What are foraminifera?

Foraminifera (forams for short) are single-celled organisms (protists) with shells or tests. They are abundant as fossils for the last 540 million years. The shells are commonly divided into chambers that are added during growth. The shell may be made of **organic compounds, sand grains or other particles** cemented together, or **crystalline $CaCO_3$** (calcite or aragonite).

Fully grown individuals range in size from about 100 micrometers to almost 20 centimeters long. Some 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 algae, to small animals such as copepods. They catch their food with a network of thin pseudopodia (called reticulopodia) that extend from one or more apertures in the shell. Benthic (bottom-dwelling) foraminifera also use their pseudopodia for locomotion.

WHERE DO THEY LIVE?

There are an estimated 4,000 species living in the world's oceans today. Of these, 40 species are planktonic, that is they float in the water. The remainder live on or in the sand, mud, rocks and plants at the bottom of the ocean. Foraminifera are found in all marine environments, from the intertidal to the deepest ocean trenches, and from the tropics to the poles, but species of foraminifera can be very particular about the environmentin which they live. Some are abundant only in the deep ocean, others are found only on coral reefs, and still other species live only in brackish estuaries or intertidal salt marshes.

Foraminifera are among the most abundant shelled organisms in many marine environments. A cubic centimeter of sediment may hold hundreds of living individuals, and many more dead shells. In some environments their shells are an important component of the sediment. For example, in regions of the deep ocean far from land the bottom is often made up almost entirely of the shells of planktonic species.

Factors controlling the distribution of foraminifera

1-Food

Foraminifera feed on small bacteria, algae, dead organic particles.

2-Predation

Benthic foraminifera are ingested by worms, crustaceans, gastropods, echinoderms and fish.

3-Substrate

Silty and muddy substrates are often rich in organic debris and the small pore spaces contain bacterial blooms. Such substrates are therefore attractive to foraminifera and support large populations. Many of these species are thin-shelled, delicate and elongate forms. The larger pore spaces of sands and gravels contain fewer nutrients and therefore support sparser populations. Foraminifera from these coarser substrates may be thicker-shelled, heavily ornamented and of biconvex or fusiform shape. Although foraminifera have been found living up to 200 mm below the sediment surface, the majority are feeding within the top 10 mm or so, the depth of burial varying between species.

4-Temperature

Each species is adapted to a certain range of temperature conditions. Stratification of the oceans results in the lower layers of water being cooler, as for example in tropical waters where the surface may average 28ºC but the bottom waters of the abyssal plains may average less than 4ºC. In several planktonic species (e.g. *Globigerina pachyderma*) warm and cool populations can be distinguished by a predominance of right-hand (dextral) or left-hand (sinstral) coiling.

5- Salinity

The majority of foraminifera are adopted to normal marine salinities (about 35 ‰) and it is in such conditions that the highest diversity assemblages are found. The most common benthic foraminiferal species that thrive in a wide range of salinity variations is *Ammonia tepida.*

- The majority of foraminifera are adopted to normal marine salinities (about 35 ‰) and it is in such conditions that the highest diversity assemblages are found.
- The low salinity of brackish lagoons favors low diversity assemblages of agglutinated foraminifera (e.g. *Reophax*) and certain Rotaliacea (e.g. *Ammonia*).
- The soft, tectinous *Allogrominia* are found in fresh and brackish waters, but they are rarely encountered as fossils.
- The high $CaCO_3$ concentrations of hypersaline waters favor the porcelaneous Miliolina (especially Miliolidae, e.g. *Triloculina*) but deter most other groups. **Triangular plots of the relative proportions of Textulariina, Miliolina and Rotaliina have proved useful as indices for paleosalinities.**

6- $CaCO_3$

The solubility of $CaCO_3$ is less in warm than in cool waters. $CaCO_3$ solubility also increases with pressure (i.e. depth). The ratio of CO_2 to O_2 increases with depth because algae cannot photosynthesis below the photic zone, although animals continue to respire. This leads to a decrease in pH with depth, from about 8.2 to as low as 7.0. The level at which $CaCO_3$ solution equals $CaCO_3$ supply is called the calcium carbonate compensation depth (or CCCD). The net result is a drop in the number of calcareous organisms with depth, there being few below 3000 m. For this reason, the agglutinated foraminifera dominate populations from abyssal depths.

CLASSIFICATION OF FORAMINIFERA

Traditionally, classification of foraminifera has been based primarily on characters of the shell or test. Wall composition and structure, chamber shape and arrangement, the shape and position of any apertures, surface ornamentation, and other morphologic features of the shell are all used to define taxonomic groups of foraminifera. New research is adding molecular data on relationships among species that may greatly affect how these organisms are classified.

