South Valley University
Faculty of Science
Geology Department
Micropaleontology (Foraminifera)
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Course contents:

1- Introduction, History of study, applications, Preparation techniques.

2- Range, living foraminifera, biology, life cycle.

3- Classification, test morphology (wall structure).

4- Test morphology (chamber shape, chamber arrangement).

5- Test morphology (aperture and openings, Pores, ornamentation).

6- Ecology.

Further readings:

1- Elements of micropaleontology; Bignot, G. 1985.


3- Introduction to marine micropaleontology; (eds) Bilal U. Haq & Anne Boersma, 1983.

4- Foraminifera; John R. Haynes, 1981.

5- Internet sites (Yahoo and google search).
Kingdom: Protista
Subkingdom: Protozoa
Phylum: Sarcomastigophora
Subphylum: Sarcodina
Super class: Rhizopoda
Class: Granuloreticulosea
Order: Foraminiferida (foraminifera).

Introduction:

The order foraminiferida or foraminifera as they are informally called forms the most important group of microfossils for two reasons: first, they are abundant in rocks and there are numerous species; second they provide valuable information in the dating of strata and the reconstruction of sedimentary environments.

Foraminifera are an order of single-celled protests that live either on the sea floor or amongst the marine plankton. The soft tissue (protoplasm) of the foraminiferid cell is largely enclosed within a shell (test) variously composed of secreted minerals (calcite, aragonite or silica) or of agglutinated particles. This test consists of a single chamber or several chambers mostly less than 1 mm across and
each interconnected by an opening (foramen) or several openings (foramina). Foraminifera are known from early Cambrian times through to recent times. 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 (1964). Unpicking this nomenclature tells us that foraminifera are testate (that is possessing a shell), protozoa, (single celled organisms characterised by the absence of tissues and organs), which possess granuloreticulose pseudopodia (these are thread-like extensions of the ectoplasm often including grains or tiny particles of various materials).

**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 recognized 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.

Applications

As previously mentioned, foraminifera have been utilized for biostratigraphy for many years, and they have also proven invaluable in palaeoenvironmental reconstructions most recently for palaeoceanographical and palaeoclimatological purposes. For example palaeobathymetry, where assemblage composition is used and palaeotemperature where isotope analysis of foraminifer tests is a standard procedure. In terms of biostratigraphy, foraminifera have become extremely useful, different forms have shown evolutionary bursts at different periods and generally if one form is not available to be utilized for biostratigraphy another is. For example preservation of calcareous walled foraminifera is dependent on the depth of the water column and Carbonate Compensation Depth (CCD) (the depth below which dissolution of calcium carbonate exceeds the rate of its deposition), if calcareous walled foraminifera are therefore not preserved agglutinated forms may be. The oldest rocks for which foraminifera have been biostratigraphically useful are Upper Carboniferous to Permian strata, which have been zoned using the larger benthic fusulinids. Planktic foraminifera have become increasingly important biostratigraphic tools, especially as petroleum exploration has extended to offshore environments of increasing depths. The first and last occurrence of distinctive "marker species" from the Cretaceous
to Recent (particularly during the Upper Cretaceous) has allowed the development of a well established fine scale biozonation. Benthic foraminifera have been used for palaeobathymetry since the 1930's and modern studies utilize a variety of techniques to reconstruct palaeodepths. For studies of relatively recent deposits simple comparison to the known depth distribution of modern extant species is used. For older material changes in species diversity, planktic to benthic ratios, shell-type ratios and test morphology have all been utilized. Variations in the water temperature inferred from oxygen isotopes from the test calcite can be used to reconstruct palaeoceanographic conditions by careful comparison of changes in oxygen isotope levels as seen in benthic forms (for bottom waters) and planktic forms(for mid to upper waters). This type of study has allowed the reconstruction of oceanic conditions during the Eocene-Oligocene, the Miocene and the Quaternary. Benthic foraminifera have been divided into morphogroups based on the test shape and these groups used to infer palaeo-habitats and substrates; infaunal species tending to be elongate and streamlined in order to burrow into the substrate and epifaunal species tending to be more globular with one relatively flatter side in order to facilitate movement on top of the substrate. It should be remembered, however, that a large variety of morphologies and possible habitats have been recognized making such generalizations of only limited use. Studies of modern foraminifera have recognized correlations between test wall type (for instance porcelaneous, hyaline, agglutinated), palaeodepths and salinity by plotting them onto triangular diagrams.
Preparation Techniques

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

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 foraminifera from reef type settings.

Planktic and smaller benthic foraminifera 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 until 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 preparations of each sample to prevent contamination.

