
7. Interiomarginal multiple.
8. Areal cribrate.
9. Phialine lip.
10. Bifid tooth.
11. Umbilical teeth.
12. Umbilical bulla.

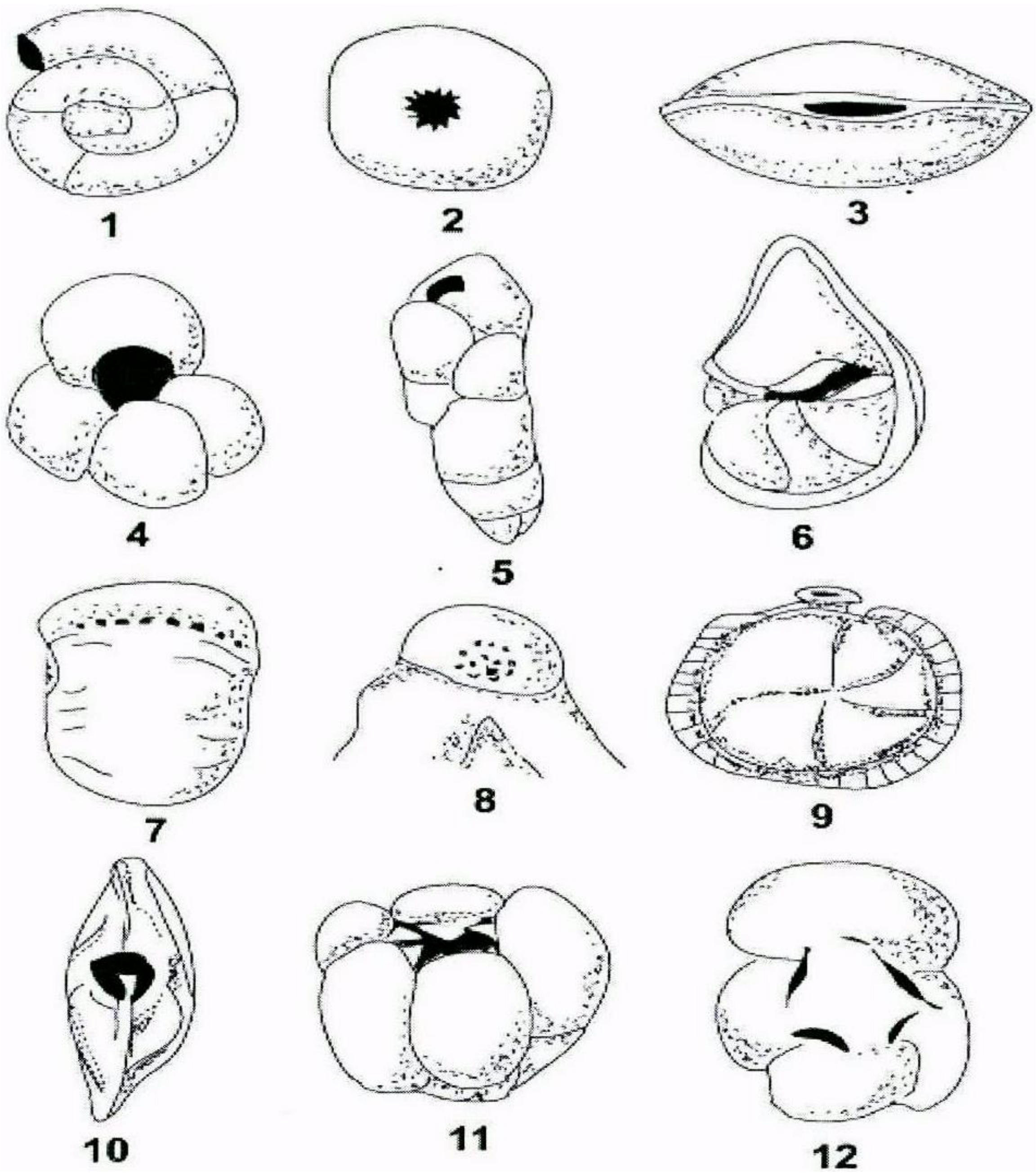


Fig4: Apertures

2.2.6. What do Forams.eat?

Almost everything:

- Herbivores: sraze alae.
- Passive suspension feeding (pseudopods), e.g., C. wuellerstorfi.
- Deposit feeding (very common in deep sea).
- Ingest sediment, algal cells, bacteria, organic detritus.
- Carnivory (also multicellular organisms); sticky pseudopods.
- Parasitism (other Forams., molluscs).
- Uptake of dissolved organic matter.
- Endosymbiosis: algae, possibly bacteria; kleptochloroplasts.
- Many are selective feeders, e.g., fresh phytoplankton, more degraded matter.

2.2.7. Who eats foraminifera?

- In general: detritivores (non-selective: take up mud with foraminifera and other food particles).
- Mollusca, including various snails (gastropods, e.g., Natica), juveniles of which drill holes in tests.
- Specialized Foram.eater: scaphopods (Dentalium), elephant's tooth shell.

2.2.8. Reproduction

Complex alternation of sexual-asexual generations

- No males and females differentiated
- variable how common sexual reproduction is: many species have many asexual generations per sexual generation
- Note that the gametes may exist in free form for at least several days, and function as 'propagules', i.e., help in spreading benthic forms worldwide (hence many cosmopolitan taxa).

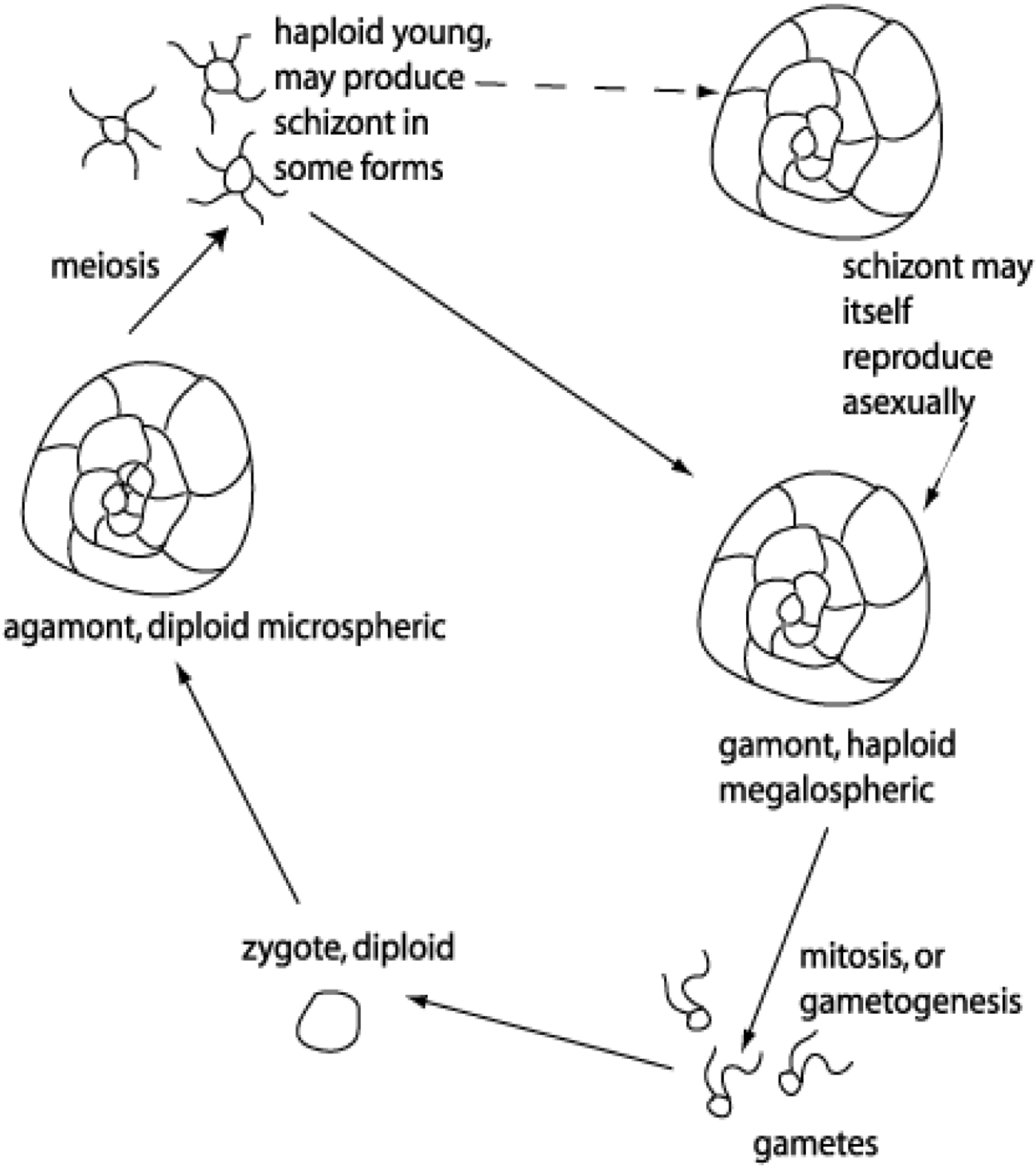


Fig.5: A generalised foraminifera life cycle note alternation between a haploid megalosperic from and diploid microspheric form. Redraw from Goldstein,(1999).

2.3. Life Cycle

Diagram showing generalised foraminiferal life cycle click to view larger version of the approximately 4000 living species of foraminifera the life cycles of only 20 or so are known. There are a great variety of reproductive, growth and feeding strategies, however the alternation of sexual and asexual generations is common throughout the group and this feature differentiates the foraminifera from other members of the Granuloreticulosea.

An asexually produced haploid generation commonly form a large proloculus (initial chamber) and are therefore termed megalospheric. Sexually produced diploid generations tend to produce a smaller proloculus and are therefore termed microspheric.