Chamber arrangements commonly found in living species are shown in figures 1-6. The following terms are used: Unilocular refers to a shell made of a single chamber Uniserial refers to chambers added in a single linear series. Biserial refers to chambers added in a double linear series Triserial refers to chambers added in a triple linear series. Planispiral refers to chambers added in a coil within a single plane like the chambered nautilus. Trochospiral refers to chambers added in a coil that forms a spire like a snail shell. Milioline refers to an arrangement where each chamber stretches the full length of the shell and each successive chamber is placed at an angle of up to 180 degrees from the previous, relative to the central axis of the shell. Terms such as planispiral-to-biserial and biserial-to-uniserial are used when the mode of chamber addition changes during growth.

Of the various kinds of wall composition and microstructure found in foraminifera, three basic types are common among living species. **Agglutinated** shells may be composed of very small particles cemented together and have a very smooth surface, or may be made of larger particles and have a rough surface. **Hyaline** shells are made of interlocking microcrystals of $CaCO_3$, and typically have a glassy appearance and pores that penetrate the wall. **Porcelaneous** shell walls are composed of microscopic rod-shaped crystals of $CaCO_3$. These have a milky, translucent to opaque look and generally lack pores beyond the initial chambers. In some porcelaneous species, small depressions in the surface ornamentation give the appearance of pores. Another type of wall structure, called microgranular, is made of tightly packed equidimensional rounded grains of calcite. This wall type is found in many Paleozoic foraminifera including the fusulinids.

Figures 1-6. These images were captured using the Environmental Scanning Electron Microscope at the UC Museum of Paleontology, Berkeley, CA.

