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Some Perspective on Testate Rhizopods

TESTATE RHIZOPODS AS RELIABLE, COST-EFFECTIVE INDICATORS

Many types of proxy indices, both physical/chemical and biological, have been used to estimate changes in various environmental parameters that are then related to the problem under consideration. The focus of this book is on environmental proxies derived from two "groups" of testate rhizopods: foraminifera and thecamoebians (Fig. 1.1). These two groups have a great advantage over most other biological indicators because they leave a microfossil record that permits the reconstruction of the environmental history of a site in the absence of original (i.e., real-time) physiochemical baseline data. The utility of foraminifera and thecamoebians as environmental sentinels also derives from a comprehensive field data base that has been compiled for these organisms over a wide range of marine and freshwater settings and not necessarily from an in-depth understanding of their physiological limitations (e.g., Murray, 1991). By their nature, foraminifera and thecamoebians occur in large numbers; this means that small samples (<10 cc) collected with

Phylum SARCODARIA		
Superclass RHIZOPODA		
Class LOBOSA	Class FILOSA	Class Granuloreticulosa
Order THECOLOBOSA (= Arcellinida)	Order TESTACEALOBOSA (= Gromida)	Order FORAMINIFERIDA (= Foraminifera)
THECAMOEBIANS	? ALLOGROMIIDS ?	? FORAMINIFERA ?

Figure 1.1. Taxonomic position of foraminifera and thecamoebians. Notice the "fuzzy" distinction between all the groups; most of these differences are based on soft parts, such as pseudopodia, which are typically never observed in the fossil record. (This diagram is a composite from several texts, including Loeblich and Tappan, 1964, and Medioli and Scott, 1983.)

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small-diameter coring devices usually contain statistically significant populations. Many biological environmental indicators commonly used in monitoring and impact-assessment studies are organisms that are logistically difficult to collect and expensive to analyze (e.g., molluscs, polychaetes, bacteria, etc.). While these might be more definitive proxies in some situations, they often require large samples (several liters of sediment) or a typically lengthy preparation to retrieve a statistically significant number of specimens/data for an environmental determination. Moreover, the storage of reference samples of these larger organisms can have negative implications for low-budget projects. A critical aspect for the reconstruction of paleoenvironments is that many macro-invertebrates (e.g., polychaetes) leave no easily discernible fossil trace, so that long-term monitoring activities are required to collect a serial baseline data set. Similar information often can be deduced from the fossil foraminiferal assemblages collected in sediment cores. In the case of testate rhizopods, literally hundreds of samples can be collected in a day, and all can be processed within a week. Detailed examination of assemblages and specimen counting takes time, of course, but a skilled micropaleontologist can examine and count as many as ten samples per day. Environmental variation at a particular site is evaluated through examination of the microfossil assemblages contained in successively older core subsamples.

Contrasting these laboratory tasks with those required for macro-invertebrates, other microfossil groups, or even bacteria, shows that foraminifera and thecamoebians can be very attractive from a cost/benefit perspective. Conversely, for quantitative historical studies, macro-invertebrates are usually impractical.

Chemical studies (i.e., isotopes, nutrients, organic matter, trace metals, sulfides, etc.) can sometimes provide chronological and process-related information (e.g., ^{210}Pb; Smith and Schafer, 1987), and can be compared with the microfossil assemblage "signal" to test for environmental impacts (e.g., Schafer et al., 1991). Chemical tracers may not be reliable when used as independent paleoenvironmental proxies because diagenetic processes can change the "fingerprint" of chemical fluxes in subsurface deposits to a much greater degree and more rapidly than would be predicted for the fossil record (e.g., Choi and Bartha, 1994). Many studies have concluded that, whenever practical, chemical and biological parameters should be used together, since they offer greater potential for linking cause-and-effect relationships (e.g., McGee et al., 1995; Latimer et al., 1997).

UTILITY OF TESTATE RHIZOPODS AS ENVIRONMENTAL INDICATORS

Foraminifera and thecamoebians are one-celled animals that are closely related to each other. They form a shell (test) which, when the animal dies, remains in the sediment as a fossil. Foraminifera occupy every marine habitat from the highest high-water level to the some of the deepest parts of the ocean, and they occur in relatively high abundances (often more than 1,000 specimens/10 cc). Thecamoebians have a similar widespread distribution in freshwater environments. The combination of these two groups of similar organisms permits characterization and monitoring of all aquatic environments typically found in marginal marine settings.