Importantly in terms of the fossil record, many foraminiferal tests are either partially dissolved or partially disintegrate during the reproductive process.The planktonic foraminifera Hastigerinapelagica reproduces by gametogencsis at depth, the spines, septa and apertural region are resorbed leaving a tell-tale test. Globigerinoidessacculifer produces a sac-like final chamber and additional calcification of later chambers before dissolution of spines occurs, this again produces a distinctive lest, which once gametogenesis is complete sinks to the sea bed.

2.4. Preparation Techniques

Foraminifera range in size from several millimeters to a few tens of microns and are preserved in a variety of rock types. The preparation techniques used depend on the rock type and the "predicted" type of foraminifera one expects to find. Very hard rocks such as many limestones are best thin sectioned as in normal petrological studies, except instead of grinding to a set thickness (commonly 30 microns) the sample is ground very carefully by hand until the optimum thickness is obtained for each individual sample. This is a skilled job and requires expensive equipment but provides excellent results and is particularly used in the study of larger benthic forarninifera from reef type settings.

Planktic and smaller benlhic forarninifera are prepared by crushing the sample into roughly five millimeter fragments. The crushed sample is then placed in a strong glass beaker or similar vessel and water and washing soda or 6% hydrogen peroxide added, left to stand and then heated and allowed to simmer. The length of time the sample is left to simmer depends -on the rock type involved and if peroxide is used the sample should not be left immersed in the solution for more than about half an hour.

Next, the material is washed through a 63 micron sieve untill the liquid coming through the sieve is clean (i.e. the clay fraction has been removed). The sample can then be dried and sieved into fractions (generally 63-125 microns, 125-250 microns, 250-500 microns and greater than 500 microns) using a "nest" of dry sieves. Care must be taken to clean all sieves and materials used between the preparation of each sample to prevent contamination.

2.5. Observation Techniques

Thin sections are veiwed using transmitted-light petrological type microscopes. Washed, dried fossil samples can be picked from any remaining sediment using a fine brush and a reflected light, binocular microscope.

The best method is to scatter a fine dusting of sieved sediment on to a black tray divided into squares, this can then be scanned under the microscope and any foraminifera preserved in the sediment can be picked out with a fine brush (preferably a 000 sable-haired brush).

The picked specimens can then be mounted in card slides divided into numbered squares with sliding glass covers.

Gum tragocanth was traditionally used to attach the specimens to the slides but modern office-type paper adhesives are now used.

WARNING: Please remember all preparation techniques require the use of hazardous materials and equipment and should only be carried out in properly equiped Mioratories, wearing the correct safety clothing and under the supervision of qualified staff.

Planktonic & Benthic Foraminifera

3.1. Planktonic foraminifera and the oceans

Planktonic foraminifera are unicellular organisms with a complex cell (Eukaryotes), and genetic material within a cell nucleus. Such organisms are classified in the Superkingdom of Protists or Protista. Other eukaryotic superkingdoms include animals, plants, and fungi (mushrooms).

Prokaryotic organisms include various types of bacteria, and are subdivided into the two large groups Bacteria and Archaea (both of which have been called 'bacteria1 in the past).

If you are interested in the subdividion of life on Earth,The planktonic foraminifera are only one of the 4 common groups of eukaryotic planktonic organisms in the ocean, which make up the oozes forming on the oceans' floors.

Planktonic foraminifera live floating in the surface waters of the open ocean, and secrete a calcium-carbonate shell.

They are thus part of the 'zillions of little organisms' shown in the figure in the handout on sediment cycling and climate. These shells fall to the sea floor after the organisms reproduce.

Planktonic foraminifera live in the oceans in species assemblages which reflect the temperature of the ocean waters.

Note that high latitude species assemblages have fewer numbers of species, and the few species are all small, round balls (we call them potatoes).

At lower latitudes there are many more species, similar to species richness gradients on land (see diversity hand out). These species show much more variability in shape, with flat species surrounded by a heavy rim (called keel), glassy looking round balls and many varieties of pitted, potato shapes. Planktonic foraminifera from.

Planktonic foraminifera originated from benthic foraminifera in the late Jurassic to earliest Cretaceous (that's in the Mesozoic, about 100 million years ago).

The first planktonic foraminifera were small, rounded forms ('popcorn'), without ridges, probably with spines.

During the Cretaceous, many new species evolved, in many different shapes, with ridges and trangular shapes and so on.

Almost all of them became extinct at the end of the Cretaceous, at the time of extinction of the dinosaurs, and only the small, round forms survived. In the early Cenozoic planktonic foraminifera evolved into many new, elaborately shaped forms again.

Many of these forms became extinct in the later part of the Eocene, between 38 and 33 million years ago, when the Earth went through a period of severe cooling and the ice sheets on Antarctica became established.

Once again, the rounded form survived, and for about 10 million years were the dominant forms. Then, in the early Miocene (about 22-23 million years ago), the planktonic foraminifera once again evolved and diversified into many different shapes.

Descendants of the Miocene species now populate all the world's oceans. Foraminifera are not very abundant and diverse at high latitudes, and only one species occurs at the highest latitudes, in the Arctic Ocean and around the Antarctic continent.

3.2.Benthic Foraminifera in the deep oceans

Generally, not useful for age determination (Late Cretaceous-Paleogene; early-middle Eocene; Oligocene-early Miocene; middle Miocene-Recent. Shelf - upper slope faunas are used in biostratigraphy, as are larger benthic foraminifera (reefal environments)

3.2.I.Deep-SeaBenthic Foraminifera

Benthic foraminifera are an important component of the deep-sea biomass in the present oceans, adapted to its cold, dark, and extremely oligotrophic environments.

Faunas are highly diverse, and many species have a cosmopolitan distribution. In addition to their interest as indicator species living in the largest habitat on earth, their tests have been used extensively in isotope and trace element analysis aimed at reconstruction of past environments. This section is designed to introduce the basics of what we benthic foraminiferal taxonomy, ecology and paleoecology and their use as a proxy for interpreting the state of past oceans and climates, specifically oceanic productivity and deep water oxygenation. . Why study deep-sea benthic foraminifera?

Habitat covers a huge part of the world (largest habitat on Earth)

Habitat resistant to change -> IF faunas reflect environmental changes (e.g., temperature) -> global change

Faunas highly diverse, ecological theories may be tested (stability-diversity hypothesis, species-energy hypothesis, patchiness hypothesis)

Global extinctions in the deep sea: very unusual events, during last 90 million years only one (55 Ma ago)

Need to understand how they make test if you want to dissolved/analyze it what is 'deep-sea'? (van Morkhoven et al., 1985)

Neritic = 0-200 m

Upper bathyal = 200-600 m

Middle bathyal = 600-1000 m

Lower bathyal = 1000-2000 m

Upper abyssal = 2000-3000 m

Lower abyssal > 3000 m.

Note that "bathyal1 covers sites on continental margins as well as in open ocean (sea mounts)

3.2.2.Phylogeny of deep-sea benthic foraminifera

All common deep-sea groups today (rotaliids, buliminids, lagenids, textulariids) and many of the more common families and morphotypes within these groups have existed in the deep sea (~>1000 m) since the Late Cretaceous (~ Campanian) Miliolids are dominantly warm, shallow water forms, with few genera in the deep sea, since middle Miocene.

3.2.3. Interpretation of deep-sea benthic foraminiferal assemblages

In the 1970s, Lohmann first recognized that the water masses in the North Atlantic (e.g., AntArctic Bottom Water, AABW, and North Atlantic Deep Water, NADW) were characterized by typical foraminiferal assemblages recognized in multivariate analysis (Lohmann, 1978).

It turned out, however, that it was not possible to typify global water masses by fauna! assemblages consistently, leading to disappointment in the 1980s.In the 1990s, however, many new studies of recent faunas were directly or indirectly linked to the JGOFS (Joint Global Ocean Flux Studies), and led to recognition of the importance of food in the life of foraminifera: they depend upon food delivered from primary productivity in the surface waters, 1000s of meters away. Delivery of food to ocean floor:

Marine snow: particles mm-cm sized, consisting of dead and dying phytoplankton, zooplankton exoskeletons, fecal matter).

These fall at a speed of 102-103 m/day; a single unicellular alga would probably not even sink to the sea floor, being re-suspended many times.