Figure 1. Unilocular hyaline shell

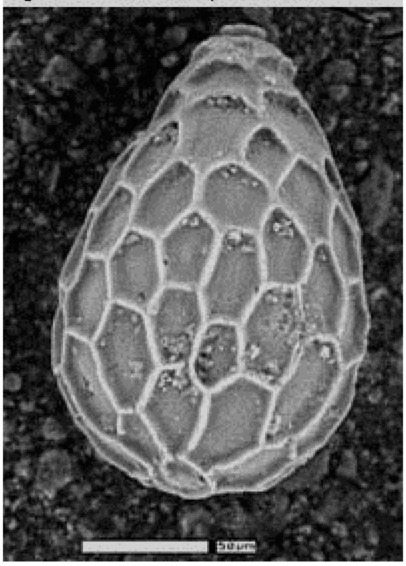


Figure 2. Uniserial hyaline shell

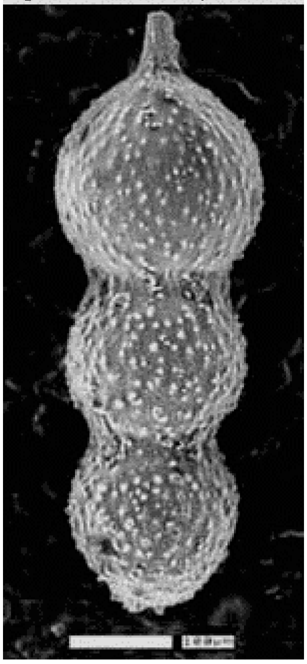


Figure 3. Agglutinated shell with biserial chamber arrangement

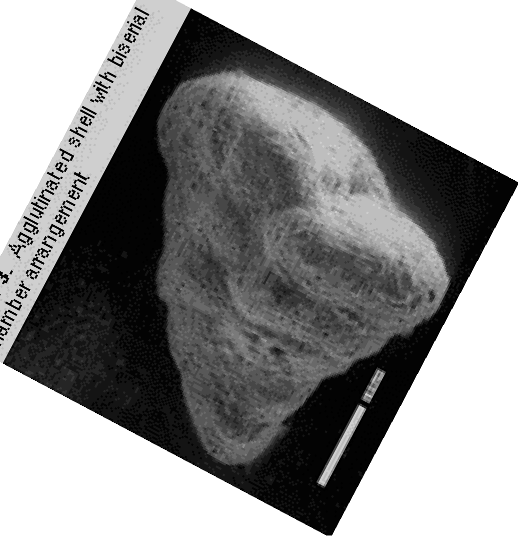


Figure 4. Planispiral coiled hyaline shell

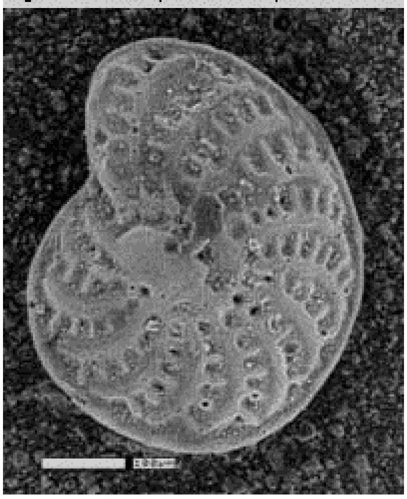


Figure 5. Trochospiral hyaline shell with large pores

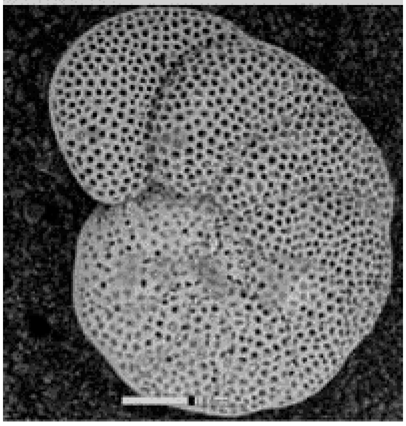
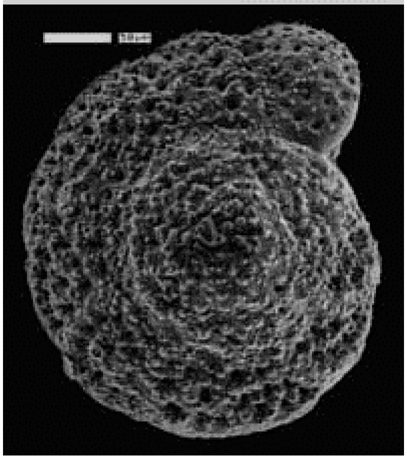


Figure 6. Trochospiral hyaline shell with bumpy surface ornamentation obscuring the first-formed chambers



Effects of reduced oxygen concentrations on the composition and structure of foraminiferal assemblages

1-Terminology:
anoxia means no oxygen - an, prefix from the Greek that means without or not (Brown 1979) - and the term is only applied to oxygen values equal to zero. The term "anaerobic" is synonymous with anoxic. The word aerobia is used as a biological term referring to respiration using oxygen, even in the case of marine organisms, although the word aerobia comes from aeros, a prefix that in Greek means air.

The Oxygen minimum zone (OMZ), is the zone in which oxygen saturation in seawater in the ocean is at its lowest. The majority of marine organisms require oxygen in order to survive.

2- Foraminiferans from low oxygen environments

These stressful conditions arise in marine and freshwater environments when organic enrichment leads to the development of large populations of organisms which consume dissolved oxygen, or when the oxygen is not replaced because of bottom-water stagnation, or a combination of all these factors. Oxygen depletion in the bottom water leads to oxygen depletion in the underlying sediment pore water (Hermelin 1992). This group of organisms seem to be particularly tolerant of low oxygen.

There are three basic test types within the foraminiferans: organic tests, agglutinated tests and calcareous tests. These groups exhibit different degrees of tolerance to low oxygen concentrations. Calcareous foraminiferans, particularly rotaliids and buliminids, tend to survive better in low oxygen environments than soft-shelled species, and are often abundant. Calcareous foraminiferans seem to be more tolerant of low oxygen environments than either agglutinated or organic-walled foraminiferans. Typical low-oxygen taxa include the following genera *Bulimina, Uvigerina* and *Heterohelix*. These Foramonifera need trace amounts of oxygen to survive.

WHY ARE THEY IMPORTANT?

The study of fossil foraminifera has many applications beyond expanding our knowledge of the diversity of life. Fossil foraminifera are useful in biostratigraphy, paleoecology, paleobiogeography, and oil exploration.

BIOSTRATIGRAPHY

Foraminifera provide evidence of the relative ages of marine rocks There are several reasons that fossil foraminifera are especially valuable for determining the relative ages of marine rock layers. They have been around since the Cambrian, over 500 million years ago. They show fairly continuous evolutionary development, so different species are found at different times. Forams are abundant and widespread, being found in all marine environments. Finally, they are small and easy to collect, even from deep oil wells.

PALEOECOLOGY AND PALEOBIOGEOGRAPHY

Foraminifera provide evidence about past environments Because different species of foraminifera are found in different environments, paleontologists can use the fossils to determine environments in the past. Foraminifera have been used to map past distributions of the tropics, locate ancient shorelines, and track global ocean temperature changes during the ice ages. If a sample of fossil foraminifera contains many extant species, the present-day distribution of those species can be used to infer the environment at that site when the fossils were alive. If samples contain all or mostly extinct species, there are still numerous clues that can be used to infer past environments. These include species diversity, the relative numbers of planktonic and benthic species, the ratios of different shell types, and shell chemistry.

The chemistry of the shell is useful because it reflects the chemistry of the water in which it grew. This data helps us understand how climate and ocean currents have changed in the past and may change in the future.

OIL EXPLORATION

Foraminifera are used to find petroleum

Some species are geologically short-lived and some forms are only found in specific environments. Therefore, a paleontologist can examine the specimens in a small rock sample like those recovered during the drilling of oil wells and determine the geologic age and environment when the rock formed. As a result, since the 1920's the oil industry has been an important employer of paleontologists who specialize in these microscopic fossils. Stratigraphic control using foraminifera is so precise that these fossils are even used to direct sideways drilling within an oil-bearing horizon to increase well productivity.