Observation Techniques

Thin sections are viewed 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.
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 rotaliinids and in the Jurassic the textulariinids. 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 foraminifera of the nummulites, soritids and orbitoids. 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.
Living Foraminifera:

Foraminifera are unicellular organisms belonging to the rhizopod protozoa (protista). Their protoplasm, differentiated into endoplasm and ectoplasm, is emitted in the form of retractile pseudopodia, which are granular, anastomosing filaments. These are used in catching prey.

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 utilize 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 *Notodendrodes antarctikos*, 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 utilize their pseudopodia to capture food from the water column, or interstitial pore waters, *Elphidium crispum* forms a "spider's 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 symbiotically with photosynthesising algae such as dinoflagellates, diatoms 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.
Life Cycle:

Diagram showing a generalised foraminifera life cycle note alternation between a haploid megalospheric form and a diploid microspheric form.

Redrawn from Goldstein 1999.

Of the approximately 4000 living species of foraminifera the life cycles of only 20 or so are known. There is 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 forms a large proloculus (initial chamber) and are therefore termed megalospheric. Sexually produced diploid
Foraminifera 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 *Hastigerina pelagica* reproduces by gametogenesis at depth, the spines, septa and apertural region are resorbed leaving a tell-tale test. *Globigerinoides sacculifer* produces a sac-like final chamber and additional calcification of later chambers before dissolution of spines occurs, this again produces a distinctive test, which once gametogenesis is complete sinks to the sea bed.

**Classification**

Foraminifera are classified primarily on the composition and morphology of the test. Three basic wall compositions are recognised, organic (protinaceous mucopolysaccharide 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 equidimensional subspherical 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.

**Test Morphology:**

Foraminifera are animals which build a shell; and for paleontologists the characteristics of the shell are the primary features which can be used to distinguish one species from another.

**Wall Structure:**

The most readily obvious feature distinguishing one foraminifer from another is its wall type. Whether the foraminifer builds its test wall by cementing together exogenous grains, by carbonate mineralization, or by some combination of these two processes separates the three primary foraminiferal groups, the agglutinated, the calcareous, and the microgranular foraminifera.

*Agglutinated wall structure*

In these, organic and mineral matter from the sea floor is bound together by an organic, calcareous or ferric oxide cement. The grains are commonly selected for size, texture or composition (e.g. coccoliths, sponge, spicules and heavy minerals). Other agglutinated forms are non-selective and will employ any particle from a substrate as long as it lies in the appropriate size range.
Microgranular walls

Microgranular walls evolved during the Paleozoic and are considered the link between the agglutinated and the precipitated tests in foraminifera. Microgranular particles of calcite cemented by a calcareous cement characterize this wall type and give it a sugary appearance.

Calcareous walls- hyaline type

Calcareous wall may be composed of either low or high Mg calcite, or aragonite which is confined to only two foraminiferal families. Hyaline calcareous tests are characterized by the possession of minute perforation in the test wall. The calcareous hyaline are generally glassy (hyaline) when viewed with reflected light and grey to clear in transmitted light.

Calcareous walls- porcelaneous type

The term porcelaneous derives from the shiny, smooth appearance of the tests and is the result of the orientation of submicroscopic crystalline may be randomly arranged or organized in brick-like patterns, but both patterns give the test a smooth, opaque appearance (milky white) in polarized light. Both in shallow-marine and in deeper environments porcelaneous tests are often composed of calcite with high proportion of Mg.
Chamber shape and chamber arrangement:

Foraminiferal tests may possess one or more chambers. The initial chamber is most often spherical or oblate with an aperture. Later chambers range in shape from tubular, spherical, ovate to several others. Additional chambers are added in a variety of patterns termed chamber arrangements:

1- Uniserial: the chamber arranged in a single row; if it forms a curved row, it is termed arcute; if a straight series, it is termed rectilinear.

2- Biserial: the chambers arranged in a double row.
3- Triserial: Chambers are added every 120° in a spiral fashion.
4- Polyserial: the chambers arranged in a multiple row.
5- Planispiral: the chamber arranged spirally around an axis of coiling and the spiral lies in a single plane.

Principle types of chamber arrangement. 1, single chambered; 2, uniserial; 3, biserial; 4, triserial; 5, planispiral to biserial; 6, milioline; 7, planispiral evolute; 8, planispiral involute; 9, streptospiral; 10-11-12, trochospiral (10, dorsal view; 11, edge view; 12, ventral view).
Redrawn from Loeblich and Tappan 1964.
6- Trochospiral: when the spiral does not lie in one plane, but progresses up the axis of coiling, the chamber arrangement becomes helicoidal.

7- The Miliolidae have a streptospiral arrangement. The arched chambers, tangential at their two extremities with the extension axis, are arranged in cycles of five, three or two loculi or one loculus. Each new chamber has its aperture facing the aperture of the preceding chamber.