Scasonality of productivity at pelagic mid latitudes: pulse of phytodetritus, followed by rapid growth-reproduction of some benthic foraminifera

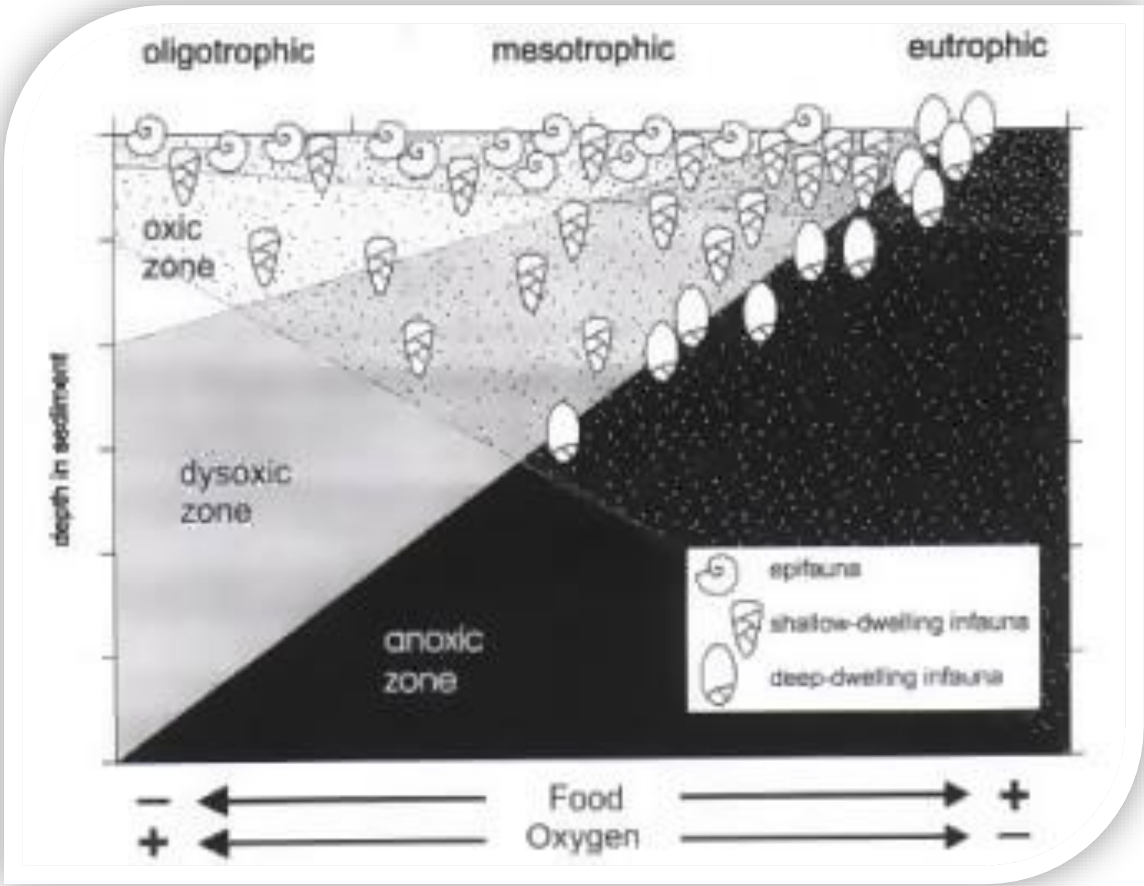
Relatively high, continuous supply along continental margins; there freshly produced organic matter is augmented with more refractory organic material derived from lateral transport. Food from surface to bottom:

Very little (-1% or less) primary produced material reaches sea floor; follows seasonal productivity ('fresh phytodetritus)

Ballasted by silica (diatoms), carbonate (foraminifera), dust; in fecal pellets; in glutinous material (diatoms, cyanobacteria); in "giant balls of mucus1, larvacean (tunicate) houses; carrion falls ('dead whales1); lateral transport (refractory organic matter).Discrepancy between food requirements of faunas and supply in sediment traps: faunas need more than what is delivered

In the present world we thus see bentho-pelagic coupling, in which the benthic faunas reflect what happens at the ocean surface where their food is produced.

Jorissen et al., 1995: TROX model (TR - trophic, food; OX - oxygen). Food is main limiting/determining factor in low food regions, where all organic matter is used up at the sediment/water interface.



Fig(6): Food from surface to bottom

- In such regions there is no food for infaunal) within sediment) species.
- In very high food regions, the foraminifera and other organism do not eat everything raining down, and the sediment pore waters become anoxic (oxidation of some organic matter); here also foraminifera can not live within the sediment.
- In mesotrophic regions foraminifera may live down until 10-15 cm, with epifaunal, shallow infaunal, middle infaunal and deep infaunal taxa.

3.2.4. Importance of deep-sea benthic foraminifera

- Widely varying estimates of total oceanic foraminiferal biomass; up to 50% of eukaryotic biomass (0.02 to 10 g/m2).
- More than 106/m2.
- Opportunistic feeders: species are not usually proxies for a simple environmental parameter (depth, salinity, food supply, oxygen). Fundamental niche: species could theoretically exist under these condition.
- Realized niche: species really exists under these conditions (smaller space than fundamental niche).

3.3.Benthic Forams.: what is proxy for what?

1. Planktic/Benthic ratio: paleodepth, dissolution, surface productivity.
2. Benthic Forarhiniferal Accumulation Rate: surface productivity.
3. Species % abundance, Species Diversity: paleodepth, oxygenation of bottom waters, productivity, seasonality of productivity, labile/refractory organic matter, water masses, current activity, CaCOscorrosivity.
4. Morphotypes': microhabitats (infaunal/epifaunal) oxygenation, productivity.

3.3.1.Planktic/Benthic

- Paleodepth: plankticForams.not in coastal zones (neritic), P/B »100 in open ocean.
- Dissolution: planktic Forams fragment, dissolve before benthics; deep-sea floor low P/B values indicate depth below lysocline.
- Surface productivity: more difficult, but at higher food supply productivity (or: in shallower waters) more benthic foraminifera.

How to distinguish planktic and benthic foraminifera:

- If there are zillions of them (in absence of dissolution), they're plankton.
- There are many fewer planktic species, so know your planktics (size fraction). In plankton, the chamber form is inflated, the wall structure may be cancellate, aperture is interiomarginal (but aperture may be covered, there may be multiple apertures).
- Difficulties: Trochospiral forms : look at aperture

  Biserial forms: look at aperture (but there are forms, e.g., biserial genus Streptochi/u, looks very much like the benthic genus Bolivina.

3.3.2. Benthic Foraminiferal Accumulation Rate (bfar):

How does food reaching bottom relate to primary productivity?

- Linkage between surface productivity and quantity of bottom life (Herguera & Berger; number of Forams/ mVkyr; >150 mm).
- How much food reaches the sea floor: not only dependent upon productivity (water depth), not a linear relation.
- Lateral transport of organic matter (focusing).
- Labile/refractory organic matter.
- Discrepancy between observations of sediment community oxygen consumption and particulars organic carbon (SCOC: POC).

3.3.3.1. Species % abundance

- Palcodepth: observation (photosymbionts).
- Oxygenation of bottom waters, productivity: very difficult to separate effects.
- Seasonality of productivity: ''phytodetritus species', i.e., observation.
- Labile/refractory organic matter: observations, feeding experiments.
- Water masses: observations.
- Current activity: observations, shape of foraminifera ('tree-shaped').
- CaCO corrosivity: observations (Nutiallidesumbonifera).

3.3.3.2. Species Richness, Diversity

- Deep-sea faunas: highly diverse, many species rare, few species common (many benthic specimens needed for analysis).
- Species richness: number of species (number of specimens counted) - rarefaction techniques.
- Various mathematical expressions of a 'combination of number of species present and evenness of distribution of specimens over species (e.g., Shannon-Weaver).
- Low diversity, high dominance (low evenness): disturbed/not favorable environment.

3.3.4. Morphotypes': Infaunal/Epifaunal

- Can we determine mode of living from shape of test? E.g., infaunalepifaunal? Thus know the 'microhabitaf in which the foram lives? Example: biserial ^ infaunal; trochospiral = epifaunal.
- Partially, yes. Many exceptions, even with present-day Forams. (Buzas et al., '93: assignments - 75% correct).
- Foraminifera move through sediment (follow food and/or oxygen gradients).
- Effects low oxygen (oxygen important ONLY if <0.5 to 1.0 mg/L); Kaiho Benthic Foram. Oxygenation Index BFO1 doubted (Kaiho, 1994, 1999)

How to define infaunal and epifaunal:

Average Living Depth (ALDn,), Jorissen et al., 1995:

- Epifaunal/epiphytic: living above sediment - water interface (rocks,plants).
- Epi/shallow infaunal; 0-1.5 cm.
- Intermediate infaunal: 1.5-5.0 cm.
- Deep infaunal: 5-10 cm.

- Example of difficulties: e.g., what is environmental significance of faunas dominated by small, thin-walled specimens?
- Low oxygen (difficult to separate high food and low oxygen effects).
- Opportunistic growing (high food -> early reproduction, rapidly varying circumstances).
- $CaCO_3$ corrosive.
- Just on faunas, not possible to decide which is most important factor in specific case.

3.4. Cenozoic benthic foraminiferal events

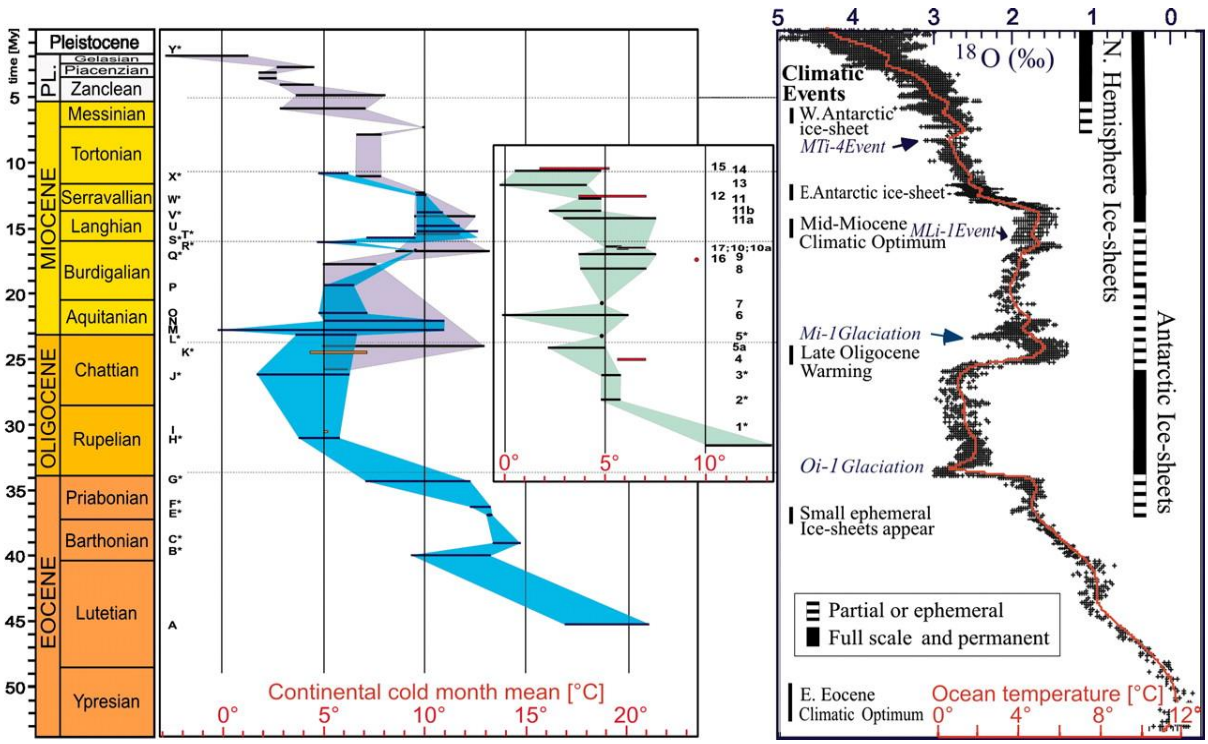
- Non-event at K/T boundary.
- Extinction at P/E boundary.
- Gradual turnover across oxygen isotopic events Eocene-Oligocene and middle Miocene.
- 'Stilostomella' extinction (1,2-0.6 Ma; Mid Pleistocene revolution).
-
- 