There are many reasons that a particular marine organism may be useful as an environmental indicator. Some relate to pressure for worldwide standardization (e.g., the blue mussel, *Mytilus*), while others focus on sensitivity to low levels of certain kinds of anthropogenic contaminants (e.g., bacteria; McGee et al., 1995; Bhupathiraju et al., 1999). Still others have special application because of their ability to tolerate extreme conditions and/or to react quickly to environmental change (e.g., polychaete worms; Pocklington et al., 1994). Because of their comparatively high species diversity and widespread distribution, the testate rhizopods encompass many of these traits. Perhaps more importantly, these organisms are of unique value because of their easily accessible fossil record, which has become a fundamental tool of natural scientists for reconstructing the characteristics and timing of historical environmental variation in a broad spectrum of marine settings.

Foraminifera and thecamoebians are good ecosystem monitors because they are abundant, usually occur as relatively diverse populations, are durable as fossils, and are easy to collect and separate from sediment samples. Although most of them fall into micro- and meio-fauna size ranges (usually between 63 and 500 mm), they can typically be readily observed under a low-power (10–40×) stereomicroscope. No other fossilizable groups of aquatic organisms are so well documented in terms of their environmental preferences for the broad spectrum of locally distinctive environmental conditions found in the coastal zone. Hence, once the characteristics of modern living assemblages have been defined for particular environments, it is usually possible to go back in time using their fossil "signal" to reconstruct paleoenviron-

ments with a high degree of confidence, or to monitor and manage contemporary environmental variation associated with remediation or change of use. Although the model transfer approach may be enhanced by an understanding of the seasonal variation of living populations (e.g., Jorissen and Wittling, 1999; Van der Zwaan et al., 1999), it is not essential since living specimens ultimately accumulate into a total (fossil) population that intergrates small spatial and temporal variations which reflect relatively steady-state conditions (Scott and Medioli, 1980a).

SOME LIFESTYLE ASPECTS OF TESTATE RHIZOPODS

Habitat Preferences

Benthic foraminifera and thecamoebians occupy virtually every benthic aquatic habitat on earth, while planktic foraminifera are usually restricted to open ocean settings. Consequently, in open marine water settings, it is possible to simultaneously study both pelagic and benthic environmental issues. This unique feature of the foraminifera is made possible by the fact that planktic and benthic foraminifera accumulate together as fossils in seafloor sediments in association with living specimens (e.g., Scott et al., 1984). As with most organisms, the diversity of foraminiferal populations usually increases as the environment attains greater stability (i.e., as it becomes more oceanic and warmer). Highest diversities occur in reef environments, which can be considered the marine equivalent of tropical rain forests (Boltovskoy and Wright, 1976; Haynes, 1981; Murray, 1991).

Foraminifera and Thecamoebian Tests

■ Foraminifera

The test – or external skeleton – of foraminifera is composed of several types of material (Loeblich and Tappan, 1964). This characteristic forms the basis for defining the higher taxonomic levels of the group (Fig. 1.2). Subdividing these higher groups can be done using external morphologies, a summary of which is presented in Figure 1.3.

