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INTERPRETING PALEOENVIRONMENTS WITH MICROFOSSILS

For grades 10-12
Adapted by Laura Sanders, Environmental Science Institute, March 2011
From Dr. Stephen J. Culver of the Department of Paleontology at The Natural History Museum in London.
View the original lesson plan at: http://www.ucmp.berkeley.edu/fosrec/Culver.html

Length of Lesson: 1-2 class periods

SAMPLES OF POTENTIAL TEKS ADDRESSED THROUGH THIS LESSON:
§112.32. Aquatic Science, Beginning with School Year 2010-2011: 1A, 2F, 2G, 2H, 2J, 3E, 10A,
§112.34. Biology, Beginning with School Year 2010-2011: 1A, 2F, 2G, 2H, 3B, 7A, 8B, 12B,
§112.36. Earth and Space Science, Beginning with School Year 2010-2011: 1A, 2E, 2F, 2G, 2I, 3B, 3E, 7A, 8A, 8B

CONCEPTS:
*Interpreting Paleoenvironments with Microfossil*s shows how knowledge obtained via study of modern organisms can be used by scientists to infer environmental conditions in the past. It also demonstrates the predictive side of science; for example, what might happen if a particular pollutant is introduced to an estuary, or on a much larger scale, what might happen to coastal ecosystems if sea-level rose as a result of anthropogenic global warming and subsequent collapse and melting of polar ice sheets.

PERFORMANCE OBJECTIVES:
The students will be able to:
- Describe the differences and similarities between planktonic and benthic foraminifera.
- Describe the differences and similarities between hyaline, porcelaneous and agglutinated foraminifera.
- Calculate the proportion of planktonic specimens in a sample.
- Establish the species diversity of a sample.
- Establish the shell-type ratio of a sample.
- Reconstruct the environment of deposition of the sample.

MATERIALS:
- Foraminifera Background Information (see attachment)

Per Student or Group of Students:
- Sediment collection of foraminifera specimens
- 240m fine mesh sieve
- Sharp knife
- Picking tray
- Gum tragacanth-coated cardboard slide

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- Student worksheet (see attachment)

TEACHER PREPARATION:

If you live by the sea you can collect live or dead foraminifera from the surface of mud or sandflats exposed in estuaries or lagoons at low tide. Sandy beaches are the marine versions of deserts: the sediment is so well-sorted by wave action that there is little food for foraminifera and so few species live there. You can, however, often find the shells of dead forams concentrated in the troughs between ripple crests. You can collect samples from these modern environments and ask the students to analyze the foram assemblages and to reconstruct the environment of deposition.

If you live inland, you will need to collect samples of sediment or rock containing foraminifera. Although the fossil record of forams stretches back to the Cambrian, Cretaceous or Cenozoic material would be the best for you to work with because the farther back in geologic time one goes, the greater the differences between fossil and modern assemblages — thus it becomes more difficult to apply the concept of uniformitarianism.

ENGAGE:

Students may spend a few minutes researching foraminifera through web searches, library searches, academic journal articles and share with the class at least one interesting fact they have learned, such as how they move, how they eat, their evolution and history, what types are possibly located near the school depending on geographic location, etc. The additional slideshow could be shown with the background foraminifera information attached shared as well, which introduces paleoenvironments.

EXPLORE:

1) Choose the preparation technique most suited for the kind of sediment or rock that you have collected. Unconsolidated fine-grained rocks are the easiest to work with because little disaggregation is needed and the finer the sediment the fewer the sand grains for you to pick through in your search for foraminifera.

2) Once the sample is disaggregated, wash it over a fine mesh sieve (240 m) to remove all the silt and clay (you can use a 125 m mesh sieve but the smallest forams will be lost).

3) The material remaining on the sieve should be transferred to an evaporating dish and oven or air-dried. The dried sediment should then be poured into a cone-shaped pile on a piece of paper. Use a sharp knife to divide the sediment into halves, quarters, eighths, etc., until you have a small enough portion to pour onto a picking tray so that no sediment grains cover other grains.