Fig7: Formation on Antarctic ice sheets

Note: diversity high globally in greenhouse world, drops, and diversity gradient may have been established at formation on Antarctic ice sheets (Thomas and Gooday. 1996: Thomas et al., 2000). Various groups of common deep-sea benthic foram in if era *(EpistomweUaexigua,* indicator of fresh phytodetritus deposition; *NuttaUidesumboniferu,* indicator of AABW) only became common at Eocene-Oligocene transition (establishment Antarctic ice cap.

3.5. What is typical in these non-analog 'Greenhouse' faunas?

- No 'phytodetritus' species (opportunistic, seasonal growth blooms).
- Unseriallagenids, stilostomellids, pleurostomellids (all long, then forms) buliminids-bolivinids common in open-ocean settings; 'high food' taxa in present oceans.
- Counterintuitive: at high temperatures, metabolic rates faster, equal food supply would mean more oligotrophic faunas.
- Less common in open ocean species with complex apertures (linked to pseudopod shape and streaming behavior; feeding habits).

3.6. Greenhouse Faunas Contradiction

- Benthic faunas suggest high food supply.
- Data from planktonic organisms suggest lower productivity.
- More efficient transfer of food to sea floor? Different pattern of ocean circulation - Hay's eddies, rather than water masses?
- Different primary producers (e.g., more diatoms? More sticky mucus, thus faster transport?
- Lower oxygen, thus less organic matter degraded? (not very promising in few of data on present Mediterranean, Red Sea).
- Primary productivity on sea floor?

3.7.Higher primary productivity on sea floor

- Symbiontic chemosynthetic bacteria.
- Present day cold seeps: benthic foraminiferal species that also occur elsewhere, bolivinids/buliminids (high food).
- Forams.living as cold-seep clams do; at higher temperatures, bacteria higher metabolic rates thus higher productivity.

3.8. K/T boundary: no benthic Foram.

- Extinction(Culver, 2003)
- WHY no serious consequences of collapse productivity' on food-starved deep-sea biota, in presence of bentho-pelagic coupling?
- Less bentho-pelagic coupling: .- Different ocean circulation, different food transfer from surface to bottom.
- More chemosynthetic productivity' on sea floorSurface productivity did NOT collapse: blooms of different taxa.

Paleocene/Eocene Benthic Foraminiferal Extinction Event:

- 30-50% species extinction; net deep-sea extinction similar globally.
- Drop in diversity (but in many places affected by dissolution).
- Many cosmopolitan, large, heavily calcified species extinct.
- Post extinction species dominance patterns NOT the same globally: some places apparently more food, some places apparently less food.
- Post extinction faunas dominated by small, thin-walled species.

3.9. What caused the global benthic foraminiferal extinction?

- Asphyxiation? (low oxygen). No independent evidence for global anoxia-hypoxia (e.g., high organic carbon, lamination), although in some places low oxygen conditions did prevail (e.g., middle East).

- Starvation? Eutrophication? It seems to be variable regionally; possibly more differences between highest and lowest productivity values.
- Dissolution? Organic-cemented, agglutinated foraminifera also show unusual faunal patterns (Glomospira-peak), and extinction also occurs at the few localities were dissolution is minor.
- Possibility: high global temperatures caused metabolic problems and productivity problems; needs further investigation.

3.10. Cenozoic benthic foraminiferal faunas

- Paleogene-Late Cretaceous community structure of benthic Forams.may reflect different structure of food supply to Forams.
- Possibility that transfer of food- from surface to bottom was different (ocean circulation?); or different primary producers (diatoms?); or different seasonality (less)?
- Possibility of greater importance of chemosynthesis for food to Forams.
- Reorganization of faunas at cooling of deep oceans reflects establishment of present-day food supply structure -> more fresh phytodetritus to sea floor.
- More reorganization in middle Miocene (more cooling, expansion polar ice sheets).
- Last, by then rare, taxa typical for earlier times extinct at Mid Pleistocene Revolution (Hayward, 2001).

3.11. Presently most abundant groups in the deep sea

- ALLOGROMIDA: organic wall, usually 1 chamber; Cambrian-Recent, ASTRORHIZIDA:agglutinated, organic cement, usually 1 chamber or branching tube; Cambrian-Recent. <* LJTUOLIDA: agglutinated, organic cement, many chambers, usually planispiral spiral; Cambrian-Recent. <*

- TROCHAMM1N1DA: agglutinated; organic cement, many chambers, usually trochosplral; Cambrian-Recent TEXTULARIlDA: agglutinated, low Mg-calcite cement; Cambrian-Recent.

  *** FUSUL1NIDA: microgranular calcite; many complex chambers; Silurian-Permian.
- *> MIL1OL1DA: high Mg calcite, imperforate, many chambers (porcellaneous, no pores); miliolid chamber arrangment; Carboniferous-Recent.
- <* CARTER1NJDA: low Mg calcite, hyaline, pores or no pores; spicules, plani- ortrochospiral; Tertiary-Recent.
- <* SPIRILL1NIDA; low Mg calcite; hyaline; single crystal; spiral; Jurassic-Recent.
- *!* LAGEN1DA: low Mg calcite, hyaline; pores, 1 or many chambers,
- uniserial or planispiral; monolamellar; Carboniferous-Recent. <* BULTMINIDA: low Mg calcite; hyaline; pores; many chambers;
- bilamellar; toothplate; Triassic?-Recent. <* ROTALTIDA: low Mg calcite; hyaline; pores; many chambers;
- bilamellar; trocho- or planispiral, annular, irregular; Triassic-Recent. <* GLOBTGERINIDA: low Mg calcite (aragonite in few extinct forms);
- pores; many chambers; bilamellar; radial crystals (PLANKTON);
- Jurassic-Recent.
- * INVOLUTIN1DA: aragonite; 2 chambers - 2nd tube. <* ROBERT1N1DA: aragonite; pores; many chambers; trochospiral; Triassic-Recent.
- *J* SlEICOLOCULINlDA: opaline silica, no pores; chamber arrangements as in miliolids; Miocene-Recent.
- Genetic evidence suggests strongly that Allogromida ("naked') and Astrorhizida (agglutinated) are one order.

Foraminifera and petroleum exploration: case studies from carbonate and clastic systems

4.1. Foraminifera in petroleum exploration

Micropaleontology in general is an important tool for the petroleum industry, finding practical uses in all stages of the exploration process. Prior to drilling, micropaleontological methods can aid the acquisition of geological field data and enhance the quality of the reservoir potential assessment by way of sequence stratigraphic correlation, paleogeographical and facies analysis, depositional and source-rock maturation determination as well as migration modeling (Jenkins, 1993). The accuracy and profitability of the drilling process itself can benefit from micropaleontological monitoring through the analysis of ditch cut- tings, essentially allowing age determination, correlation of wells, unconformity evaluation, paleoenvironmental interpretation and lithostratigraphic as well as depositional sequence characterization. Finally, in the ”post”-drilling stage of the exploration, comprising appraisal and development, the evaluation of microfossils is imperative for setting up detailed stratigraphic subdivisions and modeling reservoir connectivity.

The applications of microfossils are manifold, including biostratigraphy, paleenvironmental analysis, biogeography, paleoclimatology and thermal maturation. The scope of this paper is restricted to the relevance of foraminifera for the hydrocarbon exploration, limiting thus the amount of aforementioned uses to biostratigraphy and paleoenvironmental analysis, the differentiation of rock units and the interpretation of the depositional environment respectively, based on distinctive fossil species or genera contained in a lithological unit.

4.1.1. Stratigraphic applications

Foraminifera evolved at the end of the Precambrian and diversified through the Phanerozoic, especially in the Mesozoic and Cenozoic, making them principally useful in the subdivisions of the latter periods. Biostratigraphic zonation schemes of one form or another have been established for the whole of the Phanerozoic time, including larger benthic and planktonic foraminiferal biozonation schemes, having a resolution in the order of 1-2 Ma and being globally applicable in the appropriate facies. Other time-scales, integrating bio-, magneto-, isotope- and absolute chronostratigraphic data and covering a big part of geologic time have been set up, for example by Harland et al. (1990) and Haq et al. (1987). The subdivision of geologic time into biostratigraphic units is established by recording abundance changes of index species and the use of FADs (First Appearance Datums), LADs (Last Appearance Datums) and Concurrent Range Zones (in which the range of several fossils overlap) as biostratigraphic events. In the oil industry, the main type of zone is defined on last appearances, because the precise location of first appearances is difficult to locate accurately using ditch-cuttings owing to the problem of "caving". Quantitative biostratigraphy is a method that involves computer-assisted tech- niques such as graphic correlation or ranking and scaling, used mainly for the definition of biostratigraphic zones and sequence boundaries as well as the modeling of burial history (Jones, 1996).

