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Testate Rhizopods as Reliable, Cost-effective Indicators of Environmental Change

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Abstract

This short paper summarizes some of the techniques that have been developed and perfected over the last 30 years for use as environmental indicators. Very few fossil groups provide the information that benthic foraminifera and thecamoebians can supply because their distributions and environmental preferences are fairly well known from a large amount of work that has been done on modern distributions and these associations can be used as proxies. In this brief paper several examples are given and briefly described where foraminifera and thecamoebians have been used for detecting sea-level change, pollution detection and monitoring, hurricane periodicity, earthquake precursors, paleoclimate studies and freshwater/marine transitions.

Keywords: Foraminifera; environmental proxies; sea-level; pollution, hurricanes; earthquakes

1 Introduction

Many types of proxy indices, both physical/chemical and biological, have been used estimate changes in various environmental parameters that are then related to the problem under consideration. However benthic foraminifera and the related group, testate rhizopods or thecamoebians, offer unique aspects that are usually overlooked by the environmental community. These two groups have a great advantage over most other biological indicators because they leave a microfossil record which 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 data field base that has been compiled for these organisms over a wide range of marine and fresh water 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 (<10cc) collected with 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. Most importantly, the storage of reference samples of these larger organisms can also have negative implications for low budget projects. Perhaps most important 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 10 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. For quantitative historical studies, macro-invertebrates are usually impractical.

Chemical studies (i.e., nutrients, organic matter, trace metals, sulfides, etc.) can sometimes provide chronological and process-related information (*e.g.*, ^{210}Pb; Smith & Schafer, 1987a), 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 & 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; Scott *et al.,* 2005).

2 Some Examples of Applications

There are many applications of these to geological problems, both in Holocene and ancient sediments. J. A. Cushman and Joseph Grzybowski introduced the use of foraminifera to find petroleum in the early part of the 20th century and that was the mainstay of foraminiferology for many years to include the present. This work usually involves simply biostratigraphy, often ignoring the paleoecological potential. In this short paper I will summarize other uses, which broaden the use of foraminifera into delineating such phenomena as hurricane periodicity, earthquakes, sea level, paleoceanography, pollution, and even deep-sea coral distribution. Most of this paper is summarized from Scott *et al.* (2001) but some new material has arisen since then which is added here.

2.1 Sea-level Studies

Many workers have used foraminifera as sea-level indicators (see: Haynes, 1981 for a review) but, prior to 1976, their resolution was limited to plus or minus a several meters, especially if offshore assemblages were used. The assemblages described here should provide an accuracy of plus or minus a few centimeters at best, and 50 cm at worst. In 1976, the absolute accuracy of salt marsh foraminiferal vertical zonations was verified in Southern California (Scott, 1976) and later compared on a worldwide scale (Scott & Medioli, 1978, 1980a). Since that time, much more work has been done to verify that the relationship exists everywhere (*e.g.*, Scott D.K. & Leckie, 1990; deRijk, 1995; Patterson, 1990; Petrucci *et al.,* 1983; Jennings & Nelson, 1992; Gehrels, 1994, Horton *et al.,* 1999a, b). It appears that the same 8-10 species of marsh foraminifera are ubiquitous throughout the world's salt marshes, especially in the upper half of the marsh. The reason salt marshes in general, and marsh foraminiferal zones in particular, have been used widely for sea-level studies is that the entire marsh environment is confined to the upper half of the tidal range (Chapman, 1960). For most tidal ranges this means that the whole vertical range of the salt marsh deposit is one meter or less. This was adequate when sea level was first being investigated in relation to deglaciations. However, in investigating global warming driven sea-level movements of only a few centimeters, a ±1m resolution is of little value (Houghton *et al.,* 1990; Scott *et al.,* 1995a,b).

Marsh species appear to have been successful for a very long time - what appear to be the same species have been found in the Early Carboniferous (almost 400 million years ago) in Nova Scotia (Thibaudeau, 1993; Wightman *et al.*, 1994) and most recently in the early Cambrian in Nova Scotia (Scott *et al.*, 2003). What this means is that ancient sea levels potentially can be determined for most of the sedimentary geologic record.