When a series of chambers is arranged spirally or coiled about an axis, the chambers involved in one complete revolution are termed a whorl or coil. The degree to which one whorl covers, or hides a previous one, is known as the degree of involution. Where the majority of the previous coils are hidden, a species is termed involute, while evolute if the majority of the previous coils are visible.

On a coiled test the side of the foraminifer showing the trace of the coil, or spiral, is termed the spiral side. The opposite side is termed the umbilical side. The umbilicus, the axial space between the inner
wall margins of the chambers belonging to the same coil, may not necessarily be present. The area where one chamber meets another is the suture area and represents the line of junction projected to the surface of the test.

**Apertures and openings:**

The aperture is the primary opening of the test to the outside environment. Apertures vary in size and shape and the shape is most often a function of the shape of the chamber on which they are located. The aperture is found in the wall of the final chamber and serves to connect the external pseudopodia with the internal endoplasm, allowing passage of food and contractile vacuoles, nuclei and release of the daughter cells.

Aperture may be single or multiple in number and terminal, areal, basal extraumbilical, umbilical or sutural in position. Their shape varies widely, e.g. rounded, bottle-necked (phialine), radiate, dendritic, sieve-like (cribrate), circular form, slit- or loop-shaped.
Sculpture:

The external surface of the test may bear spines (termed spinose), keels (carinate), rugae (rugose), fine striae (striate), coarser costae (costate), granules (granulate).
Ecology:

During life, forams are either benthonic or planktic, relying on their pseudopodia for both locomotion and creating water currents for food gathering. Benthic forms inhabiting shallow to deep water environments can be recognized by their larger size, thick heavily ornamented walls, and less "globular" shape. Planktic forams are recognized by their thin, and often perforated, tests and globular inflated chambers. You should be able to recognize the difference between the two types of forams.

Numerous foraminifera inhabit the benthic environment. Some move freely over the sea-bed or in the first few millimeters of sediment. Others use their pseudopodia or calcareous secretions to attach themselves to supports such as rocks, shells and seaweed. Most are marine and stenohaline (they can tolerate only very small variations in the salinity of the water). Certain groups, however, having a porcelaneous test (e.g. the milolines) can live equally well in hyperhaline environments (lagoons with a salinity >35 Parts per mile (‰). Certain types such as the agglutinates (e.g. *Eggerella*) and hyalines (*Nonion*) prefer water with a low salinity e.g. brackish
lagoons and estuaries. Still others (e.g. Trochammina and Elphidium) can adjust to considerable variations in salinity and may be found in all environments with the exception of lakes where foraminifera never live. Foraminifera are used to interpret past water depth, since depth-and space related parameters are of greatest significance, the foraminifera occupying different levels according to local values for temperature, oxygen content, light, etc. As a general role, species with a hyaline test occur everywhere but in the deepest areas. Species with agglutinated testes are similarly ubiquitous but they alone survive at depth below 4000 to 5000 m.

**Ecology**

The physical environment of the ocean basins, the chemical constitution and dynamics of sea water, and all of the organisms dwelling in the ocean comprise the marine ecosystem. Indicator faunas have become one of the several indices that can be used to characterize a particular environment. Other indices now used include the planktic to benthic (P/B) ratio, the ostracode to foraminifera ratio, the calcareous to agglutinated ratio, the percentage of various families present, diversity indices.

**Physical variables**

There is a combination of variables that controls the distribution of individual foram. Water depth, Temperature, etc. Temperature is one of the most important and easily determined variables affecting benthics. Foraminifera are found living at temperatures from 1° to over 50°C. Some variables affecting foraminiferal distribution indirectly like hydrostatic pressure, light intensity.
Numerous foraminifera inhabit the benthic environment. Some move freely over the sea-bed or in the first few millimeters of sediment. Others use their pseudopodia or calcareous secretions to attach themselves to supports such as rocks, shells and seaweed. Most are marine and stenohaline. Certain groups, however, having a porcelaneous test (milioline) can live equally well in hyperhaline environments (lagoons with salinity > 35 parts per mile (%)).

**Chemical variables**

1- **Salinity**

Foraminifera inhabit environments with salinities ranging from a typical open ocean value of 35 ‰ to as high as 45 ‰. The genus Discorbinopsis was found to tolerate salinities up to 57 ‰. At the other extreme, a river and its estuary may have salinities varying from as low as 15 ‰ to .05 ‰ and still contain foraminifera. The lower the salinity of the environments the lower the diversity of the faunas there.

2- **Alkalinity**

As a function of the concentration of CO2 in the water, alkalinity is governed chiefly by temperature, pressure, and biological respiration. The top 500 m of sea water are said to be saturated with
respect to calcium carbonate which reflects the high alkalinity in this region. Below 500 m water is considered under saturated with respect to calcium carbonate. Below this depth the lower alkalinities tend to cause calcium carbonate to dissolve.