Sequence stratigraphy is very useful in the petroleum exploration, since there are certain stratigraphic controls on the hydrocarbon habitat, i.e. preferential development of source-rocks, reservoir-rocks and top seals within the sequence stratigraphic framework. The Transgressive Systems Tract as well as the Low- stand Fan Systems Tract are particularly sand-prone and therefore constitute attractive petroleum exploration targets (Jones, 1996). Foraminifera can either be used to characterize systems tracts in a clastic sequence, or to correlate se- quence stratigraphic data to absolute age values (biochronostratigraphy). The first is accomplished on the basis of the observation, that no microfossils are unique to certain systems tracts, but that there are some criteria that help iden- tify the position within a sequence, e.g. abundant large arenaceous foraminifers are thought to reflect relatively rapid mud deposition in a deep marine facies, which most likely occur in the Lowstand Fan Deposit; the Highstand Systems Tract is characterized by rapidly prograding shorelines and a substantial influence of rivers and deltas, hence ”turbid water” marine foraminifera tend to dominate (van Gorsel, 1988). Also, generally there tends to be a greater influx of planktonic foraminifera in Highstand Systems Tracts. Sequence stratigraphic data, such as relative change of coastal onlap, is matched to existing global standard biostratigraphic zonation schemes and the global eustatic curve in order to delineate systems tracts and to allow a correlation of sequences beyond a regional scale.

4.1.2. Paleoenvironmental applications

Foraminiferal abundance, diversity and dominance patterns enable the discrimination of a range of environments, that through the use of cross-plots of foraminiferal ”morphogroups” (Fig.1) and the analysis of depth-related morphological trends can be further enhanced. Moreover, the ratio of planktonic to benthic foraminifera is an indirect measure for depth (Fig.2). The degree of oxygenation of the bottom sediment can be deduced from the proportions of epifaunal and infaunal morphotypes, representing oxygen-poor and oxygen-rich environments respectively. A uniformitarian approach to this field of research is questionable due to unstable climatic conditions during the Plio-/Pleistocene and the related shifting rates in run-off and nutrient enrichment. In addition, comparisons can only be made with confidence in extant species (Jones,1996). Some foraminifera benefit from a symbiotic relationship with algae, in which case the distribution of individual species is governed by light require- ments: species with green algal symbionts occupy shallower environments (e.g. backreef-lagoon), while those with red algal symbionts are characteristic of reef- and fore-reef environments.

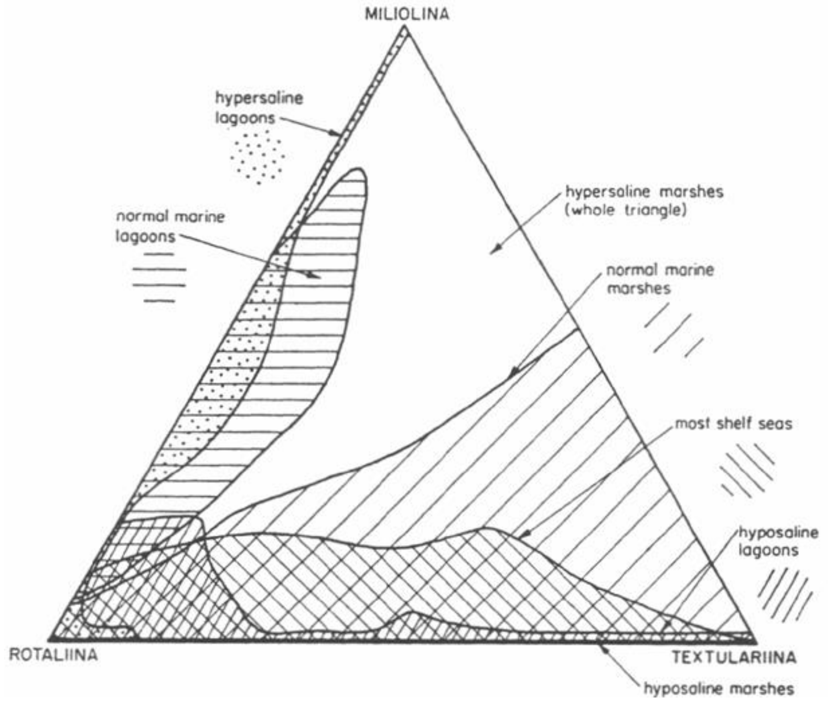


Figure 8: Discrimination of ma- rine environments by cross-plots of foraminiferal morphogroups, (from Murray, 1973).

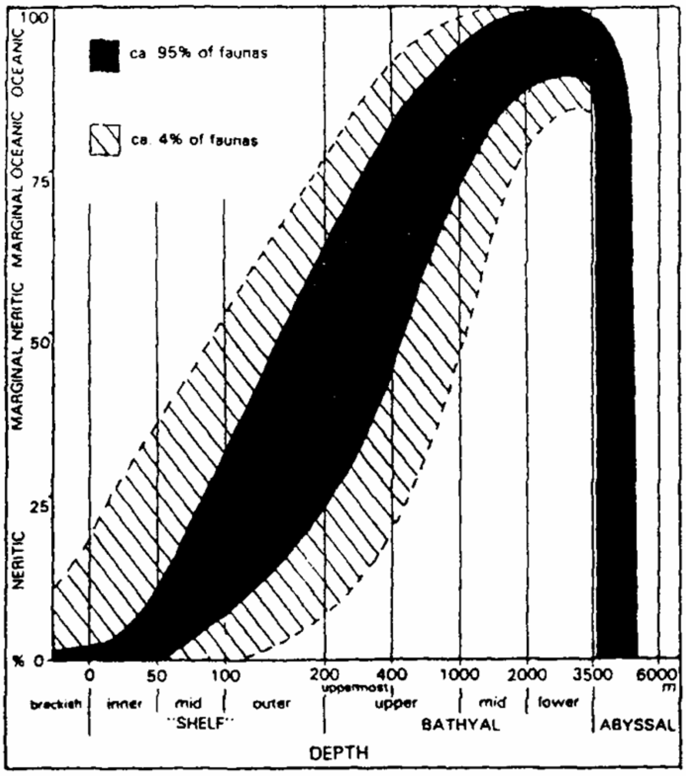


Figure 9: Variation in the ratio of planktonic to benthic foraminifera with depth, (from Hayward, 1990).

4.2.Case studies from clastic systems

In an attempt to provide paleogeographic reconstructions and a sequence strati- graphic framework for the Eastern Paratethys in the Oligocene to the Pliocene, placing particular emphasis on the South Caspian as it reflects BP's interest in the exploration and economic geology of that region, Jones and Simmons (1993) have correlated the local sequence stratigraphy with the global coastal onlap curve and used biostratigraphy to constrain this correlation (Fig.3). Since the groups that are traditionally used in the biostratigraphic zonation in the Ceno- zoic are restricted in their development in the Paratethys, the zonation relies on facies-dependent benthonic foraminifera, as well as calcareous nannoplankton, ostracods and palynomorphs. Paleontological evidence in each case validates a regressive or transgressive tendency and indicates whether a lithological unit can be calibrated against global sequences.

Nagy (2005) combines diagnostic features of foraminiferal facies with sedimen- tary data to elucidate the sequence stratigraphic development of the Paleocene Firkanten Formation in the Central Basin of Spitzbergen, which contains commercially important coal seams close to its base. Lithofacies and foraminiferal abundance and distribution from two sections were compared revealing a dis- tinct transgressive faunal expansion from lagoonal to prodelta conditions, re- flecting a more open marine nature of the environment and allowing for a corre- lation between these sections and the establishment of a depositional sequence stratigraphic framework as well as a paleogeographic reconstruction.