The type of shell material, in general, also determines where various species or their fossil remains can survive. For forms that secrete a $CaCO_3$ test (i.e., "calcareous" forms), this depend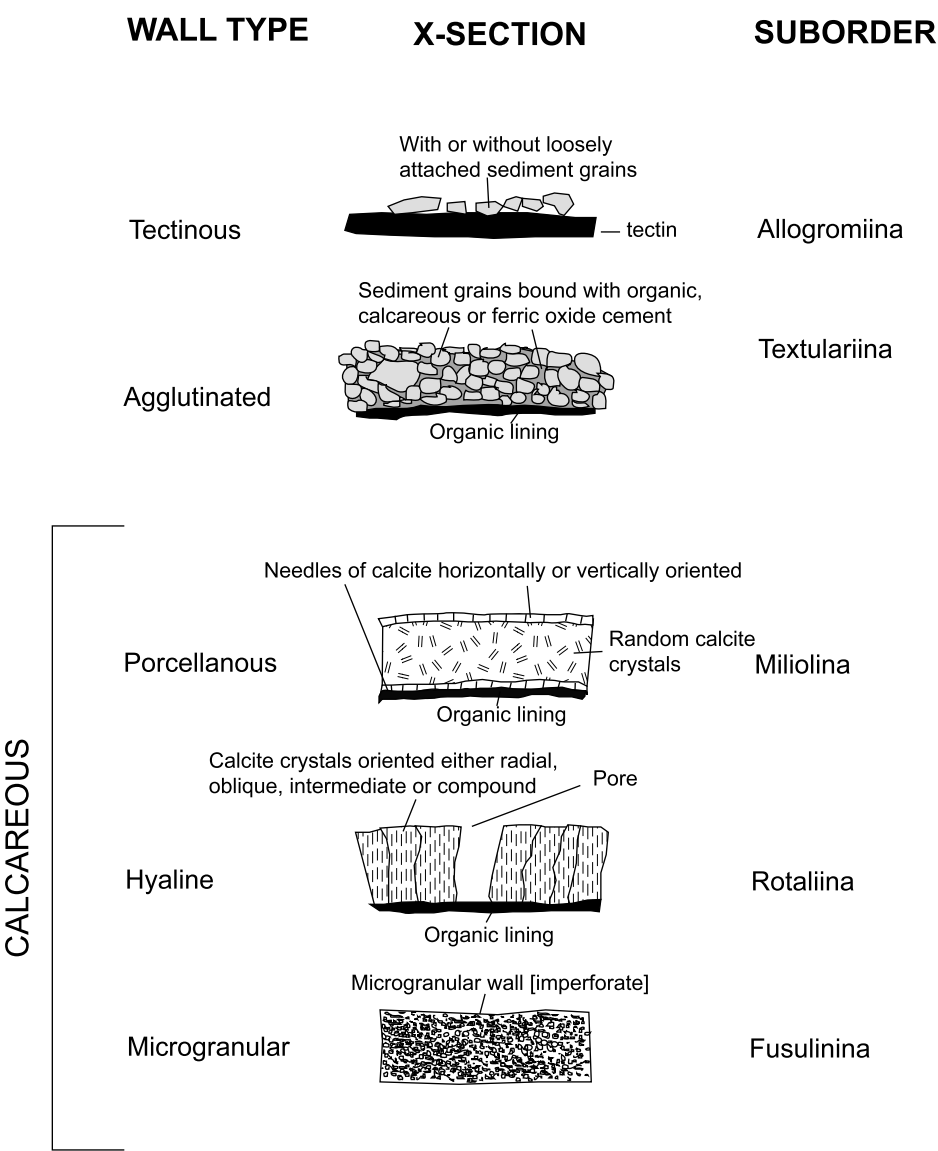s on whether or not the environment is conducive to carbonate preservation (e.g., McCrone and Schafer, 1966; Greiner, 1970). Foraminifera that form their tests by cementing detrital material (i.e., "agglutinated" or "arenaceous" forms) are considered to be the most primitive members of the group. Agglutinated foraminifera, however, can live in sediments where no carbonate is available (i.e., in areas where lowered salinities or colder water make the precipitation of carbonate difficult or impossible). Generally, as salinities and temperatures rise, agglutinated species are replaced by $CaCO_3$ secreting forms (Greiner, 1970), unless the pH is lowered by either low oxygen or high organic matter concentrations (or both in combination). These harsh conditions are often present in polluted coastal environments (e.g., Schafer, 1973; Schafer et al., 1975; Vilks et al., 1975; Sen Gupta et al., 1996; Bernhard et al., 1997) and some, such as high organic matter levels, may influence the bioavailability of contaminants to certain species (e.g., Kautsky, 1998).

■ Thecamoebians

Like foraminifera, thecamoebians can either secrete their test (autogenous test) or build it by agglutinating foreign particles (xenogenous test). A few taxa (Hyalosphenidae) can build either type, depending on circumstances and availability of foreign material. Autogenous tests are either solid and made of silica or complex organic matter, or are built of plates secreted by the organism (idiosomes). Purely autogenous tests are seldom found fossilized. The vast majority of fossilizable thecamoebians possess a xenogenous test built of foreign particles cemented together (xenosomes). The physical nature of xenosomes is exceedingly variable, and their appearance seems to be linked to the nature of local of substrate material (Medioli and Scott, 1983; Medioli et al., 1987). Thecamoebians occupy every niche in freshwater benthic environments, as well as any sufficiently moist niche such as tree bark, wet moss, and so forth. When encysted, they can travel long distances and colonize any available niche, as demonstrated, for example, by their presence in atmospheric dust collected on four continents (Ehrenberg, 1872).

Sensitivity to Environmental Change

The comparatively high species diversity of benthic foraminifera and thecamoebian populations renders local assemblages responsive to a broad range of environmental change. As Scott et al. (1997) and Schafer et al.

WALL TYPE   X-SECTION   SUBORDER

With or without loosely
attached sediment grains

Tectinous   — tectin   Allogromiina

Sediment grains bound with organic,
calcareous or ferric oxide cement

Textulariina

Agglutinated

Organic lining

CALCAREOUS

Needles of calcite horizontally or vertically oriented

Porcellanous   Random calcite crystals   Miliolina

Organic lining

Calcite crystals oriented either radial,
oblique, intermediate or compound   Pore

Hyaline   Rotaliina

Organic lining

Microgranular wall [imperforate]

Microgranular   Fusulinina

(1975) illustrated, foraminifera are often among the last organisms to disappear completely at sites that are being heavily impacted by industrial contamination. They can also proliferate in transition zones that do not appear to be utilized efficiently by other kinds of marine organisms (e.g., Schafer, 1973). When observed in a fossil setting, testate rhizopod remains often provide the only proxy information on the spatio-temporal nature of transitional environments (e.g., Scott et al., 1977, 1980). This aspect of the group is most important when studying an impacted site "after the fact," and especially in those circumstances in which original baseline data are not available. In the following chapters we illustrate how foraminifera and thecamoebian populations respond to a variety of environmental changes that may be either natural or anthropogenically induced.