4) You now need to pick a set number of forams from the tray. If time is short pick 50; otherwise pick 100 specimens. In scientific studies 300 specimens are usually picked. There is nothing magic in this number: it is an arbitrary stopping point above which additional rare species are encountered more

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and more infrequently. Make sure that you pick a representative suite of specimens. That is, do not pick only large specimens, or only small ones, or only pretty ones. The best way to do this is to mark your picking tray with a numbered grid. Then use a random numbers table to select a square. Pick all the specimens from that square and then select a second square. Continue this process until your target number is reached and the specimens have been transferred to a gum tragacanth-coated cardboard slide.

5) Sort the specimens into planktonic and benthic categories.

6) Count and calculate the proportion of planktonic specimens (percent planktonics).

7) Sort the benthic specimens into three groups based on their shell types. Count the number of specimens in each group and plot on a shell-type triangular diagram (Figure 4).

8) Sort the specimens in each group into morphological classes (morphospecies). This is easier said than done. The simplest way to approach this process is first to sort on the basis of chamber arrangement: single chambered or multichambered; straight or coiled; coiled on a single plane or coiled in a conical shape (Figure 5). Then sort the resulting groups on the basis of the shape and location of the aperture (Figures 6, 7) — the hole(s) on the last chamber from which the cytoplasm extrudes as fine strands (filopods) during life (Figure 1). Finally, sort the morphological groups on the basis of the surface sculpture (ornamentation) on the shells (Figure 8). This can be in the form of ribs, pits, spines, keels, striations, etc., often with several types of surface sculpture on one shell.

9) You can now count the number of morphological groups that you have recognized. This number is one measure of species diversity, the number of species (S) per standard-sized sample. Another measure of species diversity (which allows you to compare samples containing different numbers of specimens) is ‡. You can find the value of ‡ by plotting your sample on Figure 9.

EXPLAIN:

1) Plot your percent planktonics value on Figure 10. What water depth is indicated by this value?

2) Transfer your plot of the shell-type ratio onto Figure 3. What environments are indicated by the plot?

3) Transfer the plot that gave you the value for ‡ (Figure 9) onto Figure 11. What environments are indicated by the plot? (At this point, the taxonomic approach would be used to refine your paleoenvironmental interpretation. But this is beyond the scope of this exercise.)

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4) If you know the environmental provenance of your sample, compare the results of your analyses that might have caused inaccurate results.

5) If you do not know the environmental provenance of your sample, do you think your interpretation is reliable? Would you feel confident to recommend drilling a $1 million well based on your interpretation? (Remember, your job is on the line.) How could you improve the accuracy of your paleoenvironmental reconstructions?

ELABORATE and EVALUATE:

Students: Imagine that sea level rose by 100 m immediately following deposition of the sediment containing your foraminifera assemblage. Predict the expected characteristics of the subsequent foraminifera assemblage and explain how you came to your prediction.

USEFUL REFERENCES:

- Culver, S.J. 1987. Foraminifera, p. 169-212. *In* T.W. Broadhead, Fossil Prokaryotes and Protists. Notes for a Short Course, University of Tennessee, Department of Geological Sciences, Studies in Geology 18.
- Douglas, R.G. 1979. Benthic foraminiferal ecology and paleoecology, a review of concepts and methods, p. 21-53. *In* J.H. Lipps, W.H. Berger, M.A. Buzas, R.G. Douglas and C.A. Ross, Foraminiferal Ecology and Paleoecology, Society of Economic Paleontologists and Mineralogists, Short Course 6.
- Gibson, T., and M.A. Buzas. 1973. Species diversity: patterns in modern and Miocene foraminifera of the eastern margin of North America. Geological Society of America Bulletin, 84: 217-238.
- Gibson, T.G. 1989. Planktonic-benthonic foraminiferal ratios: modern patterns and Tertiary applications. Marine Micropalaeontology, 15: 29-52.
- Haynes, J. 1981. Foraminifera. John Wiley and Sons, New York, 433 p.
- Loeblich, A.R., Jr., and H. Tappan. 1964. Sarcodina chiefly Thecamoebians and Foraminifera. *In* R.C. Moore, ed., Treatise on Invertebrate Paleontology. University of Kansas Press and Geological Society of America, Lawrence, C (1-2), 900 p.
- Murray, J.W. 1974. Distribution and Ecology of Living Benthic Foraminiferids, Heinemann Educational Books, London, 274 p.
- The Paleontology Portal at http://www.paleoportal.org.
- Snyder, S.W. 1988. Micropalaeontology of Miocene sediments in the shallow subsurface of Onslow Bay, North Carolina continental shelf. Cushman Foundation for Foraminiferal Research, Special Publication, 25: 1-189.
- University of California Museum of Paleontology "Introduction to Foraminifera" at http://www.ucmp.berkeley.edu/foram/foramintro.html.