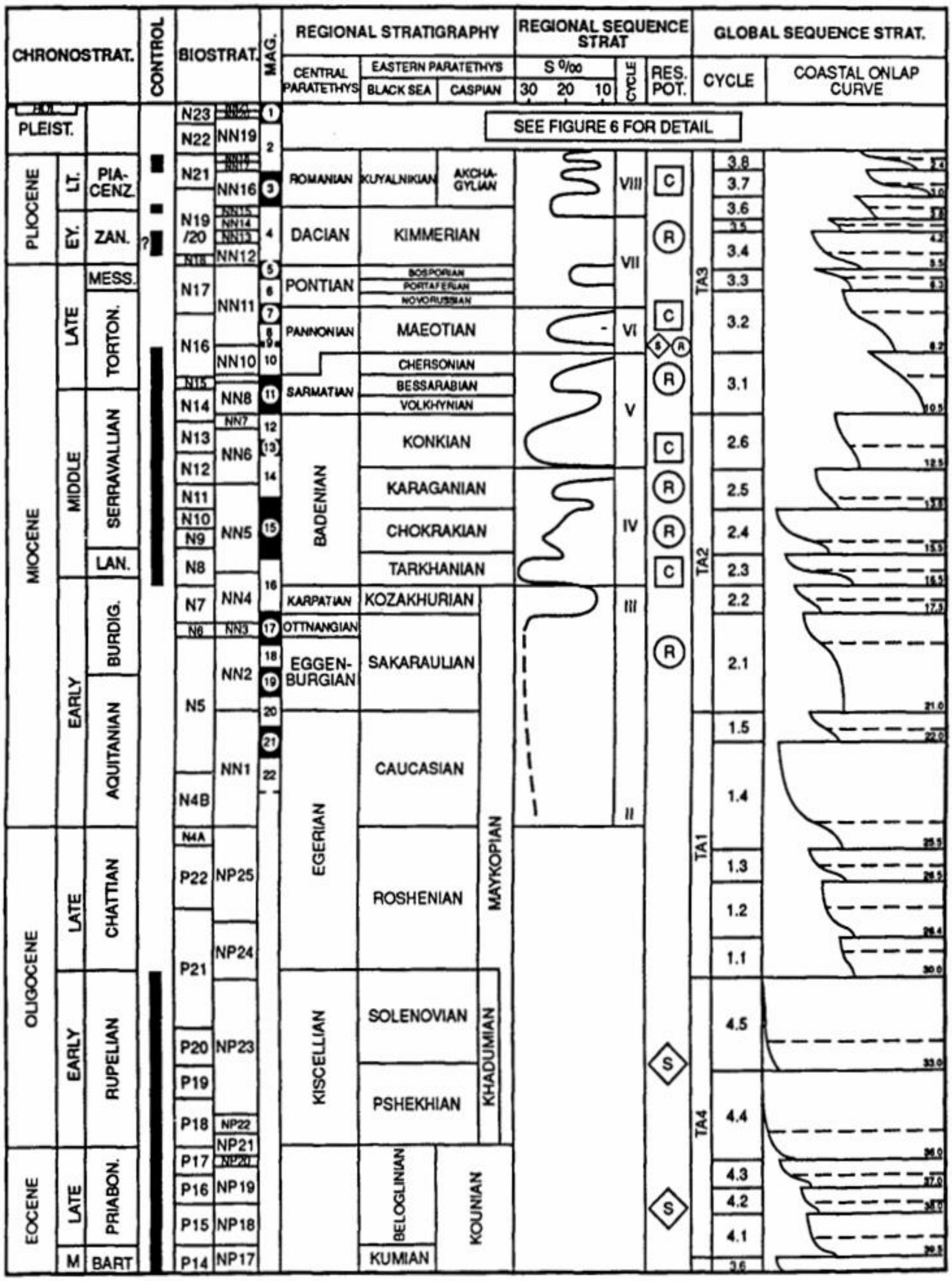


Figure 10: Eastern Paratethys stratigraphic summary and correlation with the global coastal onlap curve, (from Jones and Simmons, 1993).

In a paper on the Chipaque Formation (Cenomanian - Campanian) of Columbia, Vergara et al. (1997) stress the usefulness of agglutinated foraminifera as biostratigraphic tools and as elements in paleoenvironmental appraisals in the exploration of petroleum resources of the Eastern Cordillera. The biostratigraphic value proved limited owing to the scarcity of age-indicative fossils in the stud- ied section and the long stratigraphic ranges of many species, whereas the foraminifers proved valuable in that they were indicative of certain systems tracts, e.g. large populations were used to infer the maximum flooding episodes. In the Wanganui Basin of New Zealand, neither sedimentological nor macrofos- sil criteria were sensitive enough to allow precise correlation between systems tracts and stages in a cycle of relative sea level. Naish and Kamp (1997) examine the foraminiferal content of Late Pliocene cyclothemic shelf sequences in order to provide high-resolution paleobathymetric data and identify the stratigraphic location and paleodepth of the maximum flooding surface as well as compare the changes of the latter with the deep-sea δ18 O-derived glacio-eustatic sea- level curve. Results confirm that the foraminiferal associations and biofacies are strongly associated with their enclosing lithofacies and systems tracts. A conservative, foraminifer-derived depth-range curve is constructed, largely ver- ifying the macrofaunal inferences regarding paleodepth of the sequences and showing a clear deepening-upward trend within TSTs.

Hentz and Zeng (2003) document a low- (third-order) and high-frequency (fourth- order) sequence-stratigraphic framework for a prolific Miocene succession in the northern Gulf of Mexico shelf province, discovering that hydrocarbons are pooled within the Miocene third-order Lowstand Systems Tracts, which in turn yields a focused model for the development of abundant undiscov- ered Miocene reserves in the area. Faunal data constrained the stage bound- aries, the ages of regional biozones were converted to a revised chronology and the sequence boundaries matched to a generalized coastal onlap curve (Fig.4). Benthic foraminifera were used as paleobathymetric indicator fauna, enabling the reconstruction of water depths during deposition, from which an overall upward-shallowing trend could be deduced. The authors marked that most maximum flooding surfaces coincide with faunal floods and that fourth-order incised–valley-fill, transgressive, prograding wedge and highstand deltaic/strandplain sandstones, mostly in the third-order Lowstand Systems Tract, produce hydrocarbons. Amplitude stratal slices obtained by 3-D-seismic survey give a clear idea of features such as a valley fill incising highstand delta- plain deposits.

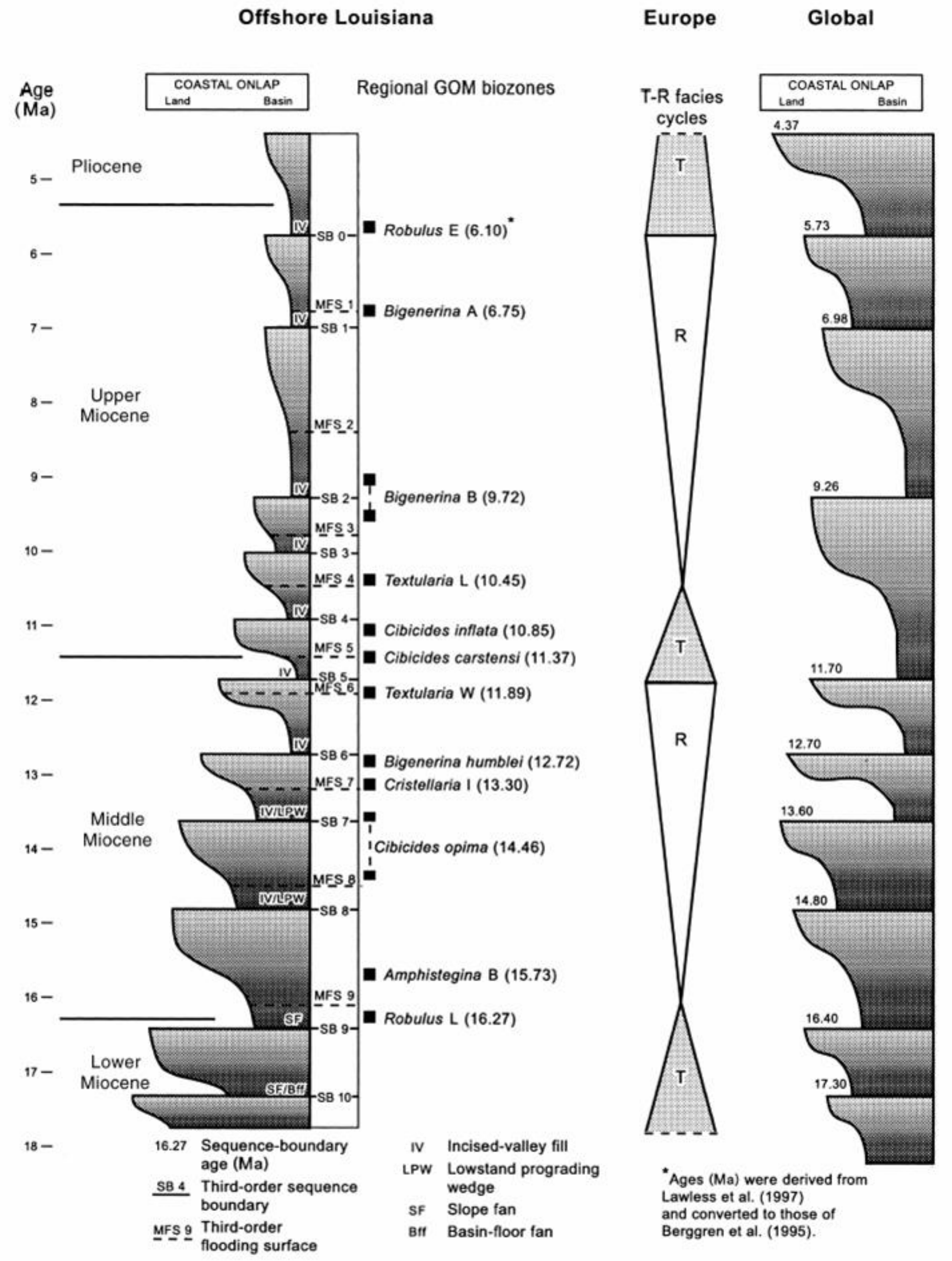


Figure 11: Comparison of the coastal-onlap curve of the study area (offshore Louisiana), the T-R cycles of Hardenbol et al. (1998) for European basins, and the global curve of Haq et al. (1988), (from Hentz and Zeng, 2003).