Figure 1.2. Different wall types of the four major groups of foraminifera and thecamoebians (after Culver, 1993).

Reproduction Mode in Relation to Environment

■ Foraminifera

There is actually very little known about this topic. Of the 10,000 known living foraminiferal species, only a handful of shallow-water species have actually been observed reproducing in the laboratory (Loeblich and Tappan, 1964), and the life cycle of foraminifera is known for only about fifty species (Lee and Anderson, 1991). It is believed generally that all foraminifera are capable of an alternation of asexual and sexual reproductive modes. In sexual reproduction, millions of swarmers (zygotes) leave the parent cell and mate, producing, presumably, a very large number of

Figure 1.3. Basic patterns of chamber arrangement in foraminifera. Intermediate or mixed arrangements are very common (after Culver, 1993).
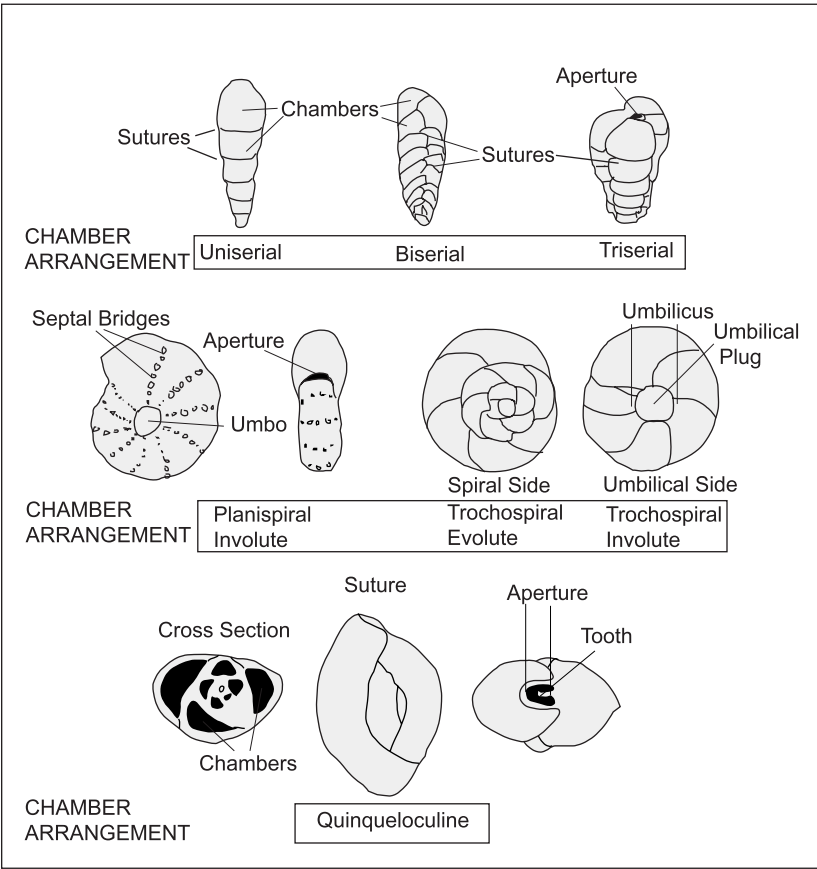
new individuals with a small first chamber and large test (microspheric form). Asexual reproduction takes place by multiple fission with the production of, at most, a few hundred new individuals with a large first chamber and small test (megalospheric form). This alternation, however, has been observed directly in only a very small number of species (Loeblich and Tappan, 1964). In most laboratory cultures – the majority of which consisted of small shallow-water forms – only asexual reproduction has been recorded. If the alternation occurred regularly, one would expect that, in an association of empty tests, the microspheric morpho-types should outnumber the megalospheric variety by several orders of magnitude. Careful observations have shown, however, that often the asexual morphotype outnumbers the sexual one in a ratio of between 1:30 and 1:34 (Boltovskoy and Wright, 1976, p. 28). This suggests a very significant dominance of the frequency of the asexual mode in certain environmental settings. Haq and Boersma (1978), in fact, observe that sexuality is very likely a secondary reproductive mechanism, while asexual reproduction is the basic and the more frequent reproductive mode of the majority of foraminiferal species.