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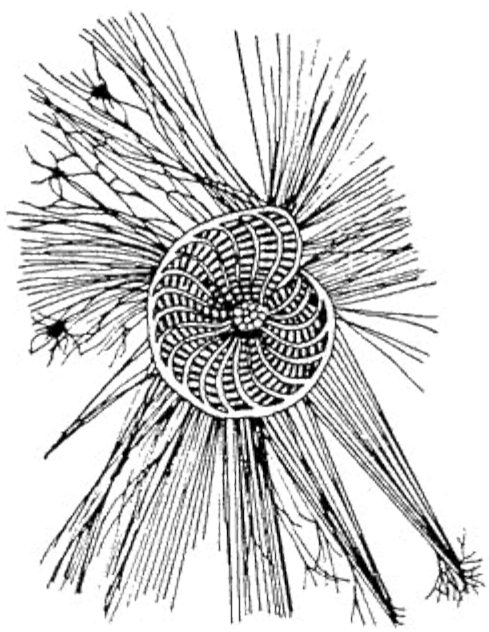
FORAMINIFERA BACKGROUND INFORMATION

Figure 1. The shallow marine benthic foraminifer *Elphidium*. Note the fine cytoplasmic streams (filopods, which have a locomotory and food capture function) extending from the spirally coiled chambered shell (from Culver, 1987, modified from Loeblich and Tappan, 1964).



Foraminifera (Figure 1) are protozoans (single-celled animals generally the size of a sand grain) with shells that are usually either composed of secreted calcium carbonate (calcareous forams) or of sediment particles collected by the organism from the surrounding environment (agglutinated forams). Foraminifera live in all marine environments from the deepest ocean floor to the intertidal salt marshes that are found behind barrier islands or around the margins of estuaries. Different kinds of foraminifera inhabit different environments — this is the simple fact that allows paleontologists to use forams as paleoenvironmental indicators. For example, some species (planktonic) float in the upper layers of the ocean's waters, whereas other species (benthic) live on the sea bed or just beneath the sediment surface.

If a paleontologist studying ancient sediments of unknown origin finds that they contain an assemblage of forams that is composed mainly of planktonic species, then he or she will make the interpretation (based on the concept that the present is the key to the past) that the sediment was deposited in an open ocean well away from land. Paleoenvironmental interpretations are made possible by recognizing several kinds of patterns in foraminiferal assemblages.

The following four approaches to paleoenvironmental interpretation have been used for several decades by oil company paleontologists. When an oil well is drilled, rock fragments are brought to the surface and among these fragments are often hundreds of specimens of foraminifera. Paleoenvironmental interpretations of assemblages from increasing depths in the well represent interpretations of older and older rocks. These changes in environment through time can be recognized in adjacent wells (via the process of correlation) and so a three-dimensional picture can be constructed of the various layers of rocks and paleoenvironments penetrated by the wells. This then allows the paleontologist to predict where oil or gas is most likely to be encountered. A further well can then be drilled to test that prediction (usually with negative results!).

- **Planktonics** — The proportion of planktonic specimens increases from 0% in shallow marine environments to more than 90% in deep marine environments. Modern planktonic forams generally have globular chambers, often with spines. Some fossil planktonics, however, particularly in the Cretaceous, had a more flattened shape, sometimes with heavy keels running around the shell.