**Biotic variables**

The study of foraminifera as members of marine communities falls into the realm of autecology. Such an approach seeks to relate the foraminifera to the food chain of which it is a part, as well as to understand the types of relations foraminifera have among themselves and with other members of the marine communities. Figures for the density of living benthic foraminifera vary from 1,000 to 2,000,000 individuals per square meter of sea bottom. When density of individuals becomes great, foraminifera have been observed to migrate away from the crowded areas.

**Planktonic foraminiferal ecology**

The distribution and ecology of recent planktonic foraminiferais essentially similar to that of other zooplankton and is primarily governed by the availability of food. Planktonics live in the water column from the surface zone down to depths of over 1,000 m. Distribution of taxa through the water column may change seasonally. In cooler seasons or at high latitudes a species may live nearer the surface than it does in warmer waters or at lower latitudes. Geographically there are close parallels between the distribution of planktonic foraminifera in modern oceans and in the past. In general smaller species are found in colder water masses or at high latitudes and larger species in warmer water or at low latitudes. Diversity is lower at high latitude and increase toward the equator.
Distribution of recent foraminifera

Foraminifera have been reported from marine environments extending from tide pools in a marsh to the abyssal plains. Each environment is characterized by its particular species, their diversity and densities. We consider that past environments may have contained many analogous components and hence modern environmental indicator faunas are carefully applied to the understanding of both recent and past environments.

Carbonate platforms, reefs and back reefs

Foraminifera occur in coral reefs environments either as adherent forms (*Homotrema*) or as epifauna in niches developed within the reef framework (*calcarina, Amphistigina, Marginopora*). Smaller benthic foraminifera are one of the primary contributors to the sediments of shallow carbonate platforms. They attach to sea weeds and grasses, algal and coral fragments. Larger foraminifera inhabit these shallow waters in association with the macroflora which foraminifera use for protection, and the microflora which the foraminifera use for food.

Brackish environments

Historically foraminifera have been considered predominantly marine organisms, with primitive or aberrant types inhabiting freshwater ecosystems. There is a group of foraminifera that occur in brackish environments and this brackish-water faunas is geographically very uniform. Brackish environments are typified by finer-sized sediments containing abundant plant detritus. The critical controlling factor in this environment is apparently the low salinity.

Marshes

Foraminifera live from the deepest tidal channels to shallow ephemeral tide pools in the march grass. Marshes and bays are
characteristically areas of high daily and seasonal fluctuations in temperature, salinity, water depth, turbidity, and water chemistry. In addition, high in organic matter and nutrients and thus support large biomasses low in diversity.

There is a marked difference between living faunas and faunas recovered from fossil march sediments. Hyaline, agglutinated and a few porcelaneous genera characteristically form the living fauna. The test of the calcareous and porcelaneous genera are frequently thin. The number of calcareous genera in the sediments, however, is significantly lower or they are altogether absent; while the number of agglutinated forms is generally the same in both sediment and living populations.

**Continental shelf and open marine**

The shallow shelf is characterized by a small fauna dominated by a few species, very few of which are agglutinated and none of which are pelagic. The inner shelf characterized by coarse-grained clean, well sorted sands containing abundant rounded shell fragments. The benthic faunas are usually highly dominated by a few species. Test are small and not strongly ornamented. A few pelagic species, usually of the genus Globigerina, may be present.

The deep inner shelf contains fine-to medium grained sand, silt, clay with common glauconite and mollusk and echinoid remains. There is an increase in the number of specimen per species. Pelagic types are more numerous and agglutinated foraminifera increase in abundance, but still have simple interiors. Middle shelf sediments are composed of clay, silt, poorly sorted sands, and abundant glauconite. Species are often highly ornamented, with pelagic types comprising from 15 to 30% of the total microfauna. Species dominance is low.
and the number of species is high. Agglutinated forms have more complex interior structures.

The outer shelf is characterized by fine grained sediments such as clays and some glauconite. Species number is high and ornamentation is strong. Planktonics constitute approximately 50% of the faunas. Arenaceous foraminifera have complex interiors. The upper continental slope strongly resembles the outer shelf. Planktonic foraminifera comprise from 50 to 85% of the microfaunas. The number of benthic species is large on the abyssal plain, though there is a dilution effect from dead planktonic tests. Planktonic foraminifera range from 75% to more than 90% of the microfauna.

The deepest-dwelling, abyssal agglutinated foraminifera are simple tube-like structures, surrounded by detrital particles held together loosely by protoplasm. The lack of carbonate in their tests reflects the absence of carbonate particles in the abyssal “red clay” environment.

Trends in bathymetry and fossil content of sediments from the shelf to the abyss.