4.3. Case studies from carbonate systems

Estimations of the proportions of carbonate rocks to the total of world's hydro- carbon production vary between 40% and more that 60%, the largest reservoirs of which are situated in the Middle East (e.g. Ghawar Field, Saudi Arabia) and Kazakhstan (e.g. Kazagan Field) (Flugel, 2004). Facies analysis is a critical exploration tool in the sense that it helps in identifying environments and establishing depositional models including the prediction of reservoir extent and rock types. Major reservoir property controls are permeability and porosity, properties that, depending on the depositional setting of the reservoir rocks, vary considerably and are further differentiated by diagenetic processes, thus there are certain settings that are favored for carbonate reservoirs (Fig.5)

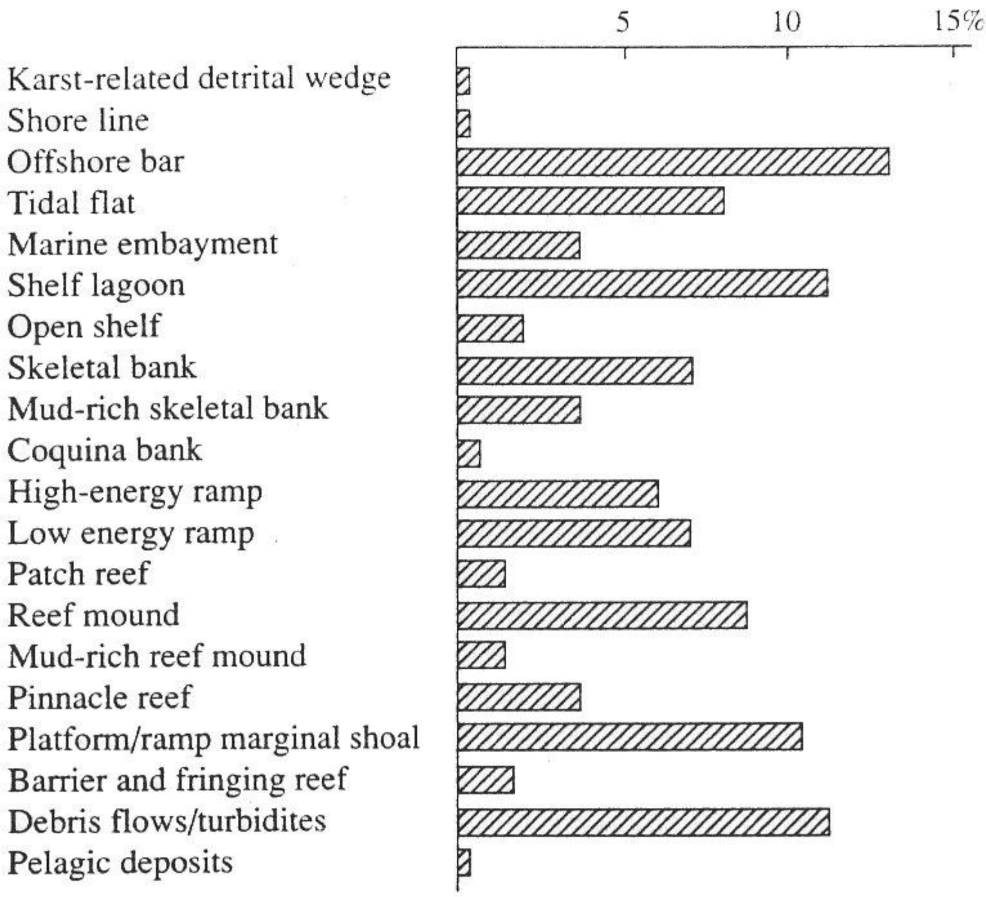


Figure 12: Spatial distribution of carbonate reservoirs, based on internet data(www.ccreservoirs.com).

Benthic foraminifera have been successfully used as facies indicators in modern and ancient carbonates due to the fact that the composition of foraminiferal assemblages varies in different parts of carbonate platforms and ramps. Hal- lock and Glenn (1986) developed a model of distribution patterns for Cenozoic foraminifera on a rimmed carbonate shelf, reflecting the Standard Facies Zones differentiated by Wilson (1975) (Fig.6).

A study of an Upper Triassic platform in the Northern Calcareous Alps by Schafer and Senowbari-Daryan (1981) proved benthic foraminifera to be ex- traordinarily useful in recognizing facies zones of all reef environments and ad- jacent areas. Next to publishing a model of foraminiferal distribution patterns of a patch reef, they developed a method for the characterization of carbonates by means of foraminiferal assemblages, involving the quantification of essential microfacies criteria, the determination of foraminifera on a species level, the examination of the frequency of the fossils, the recognition of morphological trends, the evaluation of foraminiferal assemblage composition in terms of sta- tistical analysis, and finally, the comparison to existing distribution patterns. In their paper on the ecology of larger benthic foraminifera, Beavington-Penney and Racey (2004) study depth distribution, morphology and symbiotic relation- ships in order to develop a paleoecological model that will aid the reconstruc- tion of depositional environments and promote the exploration of hydrocarbons reservoired within nummulitic limestones in offshore Tunisia and Libya. The authors observed that many factors, including depth, salinity, temperature, water-energy, substrate condition, specific life behavior, the topography of the depositional environment, turbidity and nutrient-supply may be of considerable importance in controlling foraminiferal distribution. They present an idealized distribution model for modern reef-associated foraminifera. Furthermore, a summary of the key faunal associations on carbonate ramps during the Eocene and the Oligo–/Miocene as well as a table of depth distribution of selected extant species is provided.

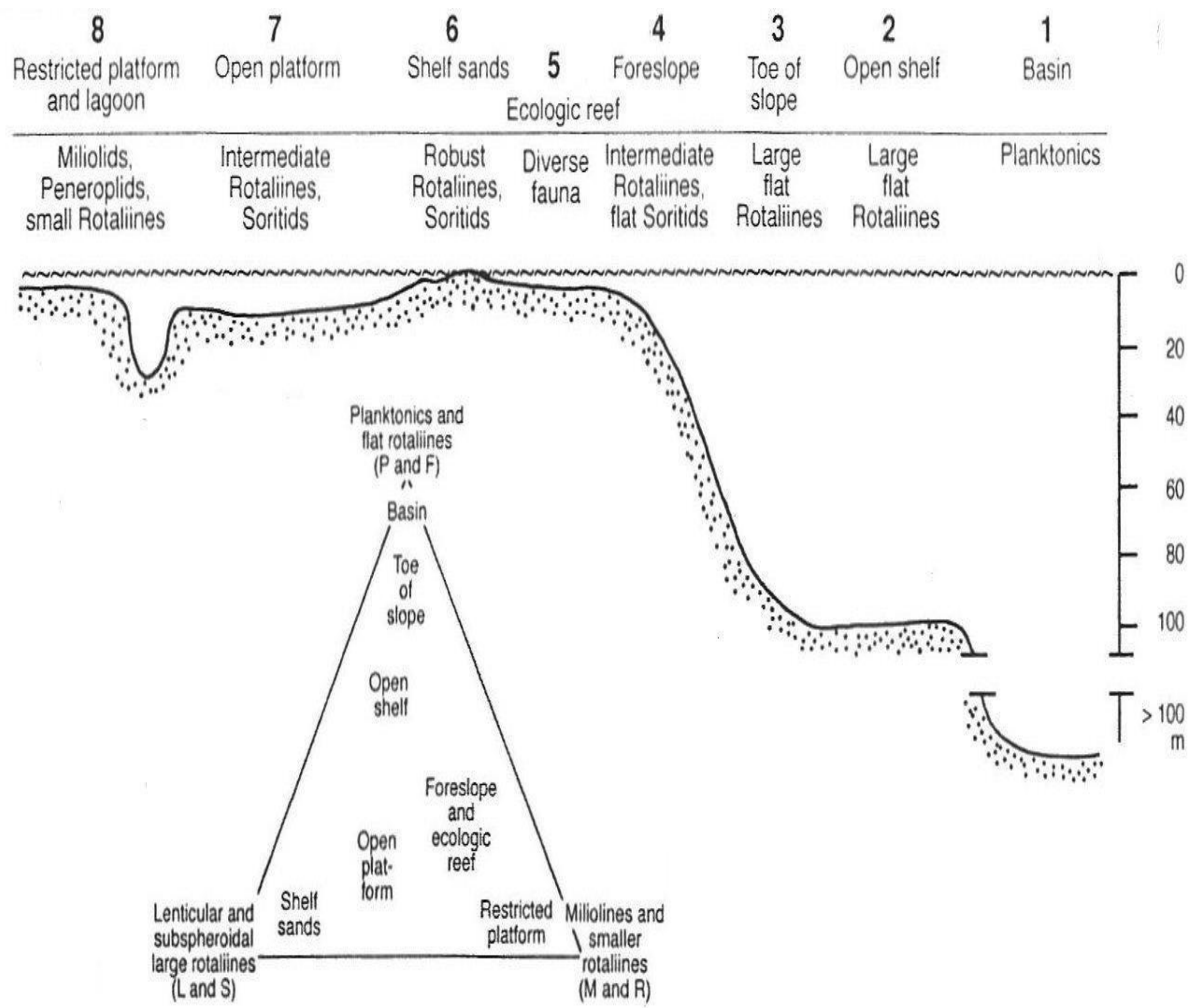


Figure 13: Distribution patterns of Cenozoic foraminifera reflecting the Standard Facies Zones differentiated by Wilson (1975); platform-basin transect with marginal reefs and ternary diagram, (from Hallock and Glenn, 1986).

Summary & Conclusion

Finally, we can say that Foraminifera are a phylum or class of amoeboid protists. They are characterized both by their thin pseudopodia that form an external net for catching food, and they usually have an external shell, or test, made of various materials and constructed in diverse forms.

Foraminifera (Forams. for short) are single-celled protists with shells. Their shells are also referred to as tests because in some forms the protoplasm covers the exterior of the shell. The shells are commonly divided into chambers which are added during growth, though the simplest forms are open tubes or hollow spheres.

Foraminifera are classified primarily on the composition and morphology of the test. Three basic wall compositions are recognised, organic (protinaceous mucopolysac charide i.e. the allogromina), agglutinated and secreted calcium carbonate (or more rarely silica).

Studies of living foraminifera, in controlled laboratory environments, have provided limited information regarding trophic strategies but much has been inferred by relating test morphology to habitat.

Foraminifera utilise a huge variety of feeding mechanisms, as evidenced by the great variety of test morphologies that they exhibit. From the variety of trophic habits and test morphologies a few generalisations may be made.