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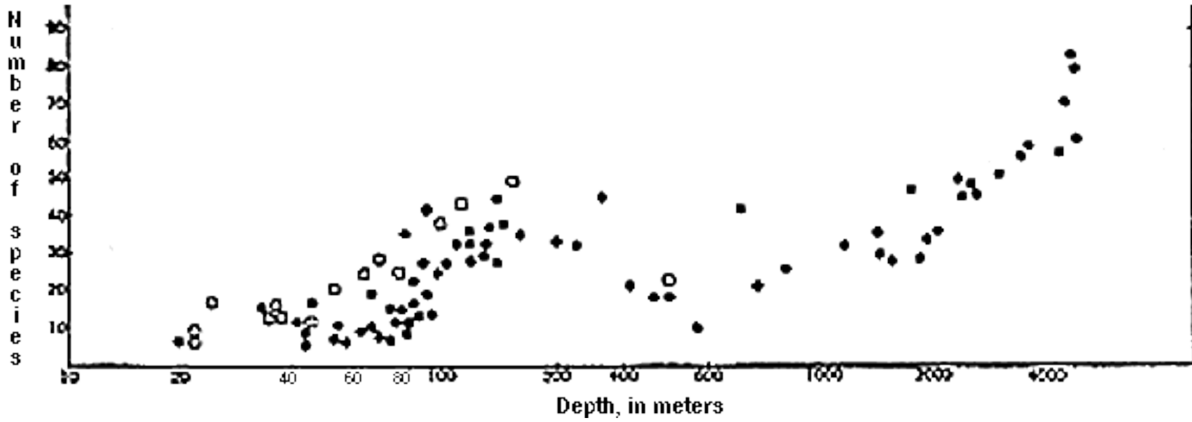
- **Species diversity** — This is simply the number of benthic species in a standard-sized sample. The general pattern recognizable in marine environments today is of increasing diversity away from shore (i.e., with increasing water depth) (Figure 2).

Figure 2. Graph of number of species versus depth for the modern Atlantic continental margin of North America (modified from Gibson and Buzas, 1973).



- **Shell-type ratios** — Benthic foraminifera can be agglutinated or calcareous. Calcareous species are divided into those whose shells have a clear or translucent appearance (hyaline) with tiny perforations (pores) and those whose shells are white and opaque and have no perforations (porcelaneous). The proportions of these three types of walls (agglutinated, hyaline, porcelaneous) in a sample of foraminifera is also characteristic of particular environments in modern seas and oceans (Figure 3). For example, assemblages characterized by high proportions of agglutinated taxa are found in intertidal marshes. Assemblages dominated by porcelaneous species characterize shallow tropical environments.

- **Taxonomic** — This is the methodology that results in the most detailed interpretations. It involves the inference of paleoenvironments based on the known environmental preferences of modern species or genera. Because it involves the exact identification of species, this approach is the most challenging, even for experts who have studied foraminifera for many years.

Figure 3. Shell-type ratio triangular diagram showing fields defined by benthic foraminiferal assemblages from known environments (modified from Murray, 1974).

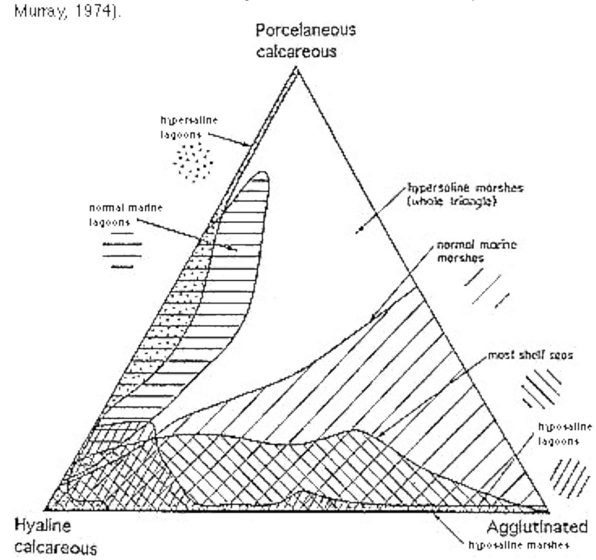


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Figure 4. Shell-type ratio triangular diagram (modified from Murray, 1974).