There is virtually no solid evidence of why alternation of generations takes place or of how often it occurs. The most rapid reproduction mode is sexual, and it occurs to take advantage of favorable conditions, or it is triggered in response to the development of extremely harsh conditions to help the organism disseminate out of a particular environmental setting (e.g., Boltovskoy and Wright, 1976). In the latter case, the zygotes, being more mobile, can be passively transported out of unfavorable or stressed areas by tidal currents. Both of these ideas are hypothetical since it is virtually impossible to observe this process in a natural setting. Also, the supposedly distinctive features of micro- and megalospheric tests have repeatedly been demonstrated to occur only in some species (Lister, 1895; Schaudinn, 1895; Myers, 1935, 1942; Grell, 1957, 1958a,b; Boltovskoy and Wright, 1976). In summary, very little is known about foraminiferal reproductive strategies in relation to environmental dynamics (e.g., Bradshaw, 1961; Buzas, 1965). However, this situation does not preclude the utilization of distribution data to define environmental change in both a spatial and a temporal context (e.g., Schafer et al., 1975; Vilks et al., 1975). Bradshaw

(1961) showed that the reproductive thresholds, at least for asexual reproduction, are lower than survival limits, so that species will tend to reproduce during the most favorable intervals in otherwise harsh environments and can grow to adult size in less than one month (e.g., Gustafsson and Nordberg, 1999).

■ Thecamoebians

There is even less known about thecamoebian reproduction. In laboratory cultures, binary fission appeared to be the only form of reproduction observed for thecamoebians (Loeblich and Tappan, 1964; Ogden and Hedley, 1980; Medioli et al., 1987). In a virtually forgotten paper by Cattaneo (1878) and in studies by Valkanov (1962a,b, 1966), however, rather convincing cases of sexual reproduction have been documented. Undoubtedly the sexual mode, if it occurs at all, is very rare and seems to have only one function, that of bringing the genotype back to mediocrity.

The Species Identification Problem

Although systematically ignored, the normal biological concept of species, based on the fertile interbreeding of individuals of the same species, does not apply to asexual organisms. Some implications of how this approach has impacted foraminiferal taxonomy are outlined below.