2.2 Rapid Climatic Events

In Nova Scotia studies, when the highest high marsh zone (zone IA) could be identified in a subsurface assemblage, Scott & Medioli (1978, 1980b) suggested that sea level could be determined with an accuracy of ± 5cm**.** Except for one New Zealand marsh (Hayward *et al.*, 1999), this particular zone has only been identified in the northeastern part of North America. It does not appear to occur in the Pacific coast or south of the State of Connecticut on the Atlantic side of the United States (Hayward & Hollis, 1994; Scott *et al.*, 1996). Marsh foraminiferal distributions in eastern South America are a mirror image of those seen in the Atlantic region of the Northern Hemisphere (Scott *et al.*, 1990). Thomas & Varekamp (1991) used a combination of marsh foraminifera and geochemical techniques to reconstruct a detailed late Holocene sea-level change in Connecticut but to date similar investigations have been confined to areas of the South Carolina coast (Collins, 1996; Collins *et al.*, 1995). The well-defined high marsh fauna observed between Nova Scotia and Connecticut is not present in South Carolina. However, in South Carolina and other locations where detailed studies have been conducted it is possible to delimit high marsh zones that provide accuracies in the range of ± 10-20cm vertically (Collins, 1996; Collins *et al.* 1995; Scott *et al.*, 1991). Later, Scott *et al.* (1995a,b) and Gayes *et al.* (1992) investigated middle Holocene changes in sea level that took place in a time span of less than 2000 years. In a South Carolina study it was possible, using marsh foraminifera zonations, to detect both a rise and a fall between 5000 and 3600 years ago - 2m of rise followed by 2m of fall, and then a slow rise that promoted deposition which eventually covered the deposits that held the record of earlier variations (Scott *et al.*, 1995b). Detection of these changes was only possible using marsh foraminiferal zonations, which, in South Carolina, are sensitive to ±30cm sea-level changes.

2.3 Paleo-Periodicity

Probably the most detailed use of fossil foraminifera assemblages to reconstruct seismic events to date was done in a study by Nelson *et al.* (1996)

where in one core from coastal Oregon they were able to identify several "steps" in the sea-level variation "curve", but not all these "steps" could be linked with seismic events. The abrupt changes were interpreted as a very strong signals of rapid elevation change from a high marsh fauna (*Trochammina macrescens*) to low marsh fauna (*Miliammina fusca*) in just a 20cm long section. These data indicated an almost instantaneous 50cm rise in relative sea level (i.e., a drop of the land), and are interpreted as seismic events at 1700 yBP and 300-400 yBP respectively. It should be noted that although there are lithologic changes at these boundaries, it is the foraminiferal zones that provide the data needed to estimate the actual changes in elevation associated with the seismic event (Jennings & Nelson, 1992).

Besides actual land movement from seismic events, tsunami deposits have been identified, in part, by means of foraminifera (Clague & Bobrowsky, 1994a,b). A tsunami layer is generally assumed to be a sandy layer that is "out of place" in a salt marsh environment. In one instance, Clague & Bobrowsky (1994a,b) encountered a high marsh interval (*Trochammina macrescens*), a sand layer with few foraminifera, and a low marsh interval (*M. fusca*), all included in about a 10cm thick layer. They interpreted this sequence as being suggestive of both a tsunami and a concurrent subsidence event.

Precursor events: In addition to documenting paleo-periodicity some interesting events prior to major earthquakes have also been recognized. Shennan *et al.* (1996, 1998) had observed some events in sediments from prehistoric earthquakes on the Oregon coast that they thought were occurring prior to large megathrust quakes. However, because the quakes were prehistoric, it was difficult to know the exact timing of the events. Shennan *et al.* (1999) had the opportunity to visit sites of exposed sedimentary sequences that represented the great 1964 Alaska earthquake (the second largest ever measured at 9.2 on the Richter Scale); it was an area where the exact history was known down to the minute when the earthquake occurred. There were exposed sections of submerged forest where the contact between the pre-quake forest and post-quake intertidal sediments was exceptionally clear and the microfossils in this case were absolutely vital to obtain the record described below. In the case above it was possible to see just 1 cm below the earthquake horizon, a change in fauna that signaled a slight brackish increase. This was further verified with more cores from Alaska as well as Oregon (Hawkes *et al.*, 2005) to include both the 1964 event as well as an event at 1100 ybp in Alaska and several prehistoric events in Oregon, which were determined from a core site that had been studied by Shennan *et al.* (1998). In the Oregon case the events had been dated previously by Shennan *et al*. (1998). The duration of the precursor for the 1964 event was determined using Pb^{210} to be 5-10 years which is far better than the 300-500 year periodicity determined using the individual earthquake horizons that occur at that frequency.