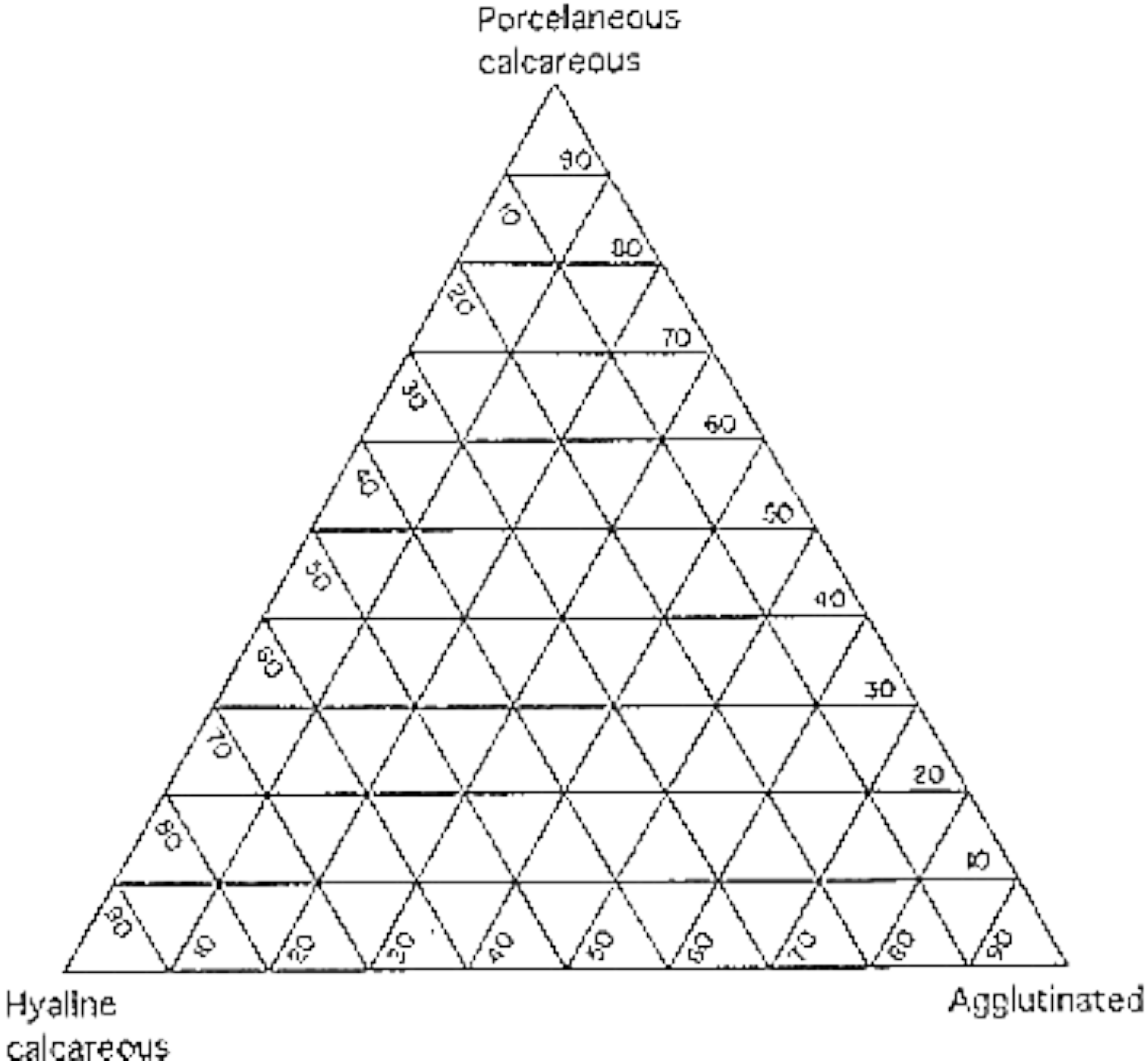

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Figure 5. Chamber arrangements in foraminifera (from Culver, 1987, modified from Loeblich and Tappan, 1964, and Haynes, 1981). The streptospiral specimen is a planktonic foram.