Boltovskoy (1965) discussed a study by Howe (1959) showing that, on average, between 1949 and 1955 two new foraminiferal names were appearing every day. A correspondence between Esteban Boltovskoy and Brooks Ellis revealed that in 1961 the literature contained the names of approximately 28,000 specific and generic taxa. In the specific case of testate rhizopods, the asexually produced individuals of the same "species," as stated by Cushman (1955), are "progressive," while sexually produced populations of the same species are "conservative." In other words, asexually produced populations should be expected to be morphologically highly variable, while sexually produced populations of the same species should be expected to be relatively stable in regard to their test structure. This may explain the presence of well-known, highly variable species of foraminifera and thecamoebians such as *Elphidium excavatum,* and *Ammonia beccarii* (foraminifera), or *Centropyxis* spp., and *Difflugia* spp. (thecamoebians), and so forth, which may not reproduce sexually at all or do so only very rarely. Most highly variable species seem to inhabit relatively dynamic nearshore environments, which is the main area of interest of this book. In these coastal settings they appear to be perfectly adapted to face all of the ecological challenges that the environment continually confronts them with. This creates a problem of species identification that has haunted micropaleontologists for almost a century. Most of the species of testate rhizopods included in this book are characterized by highly variable morphologies. Like human beings who, despite their clearly sexual reproduction, come in many sizes, shapes and colors, testate rhizopods can be grouped together only in the context of a significant sample of a population. In other words, it is almost impossible to reliably identify one single individual in isolation, whereas the identification becomes progressively easier and more accurate as the number of specimens observed increases.
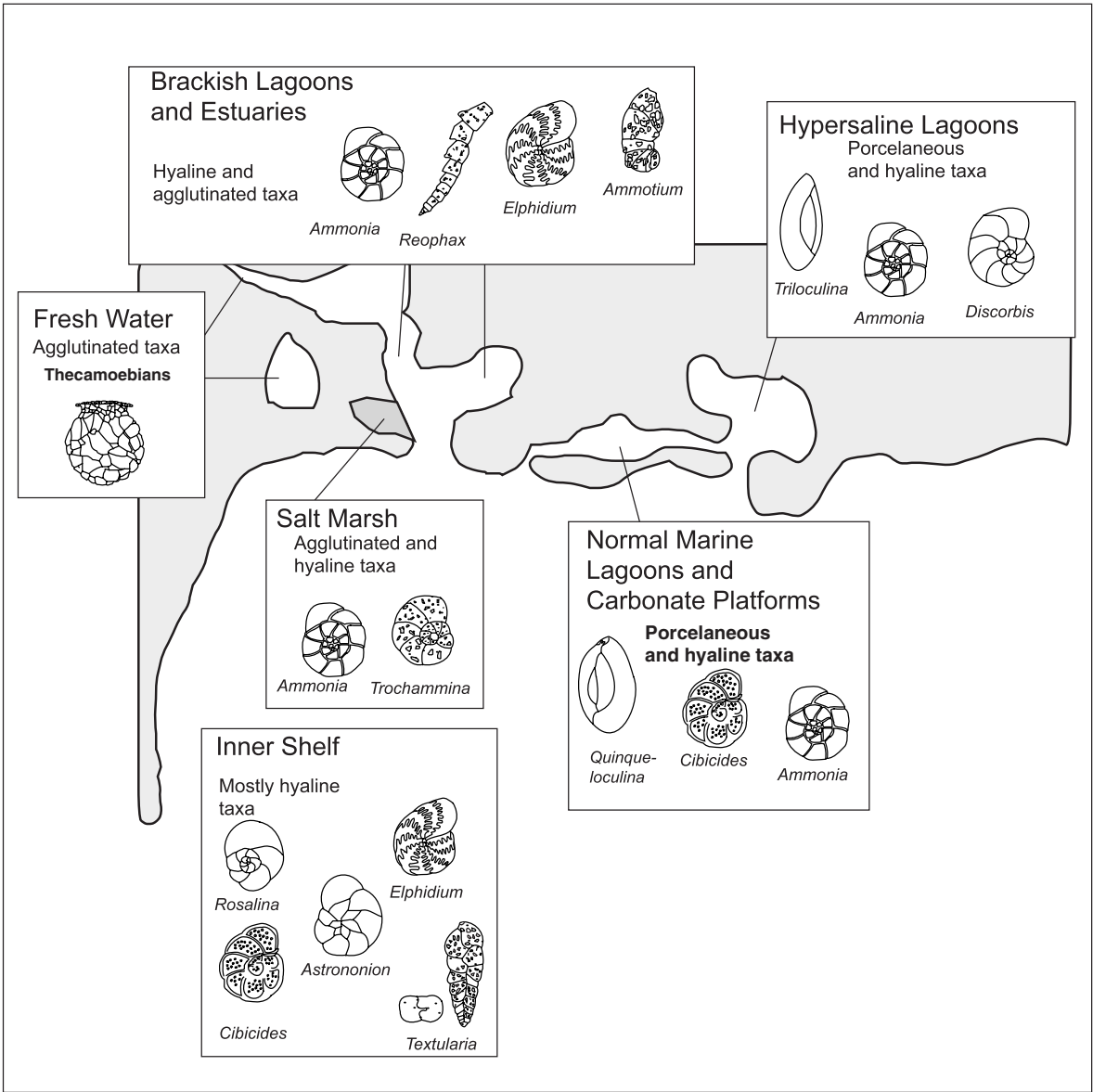
However significant these problems may be, they are an academic matter. This book was written for the non-specialist, and the authors have tried to predigest all of these problems, subjectively circumscribing the "species" discussed in a relatively few manageable and comprehensive units that are deemed to be meaningful for their pragmatic use in monitoring coastal environments.

Trophic Position of Foraminifera and Thecamoebians

Foraminifera are heterotrophic, but they are typically only one step up from primary producers. In addition, many reef forms have symbionts and can function between autotrophic and heterotrophic states (e.g., Hallock, 1981). Some planktic taxa as well as benthic reef-dwelling species have been observed eating copepods and shrimp, forms that are much higher up on the food chain than those generally associated with microorganisms (Rhumbler, 1911; Bé, 1977; Medioli, pers. observ.). For the majority of benthic foraminifera species, however, there is little information on what they really ingest. This situation reflects the fact that the basic biology of these organisms has received relatively little attention compared to investigations on their taxonomy, and on their chronological as well as areal distributions (Lee and Anderson, 1991). In most instances where foraminifera have been cultured successfully, they have been fed with various types of diatoms or ciliates (e.g., Bradshaw, 1957, 1961). It is not known, however, if the cultured species actually feed naturally on diatoms or not. In the case of salt marsh foraminifera, it appears likely that these rather primitive species, like many thecamoebians, may feed on bacteria (e.g., Kota et al., 1999), but as yet there is no hard evidence to support this idea.

There are some research results available on the biology of thecamoebians (Jennings, 1916, 1929; Ogden and

Figure 1.4. A generalized marginal marine nearshore environment showing some typical foraminiferal and thecamoebian species for each environment (after Brasier, 1980).