2.4 Hurricane Detection in Estuarine Sediments

Liu & Fearn (1993) were likely among the first to show that there was a long (several thousand year) record of hurricane strikes recorded in coastal sediments. They investigated non-tidal coastal ponds on the Alabama (USA) coast, reasoning that non-tidal inlets would record the transported sand layers associated with hurricanes without later being reworked by subsequent tidal action. A similar technique was applied in the coastal zone of South Carolina; both tidal and non-tidal coastal embayments were investigated.

Sites were selected on the basis of whether or not they might have a well-preserved record of recent hurricanes, most notably *Hugo*, which occurred in September, 1989 (Collins *et al.*, 1999). The microfossils were used to differentiate marine/non-marine sequences in the inlets, and to identify reworked sediments by means of displaced benthic foraminifera. Cores were dated using ^{210}Pb- techniques that provide chronological information for the last 100 yrs. In Price’s Inlet, *Hugo*’s impact was marked by an 8 cm thick sand layer containing many nearshore foraminifera, implying transport from offshore areas. In Sandpiper Pond, the effect of *Hugo* was detectable from the offshore foraminifera contained in sediments sandwiched between freshwater intervals deposited before and after the hurricane; in neither the structure nor in the sedimentology of this core, however, was there detectable evidence indicating a storm event. Hence, a range of responses for hurricanes in the form of different types of sediment layers and microfossil assemblages sampled in these non-tidal areas could be recognized, depending on the location of the impact point on the coast. In the more peripheral location the storm layer could not have been detected without foraminifera. Later, in a more comprehensive paper, Scott *et al.* (2003) presented a 5000 year record of hurricanes on the South Carolina coast, which helped to calibrate hurricane strike models of periodicity.

2.5 Pollution Detection

The use of benthic foraminifera as marine pollution indicators is, for the most part, a post WW II phenomenon. It is not the intent of this section to review the large number of studies on this subject that have, and continue to appear, in the scientific literature. Instead, the reader is referred to several recent comprehensive treatments on this subject (Alve, 1995; Murray, 1991; Culver & Buzas, 1995).

However one recent study utilizes the fossil potential of foraminifera to reconstruct pollution histories of two modern estuaries (Scott *et al*. 2005) which documents the changes over the last 100 years in two highly impacted estuarine systems where in one case PCB's were measured in %'s. Deformations were useful here, occurring where the pollutants were highest and ending after the PCB's had been removed. In this case high quality chemical data was available to match with the foraminiferal data.

We have also shown the sensitivity of marsh foraminifera to oil spills. Sabean (2001) examined material before and after a contolled oil spill and found massive test deformities (>10%) two days after oil had been sprayed on the test plots. The deformities ended after the oil degraded two years later. McMillan (2002) was able to detect a fossil oil spill in sediments from a 1970's spill in Nova Scotia using deformed foraminifera also.

3 Other Applications

There are many more examples of foraminiferal use including freshwater/marine transitions and estuarine zonations and classification of estuarine systems (*e.g.* Scott *et al.*, 1980; Laidler & Scott, 1996), delineation of marsh deposits in ancient sequences (*e.g*. Wall, 1976; Scott *et al.*, 1983; Tibert & Scott, 1999) and of course a long series of papers using benthic and planktic foraminifera as paleoceanographic indicators-foraminifera being able to provide both bottom and surface water proxies (*e.g.* Kennett, 1982).

The bottom line is that benthic foraminifera can be useful in almost all paralic environments in all time scales for a wide variety of measurements from sea level to pollution.

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