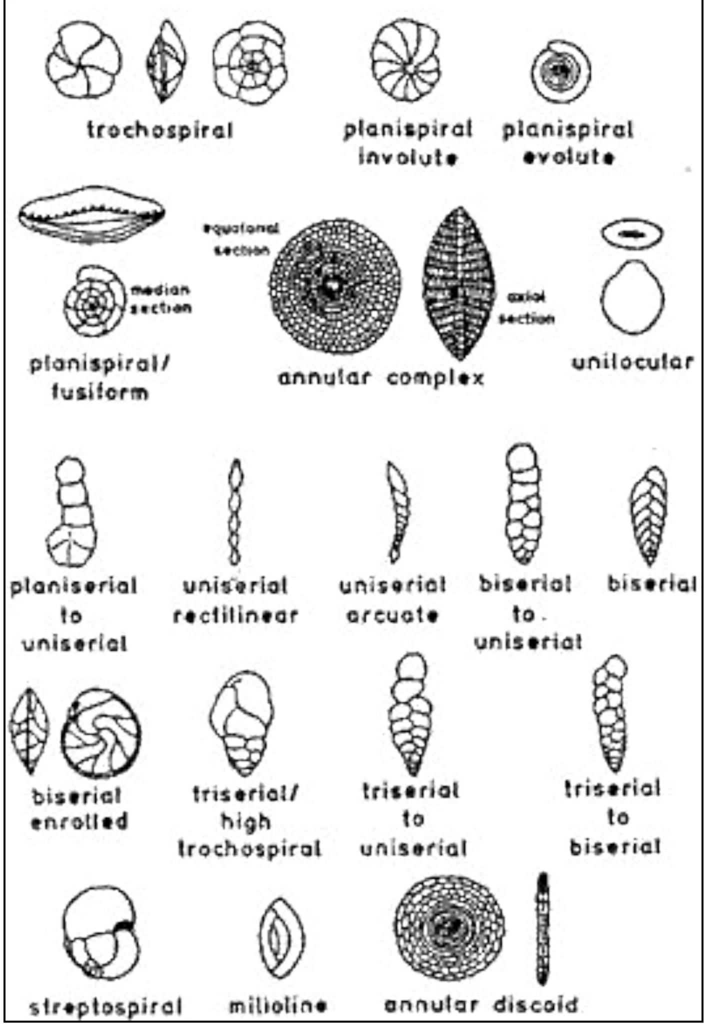

Figure 6. Shape of aperture in foraminifera (from Culver, 1987, modified from Loeblich and Tappan, 1964).

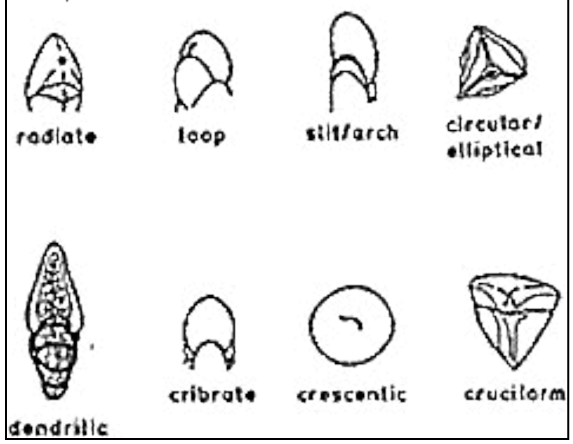

Figure 7. Position of aperture in foraminifera (from Culver, 1987, modified from Loeblich and Tappan, 1964). The specimen with an umbilical aperture is planktonic.