Foraminifera cover calcite wall of earlier chambers, and walls between chambers are (in bilamellar forms) existing of 4 layers (one from each adjoining chamber).

Chamber arrangements,single chamber(unilocular,monothalamous), uniserial, biserial, triserial, planispiral to biserial, milioline, planispiralevolute, planispiral involute, streptospiral, trochospiral.

Apertures ,open end of tube, Terminal radiate, Terminal slit, Umbilical, Loop shaped, Interiomarginal, Tnteriomarginal multiple, Areal cribrate, Phialine lip, Bifid tooth, Umbilical teeth, Umbilical bulla.

Reproduction complex alternation of sexual-asexual generations.

Benthic foraminifera are commonly refered to as the bottom dwellers. They live all along and beneath the ocean floor in the sediments. Benthic organisms live in a wide array of environments, ranging from marshes to abyssal plains. They are able to move and feed by use of pseudopodia. The type of pseudeopodia varies for each species. They are excellent indicators of ocean depth and serve as the primary biostratigraphic indicators for paleontologists. In just a handful of sediment, thousands of Forams.can be found. Their small size is key in how important they are to research. Planktic foraminifera live in the upper zone of the ocean. These creatures are distributed worldwide, but found only in the open ocean. When they die, they settle to the bottom of the ocean. Planktonic forams are indicators of ocean currents and climates. The planktic and benthic Forams.can easily be seperated, because specific Forams.only live in special conditions and environments.

Because of their diversity, abundance, and complex morphology, fossil foraminiferal assemblages are useful for biostratigraphy, and can accurately give relative dates to rocks. The oil industry relies heavily on microfossils such as Forams.to find potential oil deposits.

Calcareous fossil Foraminifera are formed from elements found in the ancient seas they lived in. Thus they are very useful in paleoclimatology and paleoceanography. They can be used to reconstruct past climate by examining the stable isotope ratios and trace element content of the shells .

For the same reasons they make useful biostratigraphic markers, living foraminiferal assemblages have been used as bioindicators in coastal environments, including indicators of coral reef health. Because calcium carbonate is susceptible to dissolution in acidic conditions, Foraminifera may be particularly affected by changing climate and ocean acidification.

References

S.J. Beavington-Penney and S. Racey. Ecology of extant Nummulitids and other larger benthic foraminifera: Applications in palaeoenvironmental analysis. Earth-Science Reviews, 67:219–265, 2004.

E. Boltovskoy, D. B. Scott, and F. S. Medioli. Morphological variations of benthic foraminiferal tests in response to changes in ecological parameters: A review. Journal of Palaeontology, 65(2):175–185, 1991.

E. Fl¨ugel. Microfacies Analysis of Carbonate Rocks. Springer Verlag, New York، .2004

P. Hallock and E. C. Glenn. Larger foraminifera: A tool for paleoenvironmental analysis for Cenozoic depositional carbonate facies. Palaios, 1:55–64, 1986.

B. U. Haq, J. Hardenbol, and P. R. Vail. Chronology of fluctuating sea-levels since the Triassic. Science, pages 1153–1165, 1987.

B. U. Haq, J. Hardenbol, and P. R. Vail. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In C. K. Wilgus, C. A. Ross, H. Posamentier, and C. G. St. C. Kendall, editors, Sea-level changes: An integrated approach, volume 42, page 71–108. SEPM Special Publication, 1988.

J. Hardenbol, J. Thierry, M. B. Farley, T. Jacquin, P.-C. de Graciansky, and P. R. Vail. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. In P.-C. de Graciansky, J. Hardenbol, T. Jacquin, and P. R. Vail, editors, Mesozoic and Cenozoic sequence stratigraphy of European basins, volume 60, page 3–13. SEPM Special Publication, 1998.

W. B. Harland et al. A Geologic Time Scale 1989. Cambridge University Press، .1990

B. W. Hayward. Use of foraminiferal data in analysis of Taranaki Basin, New Zealand. Journal of Foraminiferal Research, 20(1):71–83, 1990.

T. F. Hentz and H. Zeng. High-frequency Miocene sequence stratigraphy, off-shore Louisiana: Cycle framework and influence on production distribution in a mature shelf province. AAPG Bulletin, 87(2):197–230, 2003.

N. P. James. Facies Models. In R. G. Walker, editor, Reefs in Facies Models، pages 229–244. Geological Association of Canada, 1984.

D.G. Jenkins. Applied Micropalaeontology. Kluwer Academic Publishers, Dordrecht, 1993.

R. W. Jones. Micropalaeontology in Petroleum Exploration. Oxford University Press Inc., New York, 1996.

R. W. Jones and M. D. Simmons. A review of the stratigraphy of Eastern Paratethys (Oligocene-Holocene). Bulletins of the British Museum (Natural History), Geologic Series, 1993.

C. F. Jordan, T. C. Connally, and H. A. Vest. Middle Cretaceous Carbonates of the Mishrif Formation, Fateh Field, Offshore Dubai, U.A.E. In P. O.

Roehl and P. W. Choquette, editors, Carbonate Petroleum Reservoirs, pages .442–427Springer-Verlag, 1985.

C. G. St. C. Kendall. Sequence stratigraphy - application to exploration and production - Middle Eastern Basins of the Gulf of Mexico, 2005. Lecture Notes.

A. H. Majid and J. Veizer. Deposition and chemical diagenesis of Tertiary carbonates, Kirkuk Oil Field, Iraq. American Association of Petroleum Geologists Bulletin, 70(7):898–913, 1986.

J. W. Murray. Distribution and Ecology of Living Benthic Foraminiferids. Heinemann Educational Books, London, 1973.

J. Nagy. Delta-influenced foraminiferal facies and sequence stratigraphy of Paleocene deposits in Spitsbergen. Palaeogeography, Palaeoclimatology, Palaeoecology, 222:161– 179, 2005.

T. Naish and P. J. J. Kamp. Foraminiferal depth palaeoecology of Late Pliocene shelf sequences and systems tracts, Wanganui Basin, New Zealand. Sedimentary Geology, 110:237–255, 1997.

R. K. Olsson and E. E. Nyong. A paleoslope model for Campanian- Lower Maestrichtian Foraminifera of New Jersey and Delaware. Journal of Foraminiferal Research, 14(1):50–68, 1984.

Z. Reiss and L. Hottinger. The Gulf of Aqaba: Ecological Micropalaeontology. Springer Verlag, New

York, 1984.

P. Schafer and B. Senowbari-Daryan. Facies development and paleoecologic zonation of four Upper Triassic patch reefs, Northern Calcareous Alps near Salzburg, Austria. In D. F. Toomey, editor, European reef models, volume 30، pages 241–259. Society of Economic Paleontologists and Mineralogists, Special Publications, 1981.

J. T. van Gorsel. Biostratigraphy in Indonesia: Methods, pitfalls and new directions. In Proceedings of the Indonesian Petroleum Association 17th Annual Convention, pages 275–300, Jakarta, Indonesia, 1988.

L. Vergara, G. Rodr´ıguez, and I. Mart´ınez. Agglutinated foraminifera and sequence stratigraphy from the Chipaque Formation (Upper Cretaceous) of El Crucero section, Colombia, South America. Micropaleontology, 43(2):185.1997 ،201

J. L. Wilson. Carbonate Facies in Geologic History. Springer Verlag, Berlin، .1975

الملخص العربي

يتناول هذا البحث الفورامنيفرا (المثقبات) والتى تعد من أهم الأحافير التي تستخدم في الدراسات الأحفورية والطبقية ، واستعراض وصف لحياة الفورامنيفيرا ويعتبرها فئة من الاوليات الاميبية وحيدة الخلية ذات الاقدام الكاذبة الرقيقة لاصتياد الطعام ، وعادة ما يكون لها هيكل خارجي مصنوع من مواد مختلفة والتي شيدت فى أشكال متنوعة .

ويتضمن البحث أشكال الأصناف من حيث ترتيب الحجرات التى يصنعها الكائن أثناء مراحل نموه وكذلك موضع فتحة الصدفة والمواد التى يتكون منها جدار الصدفة .

كما استطاع العلماء عن طريق دراسة حياة بعض الفورامنيفرا في المختبر التعرف على الاستراتيجيات الغذائية المتنوعة بشكل عام .

ويتطرق البحث الى مفهوم التكاثر في الفورامنيفرا حيث انه عباره عن تناوب اجيال التكاثر الشقي والاشقي .

ويتكون جدار الصدفة من مواد كربونية او سيليكاتية او من جزيئات رملية ، ويتم التعرف على (*275000*) نوع من الكائنات الحية و الاحفورية عادة ما تكون اقل من *1* ملم في احجم ولكن بعضها اكبر من ذلك بكثير حيث يصل الى (*20*) سم .

ومما هو جدير بالذكر ان معظم الفورامنيفرا هي مائية او بحرية في المقام الأول ، ومعظم الأنواع تعيش على أو داخل الرواسب في قاع البحر مع القليل من الانواع المعروفة التى تكون عائمة في عمود الماء على أعماق مختلفة ، حيث انه تقسيم الفورامنيفرا الى فورامنيفرا قاعية و فورامنيفرا هائمة التى توجد فى المناطق العليا من المحيطات وعندما تموت فإنها تستقر في القاع وبسبب تنوع الفورامنيفرا القاعية والهائمة ووفرتها ومورفولوجيتها المعقدة فإنها مفيدة جداً فى للدراسات البيوستراتجرافية تعطي بدقة أعمار نسبية الى الصخور ، كما ان صناعة النفط تعتمد بشكل كبير على الأحافير الدقيقة للعثور على اماكن النفط المحتملة .

ويعد البحث بمثابة توضيح لمدي أهمية الفورامنيفرا فى التعرف على البيئات القديمة واعادة بناء المناخ القديم .