Hedley, 1980, and others), and several detailed life cycle histories have been worked out for this group. One species has been shown to infest floating algal mats of *Spirogyra* during the summer, forming autogenous tests. From fall to spring, a period during which *Spirogyra* does not float, the species becomes benthic and produces agglutinated tests (Schönborn 1962; Medioli et al., 1987). Thecamoebians are known to have symbionts (zoochorelles), and they are known to eat mostly diatoms and bacteria, although others have been observed to be cannibalistic (Medioli and Scott, 1983). Only about twenty to twenty-five species of thecamoebians have been reported as fossils (Medioli et al., 1990a,b), some as far back as the Carboniferous (i.e., 400 million years ago, Thibaudeau, 1993; Wightman et al., 1994).

BASIC ECOLOGIC DISTRIBUTIONS

The following is an idealized basic distribution model for marginal marine settings, including continental shelves (foraminifera) and freshwater environments (thecamoebians). Being idealized, it would be expected to change with latitude and water-mass characteristics. The examples shown are meant to be used as a framework for comparing environments from one locality to another (Fig 1.4).

Lakes and Other Freshwater Environments

Forest–lake–bog–upper tidal environments can be differentiated using thecamoebian assemblages. Generally, forms that secrete their own test dominate forest and other environments where sediment supply is low. Forms that use xenogenous material, like silt grains, tend to dominate in lake environments where sediment supply is high; the most common forms in this niche are various species of *Difflugia.* Species diversity decreases markedly with increased marine influence such that close to the upper limit of tidal activity, only *Centropyxis* spp. are found. This relationship permits the delineation of the important and very subtle marine/freshwater transition in intertidal situations.

Marshes

Marshes represent the most extreme of all marine environments, with large variations in temperature, salinity, and pH (see Phleger and Bradshaw, 1966, for a twenty-four-hour record of these variations). Very few species of marine foraminifera thrive in this environment, and their distribution seems to be controlled mainly by physico-chemical phenomena tied to exposure time (i.e., elevation above mean sea level or tidal level). For example, in adjacent intertidal and mud flats environments, oxygen and salinity often explain a significant proportion of the variance observed in macrobenthic community data (e.g., Gonzales-Oreja and Saiz-Salinas, 1998). The same marsh foraminifera species occur worldwide at all latitudes and salinity regimes, especially in the upper part of the marsh. Because of the exposure/time relationship, marsh foraminifera are distributed almost universally in vertical zones that can be used as accurate sea-level indicators, as shown in the applications presented in the following chapters. The species that occupy these high marsh areas are almost exclusively agglutinated, and the few that are not agglutinated do not fossilize in the highly organic and acidic marsh sediments.

Lagoons and Estuaries

Although lagoons and estuaries can be very different environments in terms of foraminiferal content and watermass characteristics, they are grouped together here because they are often perceived as being part of the same set of coastal settings. Lagoons are generally considered to have little or no freshwater input, and typically feature normal marine or hypersaline water. As discussed earlier, higher salinities usually favor calcareous foraminiferal species and a higher population diversity. Lagoonal-type environments are most common along warm, arid coasts such as those in the southwestern United States, the Persian Gulf, the Mediterranean, the west coast of South America, and the Australian coastline. In the tropics, special reef-type environments develop that have the highest diversity of foraminiferal faunae (e.g., Javaux, 1999). In contrast, estuaries usually contain a restricted fauna, especially in their upper reaches where salinities are lowest. In this environment, agglutinated species often dominate; calcareous species can tolerate lower salinities in warmer water. Consequently, estuarine foraminiferal associations have a strong latitudinal gradient, with agglutinated forms dominating the assemblages seen in higher latitudes (Schafer and Cole, 1986), and calcareous forms dominating in lower latitudes (e.g., Sen Gupta and Schafer, 1973).

Shelf Areas

Regional differences are perhaps greatest in marine shelf environments. Marine shelf settings span latitudinal gradients with varying degrees of mixing between coastal and oceanic waters (Fig. 1.4). Although shelf areas often are thought of as open marine, many typically "open-ocean" organisms find shelf environments too unstable in terms of temperature and salinity. Nevertheless, shelf species of benthic foraminifera attain high diversities in these environments and can be used to reconstruct the paleo-water mass distribution. As activities on shelf areas, such as petroleum exploration and bottom trawling, are expanded, this environment will come under increasing anthropogenic stress (Auster et al., 1996; Conservation Law Foundation, 1998). As a general rule, a very strong database that is well documented for the modern environments under investigation is required to allow accurate paleodeterminations and reconstructions of former environments. Microfossil assemblages can be used as proxies to reconstruct paleo-environmental conditions, but if modern faunal information is not available, past conditions cannot be conclusively or confidently defined. Unfortunately, contemporary foraminiferal data are not available in many local areas; they must be collected before fossil assemblage data can be used as a proxy of changing local marine conditions.