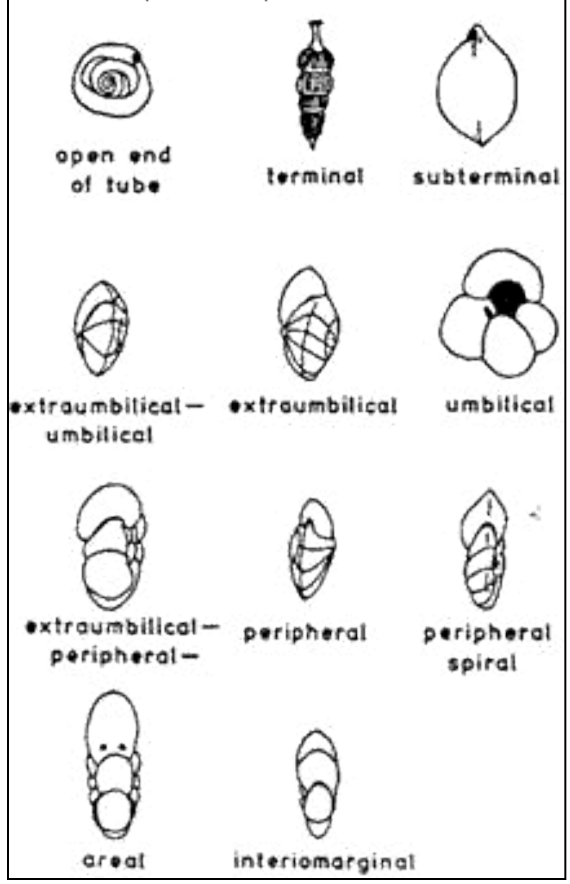

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Figure 8. Surface sculpture in foraminifera (from Culver, 1987, modified from Loeblich and Tappan, 1964). The finely spinose specimen is a planktonic foram.

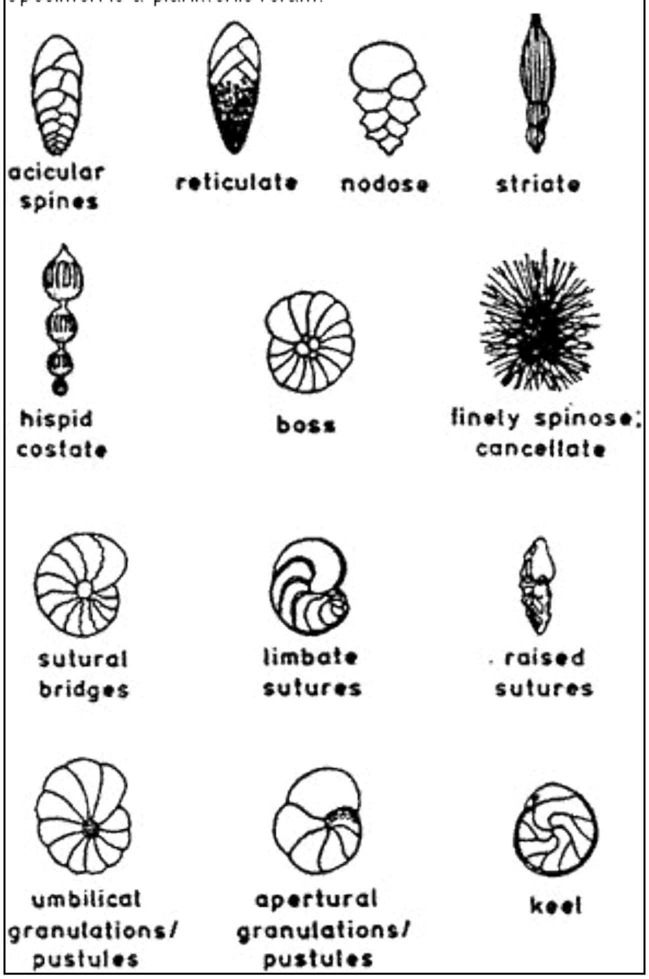

Figure 9. Species diversity (‡) diagram (modified from Murray, 1974).

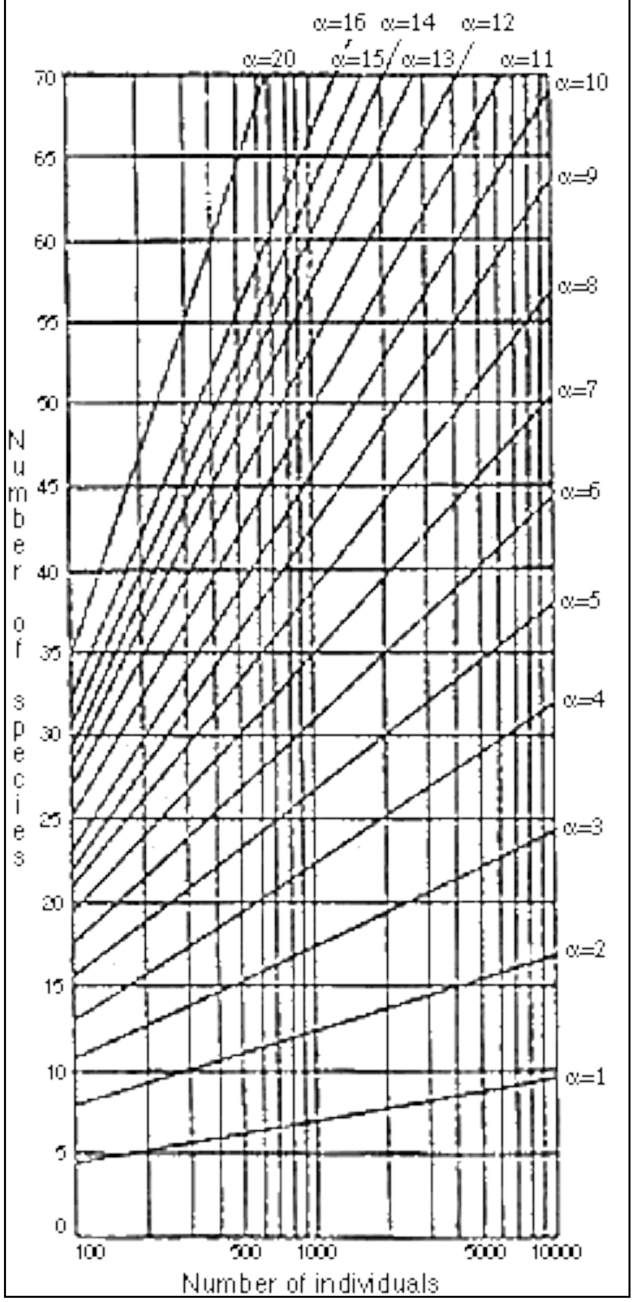

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Figure 10. Values of percent planktonics for many samples from the modern North American Atlantic continental margin. Dashed line indicates minimum depth at which any percentage is found (modified from Gibson, 1989).

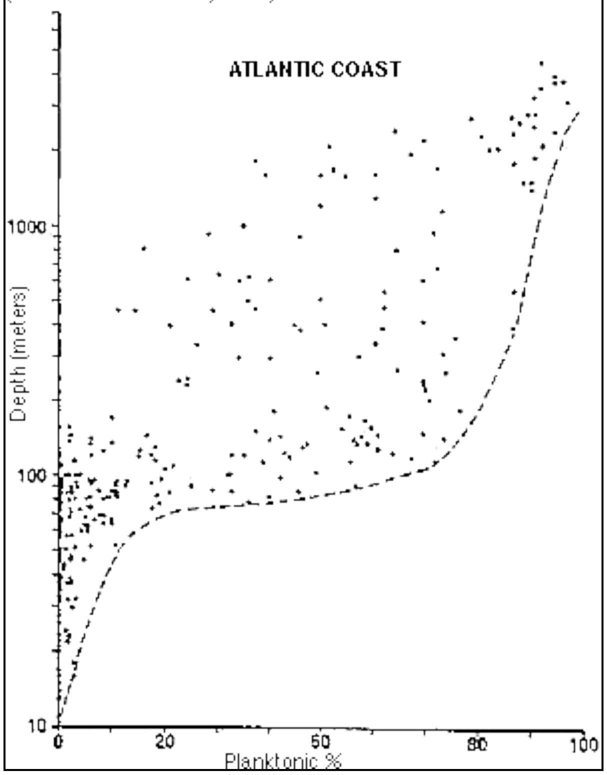

Figure 11 . Species diversity (‡) diagram showing fields defined by ‡ values for benthic foraminiferal assemblages from known environments (modified from Murray, 1974).