SPATIAL VARIABILITY AND PATTERNS

Variability of foraminiferal populations at and between stations has been addressed relatively extensively for most coastal environments (e.g., Schafer, 1968, 1971,

1976; Schafer and Mudie, 1980; Scott and Medioli, 1980a). Much less is known about the synoptic spatial distribution of freshwater thecamoebians. In general, the more stressed an environment becomes, the lower will be the variability within indigenous populations. This characteristic is usually a function of the dominance of several "opportunist" species (e.g., Schafer et al., 1991). As conditions become environmentally stable, biological relationships (i.e., predator–prey, competition, clumping) begin to override physical parameter controls, and local spatial variability of species abundances usually becomes more complex.

Between environments, especially nearshore environments, local variability usually does not exceed the differences between distinct environments (e.g., Scott and Medioli, 1980a). This characteristic is crucial to the utilization of foraminifera for environmental analysis because it facilitates the recognition of distinct zones in both contemporary and ancient sediments that should stand out in relation to spatial distribution "background noise." In a three-year study, Scott and Medioli (1980a) showed that total assemblage (i.e., living+dead specimen counts) differences between high and low marsh zones was always high enough to distinguish those zones regardless of seasonal variations in the living population. Conversely, living populations were often extremely variable compared to total populations, often because of seasonally-modulated variation in reproduction of individual species (e.g., Buzas, 1965; Schafer, 1971) and as a consequence of rapid mixing (bioturbation and turbulent mixing) of the surficial sediment layer. Scott and Medioli (1980a) pointed out that the mixing process is quite fortuitous since total populations are the closest analog to the resultant fossil populations which are what is used in most applications. The density of the total population per unit volume of surficial sediment is essentially a function of bioturbation and sedimentation rate (Loubere, 1989).

One mechanism that contributes substantially to apparent temporal and spatial variability of total population abundance and species diversity is the suite of diagenetic effects that operate on foraminifera and thecamoebian tests following their burial in sediments. The following chapters introduce some of the sampling and analytical strategies that have been used to try and "work around" the difficulties caused by bioturbation and various other diagenetic processes that destroy proxy environmental information imprinted in the marine fossil record.

SUMMARY OF KEY POINTS

- Testate rhizopods occur in large numbers/unit volume and are preserved as fossil assemblages, unlike most other larger invertebrates.
- Compared to other macroinvertebrates, microfossils are cost-effective in both collection and analyzing time, and are the only organisms preserved in statistically significantly numbers in small-diameter cores typically used in nearshore impact studies.
- As with any biological entity, taxonomy (names for species) is a problem, but this book attempts to mitigate this issue by providing detailed morphological information on important indicator species in the text and appendix.
- Distinct species assemblages can serve as proxies to characterize most marginal marine environments. Also, there are abundant data, particularly for benthic foraminifera, that relate environmental parameters to benthic assemblages. Therefore, even though not much is known about the actual biology of these organisms, these data can be used to interpret fossil assemblages.
- Diagenetic processes can have an impact on some fossil assemblages in subsurface environments. These mechanisms may alter fossil content but can often be predicted so that interpretations can be formulated in keeping with a precautionary approach.

2

Methodological Considerations

COLLECTION OF SAMPLES

This chapter emphasizes only those techniques that are pertinent to unconsolidated sediments, and essentially applicable to both foraminifera and thecamoebians. The collection and processing of hard-rock samples is rarely necessary for contemporary environmental impact evaluations. For further information on hard-rock processing, readers are referred to papers by Wightman et al. (1994), Thomas and Murney (1981), or any of the many papers dealing with microfossils in shale or sandstone.

Methods of sampling testate rhizopods are greatly facilitated by the small size and abundance of these shelled protozoans. However, because of the need to ensure that the upper several centimeters of sediment remain undisturbed during the collection process, a variety of sampling methods have been developed over the years.

Surface Samples

Most conventional spatial surveys rely on one of several types of grab samplers. Selecting a particular model is influenced by project goals and logistical and sample quality considerations. For nearshore environments that are being accessed using small craft, the 15×15 cm Ekman dredge sampler provides a good-quality small-surface (10×10 cm) sample. The closing mechanism of this device is triggered by a weight that is released at the surface after the sampler has "landed" on the seafloor. The weight slides down the hauling rope and strikes a plate that releases the spring-loaded sampler jaws (Fig. 2.1). Conversely, under exposed continental shelf conditions, where comparatively coarse sandy sediments and water depths in excess of 50 m are the norm, the preferred sampler tends to be heavier but often of a design that causes a greater amount of sample disturbance than is seen in Ekman dredge and box core